Australian Government
Bureau of Meteorology

AFDRS Forest Model

The Forest Model for AFDRS will be used for all dry sclerophyll forests and temperate woodlands where litter and shrubs dominate the understorey. Forest fuels cover only 6% of Australia but coincide with the areas of greatest population. Nationally, forest dominates 18% of Fire Weather Areas (FWAs) and is significant in 38%, though these are much higher in the southeast of the country; 90% of Tasmanian FWAs and more than 75% of Victorian FWAs are significantly influenced by forest fuels.

What is the AFDRS Forest model?

AFDRS uses the dry eucalyptus forest fire model (DEFFM, also known as the Vesta model), which was developed by Cheyney et al in 2012, extending the work of previous research, including Gould et al from 2007. Project Vesta was a broad, multi-agency experimental study that aimed to develop a nationally applicable fire behaviour model for dry eucalyptus forests in summer conditions. It used data from 116 experimental burns carried out in southwest WA in the summers of 1998, 1999 and 2001.

Inputs and outputs

The forest model specifically incorporates the structure of forest fuels into its calculations. It can do this in one of two ways: by using a Fuel Hazard Score (FHS, also known as Vesta fuel score), or by using a Fuel Hazard Rating (FHR). AFDRS uses FHS, which is a subjective assessment of the flammability of the fuel based on the bark type, density, continuity, structural development of vegetation, and accumulation of litter fuels. For instances where FHS's are not available for an area, if FHRs are available, they are converted into FHSs, otherwise default FHS values are used.

The FHS has several components: the surface FHS and the near-surface FHS, both of which are numbers between 0 and 4. The final piece of information in the FHS is the near-surface height which, unsurprisingly, is the height of the near-surface fuels.

Other inputs required for this model include the fuel moisture content, which is derived from the relative humidity and the temperature, and the 10m open wind speed, which has a reduction factor applied to account for the forest canopy.

This model does not have a go/no-go threshold; once the inputs are known, the Rate of Spread (ROS) can be calculated.

The outputs of this model are Rate of Spread, Spotting Distance, intensity, and flame height. Spotting Distance calculations are not currently included in AFDRS as they can be quite site-specific.

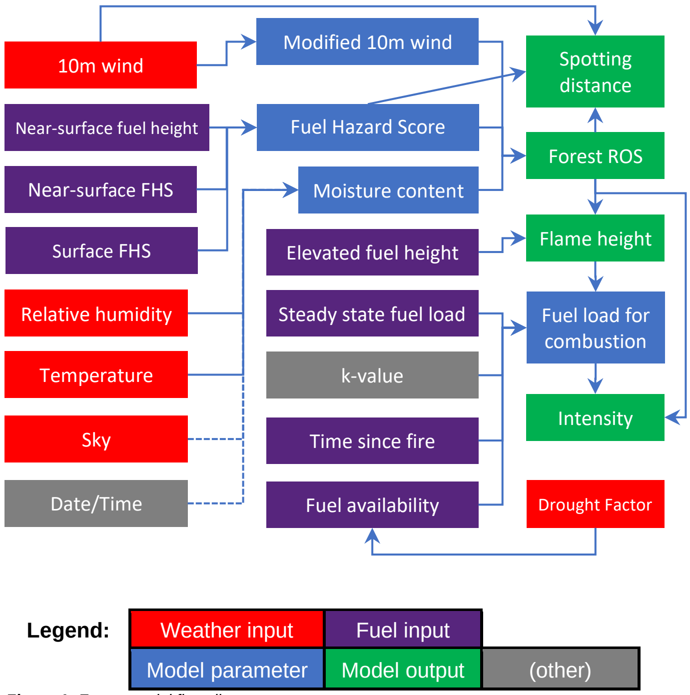

Figure 1: *Forest model flow diagram*

Model equations

The calculation for fuel moisture content, MC, varies depending on the time of day/year:

$$MC = \begin{cases} 2.76 + 0.124RH - 0.0187T & \text{12-5pm on sunny days Oct-Mar} \\ 3.60 + 0.169RH - 0.0450T & \text{otherwise for daylight hours} \\ 3.08 + 0.198RH - 0.0483T & \text{night-time hours} \end{cases}$$

Where RH is the relative humidity, and T is the temperature.

The rate of fire spread is calculated from different equations depending on whether the 10m wind is stronger than 5km/h.

For $U_{10} \leq 5$ km/h the Rate of Spread (ROS) is:

$$ROS_{forest} = 30\ \Phi\mathrm{M}f\ \ 550.5MC^{-1.495}$$

For $U_{10} > 5$ km/h the Rate of Spread (ROS) is:

$$ROS_{forest} = [30 + 1.531(U_{mod} - 5)^{0.8576} FHS_s^{0.9301} \times 1.03] \times \Phi\mathrm{M}f$$

Where:

$$\Phi\mathrm{M}f = 18.35MC^{-1.495}$$

Where FHS_s is surface fuel hazard score, FHS_{ns} is the near-surface fuel hazard score, H_{ns} is the near-surface fuel height in cm, $A = 550.5$, and $B = 28.9328854$, and U_{mod} is the 10m wind modified for the influence of the canopy:

$$U_{mod} = \frac{3U_{10}}{WRF_{Tolhurst}}$$

Where $WRF_{Tolhurst}$ is the wind reduction factor rule of thumb from K. Tolhurst with ranges from 2.5 (short woodland) to 5 (tall wet forest). If H_{ns} is unknown, the default value used by AFDRS is 20cm.

We then need to determine which layers of the fuel are involved in the fire so that we can calculate an appropriate fuel load. We do this using flame height:

$$F_{height} = 0.0193\left(ROS_{forest}\right)^{0.723} e^{0.64H_{el}} \times 1.07$$

Where H_{el} is the height of the elevated fuels (cm).

Fuel loads, in ton/ha, of the various layers of fuel in forests are given by:

$$FuelLoad_{(layer)} = FL_{(layer)}\left(1 - e^{-k_{(layer)}TSF}\right)$$

With possible layers of surface, near surface, elevated, bark, and overstorey and where $FL_{(layer)}$ is the steady state fuel load of that fuel layer, $k_{(layer)}$ is the fuel accumulation rate of that fuel layer (k-value from table in Chapter 4 of the NFDRS report), and TSF is the time since fire (in years).

The fuel load available for combustion (which we need for intensity calculations) is given by:

$$FuelLoad_{combustion} = Fuel_{availability} FuelLoad_{(layer)}$$

Where $Fuel_{availability}$ is the fraction of fuel available for combustion and varies with fuel sub-type. And $FuelLoad_{(layer)}$ is based on flame height:

$$FuelLoad_{(layer)} = FuelLoad_{(surface)} + FuelLoad_{(near\ sruface)} + FuelLoad_{(elevated)} + 0.5\ FuelLoad_{(canopy)}$$

Where:

$FuelLoad_{(elevated)} = 0, if\ flame\ height < flame\ height\ elevated$
$FuelLoad_{(canopy)} = 0, if\ flame\ heigth < height\ overstorey \times flame\ height\ crown\ fraction$

As with the other fuels, fireline intensity, I_B, uses Byram's (1959) equation:

$$I_B = h \times w \times ROS$$

Where h is the heat yield, assumed to be 18,600 kJ/kg, and w is the fuel load available for combustion converted to kg/m^2. Note that the contribution of surface litter fuel loads to intensity was capped at 10 t/ha (1 kg/m^2) to represent the process of the fire burning across and then down into the fuel bed for forests with high litter fuel loads.

The Vesta model also produces an estimate of spotting distance. For $ROS < 150$ m/h, spotting distance is estimated to be 50m. For $ROS \geq 150$ m/h, spotting distance, SD, is calculated using:

$$SD = \left|\alpha \arctan(FHS_s)\, R^{0.5} + \beta FHS_s{}^{-1} R^{-1.5} - \varepsilon\right|$$

Where $\alpha = 176.969$, $\beta = 1568800$, $\varepsilon = 3015.09$, and $R = \frac{ROS}{U_{10}{}^{0.25}}$.

Model behaviour and limitations

The Vesta model is a straightforward model with a simple algebraic equation for ROS. However, hazard scores are modelled at a landscape level for AFDRS with requires several assumptions and does not account for variations in different areas. This is an issue as the Vesta model is highly sensitive to the fuel classification (fuel hazard score); for example, a change of 1 in FHS can double the ROS output.

This model is also sensitive to the near-surface fuel height and is somewhat sensitive to moisture when RH < approx. 6%.

The original model assumes a Drought Factor of 10. AFDRS applies a correction if DF<10 (see fuel availability equations under fuel sub-types, below), but the effect of this correction is not fully understood. It has also been noted that the assumed heat yield of 18,600 kJ/kg needs further investigation.

Fuel sub-types

There are two sub-types to the Forest fuel in AFDRS: (dry) forest and wet forest.

Forest

This fuel sub-type is for dry eucalypt forests and temperate woodlands with a shrubby understorey and litter surface fuel. The Dry Eucalypt Forest Fire (Vesta) Model was developed for this type of fuel, where the litter and shrub dominated understorey provide vertical fuel continuity.

For AFDRS, forests/woodlands with a continuous grassy understorey have been classified to savanna, and open woodlands (woodlands with <10% canopy cover) with a heath understorey have been classified to shrubland.

For this sub-fuel, the fraction of fuel available for combustion for a given drought factor, DF, is:

$$Fuel_{availability\ (dry)} = 0.1DF$$

Figure 2: *Left Bottom: Dry sclerophyll forest, VIC. Top Right: Karri forest, Southwest WA. Bottom left: Wandoo open forest, Preston National Park, WA. Bottom right: understorey view of open forest of mixed eucalypt species, VIC. From a hierarchical classification of wildland fire fuels for Australian vegetation types, Cruz et al. 2015*

Wet Forest

This sub-fuel type is classified as forests with high moisture content due to the forest structure, topography, or inundation. Some examples include rainforest, wet sclerophyll forest, and swamp forest.

The fuel structure of wet sclerophyll forest, rainforest, and forested wetlands is most like a litter and shrub dominated forest. Hardwood plantations have been classified to wet forest as the canopy species are most commonly the tall eucalypt species typical of wet sclerophyll forests. However, the understorey fuel structure in these plantation forests is highly modified and varies with differing management practices.

Wet forests have a wind reduction factor and drought factor modification applied to the model. Note that only a single drought factor modification has been applied across all wet forest types, however there are likely to be significant differences in fuel availability between rainforest, wet sclerophyll forest, and forested wetlands.

For this sub-fuel, the fraction of fuel available for combustion $f_{Availability\ (wet)}$ uses the drought index (KBDI/SDI) and McArthur Drought Factor (DF) based on the Vesta Mk2 fuel availability:

$$f_{Availability(wet)} = \frac{1.008}{(1+104.9\exp(-0.9306 \times C1 \times DF))}$$

Where C1 is as an adjustment that takes into account the Wind Reduction Factor (WRF), restricted to vary between 3 and 5 and KBDI:

$$C1 = 0.1((0.0046WRF^2 - 0.0079WRF - 0.0175)KBDI + (-0.9167WRF^2 + 1.5833\ WRF + 13.5)$$

Figure 3: *Left: Temperate rainforest, TAS. Right: Tropical rainforest, southeast QLD. From a hierarchical classification of wildland fire fuels for Australian vegetation types, Cruz et al. 2015*

Original research paper: Cheney, N.P., Gould, J.S., McCaw, W.L., Anderson, W.R., 2012. Predicting fire behaviour in dry eucalypt forest in southern Australia. Forest Ecology and Management 280, 120-131.

FIND OUT MORE

For more information about the Forest Model, contact the **Fire Weather, Heatwave and Air Quality Environmental Prediction Services Team** at **fireweather@bom.gov.au**.