

PREScribed BURNING GUIDE FOR BLUE GUM PLANTATIONS



Title: Prescribed Burning Guide for Blue Gum Plantations

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1. INTRODUCTION

The main objective of this guide is to support the decision making process of prescribed burning in blue gum (*Eucalyptus globulus*) stands, increasing the likelihood of attaining fuel-hazard reduction goals without undesired effects. While the success of a prescribed fire is dependent of education, training and experience, using the guide is expected to improve the planning, execution and evaluation of prescribed fire operations. This manual is conceived for prescribed fire application in blue gum stands where understorey vegetation is not a significant component of the fuel complex, as exemplified in Figure 1. The shrub layer should cover less than one third of the ground, with an average height of less than 30 cm.

Figure 1. Typical blue gum stand to which the guide applies.



VARIABLES ABBREVIATIONS

Table 1.1. Variable abbreviations

Variable	Definition
DBH (cm)	Tree diameter at breast height
DMC	Duff Moisture Code of the Canadian FWI System
FFMC	Fine Fuel Moisture Code of the Canadian FWI System
HF (%)	Decomposing litter (F-layer) moisture content
RH (%)	Air relative humidity
SCH (m)	Maximum stem char height
SDH (m)	Stand dominant height, the mean height of the largest diameter trees in the stand (100 trees ha ⁻¹)
T (°C)	Air temperature

2. BURN PRESCRIPTION

The burn prescription indicates the conditions under which a prescribed fire operation should be carried out such that its objectives are attained. In blue gum stands it is based on weather conditions and the corresponding fire behaviour as a function of the amount of acceptable tree damage.

Table 2.1. displays the optimum range in weather-related variables and fire behaviour characteristics for prescribed burning in blue gum. Burning when two or more variables simultaneously approach their burning window extremes is not recommended, e.g. when stronger wind combines with drier fuel.

Table 2.1. *Optimum ranges in weather-related variables and fire behaviour characteristics for prescribed burning in blue gum stands.*

Elements	Variables	Range
Weather variables and fuel moisture content	Number of days since last rainfall	3-6
	Air temperature (°C)	10-14
	Relative humidity (%)	40-60
	Dead fine fuel moisture content (%)	17-22
	10-m wind speed in the open (km h ⁻¹)	0-24*
	DMC	5-10**
Fire behaviour	Rate of spread (m h ⁻¹)	10-30
	Flame length (m)	0.2-0.6

* Depending on ignition pattern

** < 9, for DBH < 13cm

Figure 2 presents the sequence of variables assessment involved in prescription development.

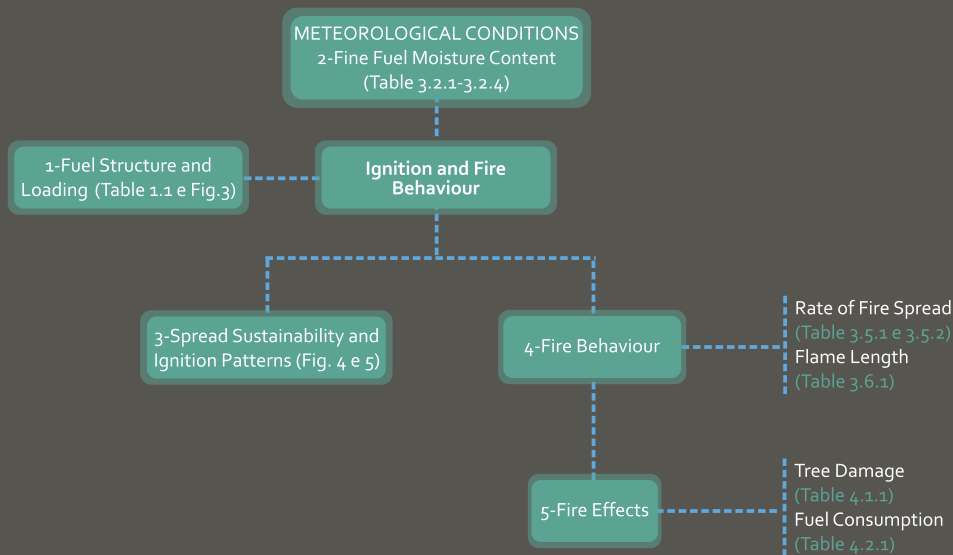


Figure 2 Prescription development diagram.

3. FIRE BEHAVIOUR PREDICTION

3.1. FUEL LOADING

Fuel quantity or loading (t ha^{-1}) is the first element that should be considered when appraising potential fire behaviour, as it is proportional to heat release and fire intensity.

Total fuel loading and fine fuel loading (1-h timelag, corresponding to diameter $< 6 \text{ mm}$, and more relevant for its role on fire spread) are estimated from the mean depth of litter (Table 3.1.1.).

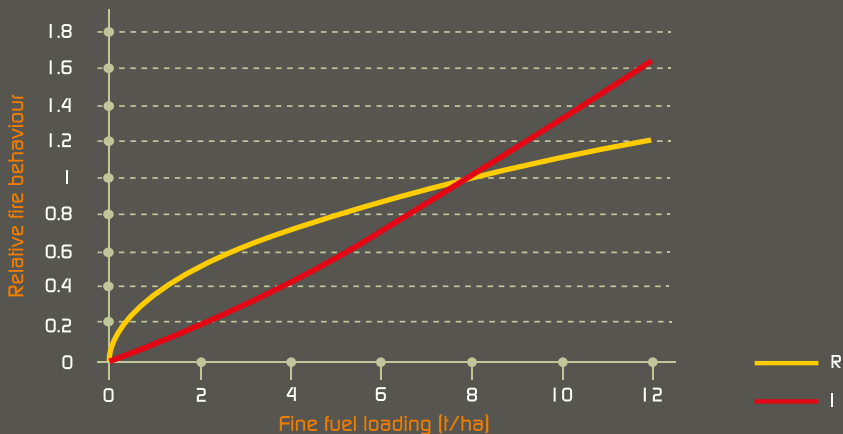
Table 3.1.1. Estimation of fuel loadings from mean litter depth

Litter depth (cm)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
Loading (t ha^{-1})	3	4	6	7	8	10	11	12	13	15	16	17	18	19	21	22	23	24	25	26	28	29	30
1-h loading (t ha^{-1})	2	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	21	22	23	24

Note: litter depth should be measured at several equidistant locations, and the mean should be weighted by the representativity of tree rows and in-between rows areas, which tend to differ in fuel accumulation.

The relative impact of fine fuel loading on fire behaviour characteristics (rate of spread and fireline intensity) is visible on Figure 3. A relative value of 1 is assigned to a fuel loading of 8 t ha^{-1} , as this is usually viewed as the threshold above which direct fire control in eucalypt forest is no longer possible under extreme weather conditions and can be used as general guidance to schedule fuel treatments.

Figure 3 Relative fire spread rate and fireline intensity as a function of fine fuel loading.



3.2. FUEL MOISTURE CONTENT

The ability to quickly and reliably estimate the moisture content of fine dead fuels is essential when planning prescribed fire operations, given its influence on fire spread likelihood, fire behaviour characteristics and fuel consumption.

Fine fuel moisture content is estimated from air temperature and relative humidity, supplemented by additional variables:

Table 3.2.1 - FFMC

Table 3.2.2 - FFMC, with correction for wind speed (Table 3.2.2.1)

Table 3.2.3 - Number of days since last rainfall, with correction for wind speed (Table 3.2.3.1)

Table 3.2.4 - FFMC and stand dominant height, with correction for wind speed (Table 3.2.4.1)

Prediction performance varies as $3.2.2 > 3.2.1 > 3.2.4 > 3.2.3$.



Table 3.2.1. Estimation of fine dead fuel moisture content from air temperature, relative humidity and FFMC.

T (°C)		10.0				12.5				15.0				17.5			
HR (%)		40	50	60	70	40	50	60	70	40	50	60	70	40	50	60	70
FFMC	70	24	26	28	31	23	24	27	29	21	23	25	28	20	22	24	26
	75	22	24	26	29	21	22	24	27	20	21	23	25	19	20	22	24
	80	20	22	24	26	19	20	22	25	18	19	21	23	17	18	20	22
	85	19	20	22	24	17	19	20	22	16	18	19	21	15	17	18	20
	90	17	18	20	22	16	17	18	21	15	16	17	19	14	15	16	18
	95	15	17	18	20	15	16	17	19	14	15	16	18	13	14	15	17

-  Out of prescription (too moist)
-  Marginal conditions (moist)
-  Regular
-  Marginal conditions (dry)
-  Out of prescription (too dry)

Table 3.2.2. Estimation of fine dead fuel moisture content from air temperature, relative humidity, FPMC and 10-m open wind speed (step 1).

T (°C)		10.0				12.5				15.0				17.5			
HR (%)		40	50	60	70	40	50	60	70	40	50	60	70	40	50	60	70
FFMC	70	25	26	29	32	23	25	27	30	22	23	25	28	20	22	24	27
	75	23	24	26	30	21	23	25	28	20	21	23	26	19	20	22	25
	80	21	22	24	27	19	21	23	25	18	20	21	24	17	18	20	22
	85	19	20	22	25	18	19	21	23	17	18	20	22	16	17	18	21
	90	17	19	20	23	16	18	19	21	15	16	18	20	14	15	17	19
	95	16	17	19	21	15	16	18	20	14	15	16	18	13	14	15	17

 Out of prescription (too moist)
  Marginal conditions (moist)
  Regular
  Marginal conditions (dry)
  Out of prescription (too dry)

Table 3.2.2.1. Estimation of fine dead fuel moisture content from air temperature, relative humidity, FPMC and 10-m open wind speed (step 2).

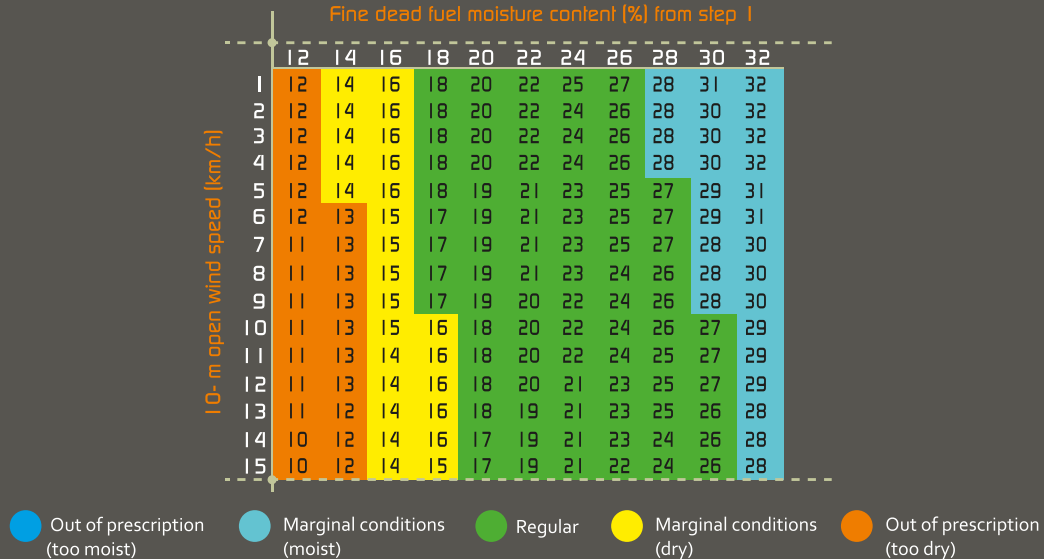


Table 3.2.3. Estimation of fine dead fuel moisture content from air temperature, relative humidity, number days since last rainfall and 10-m open wind speed (step 1).

No. days since rainfall	T (°C)		10.0				12.5				15.0				17.5			
	HR (%)		40	50	60	70	40	50	60	70	40	50	60	70	40	50	60	70
1			31	34	39	46	28	31	35	41	25	28	32	38	23	26	29	35
2			29	32	36	43	26	29	33	39	24	27	30	35	22	24	27	32
3			28	31	35	41	25	28	32	37	23	25	29	34	21	23	26	31
4			27	29	34	39	24	27	30	36	22	24	28	33	20	22	25	30
5			26	29	33	38	24	26	30	35	21	24	27	32	20	22	25	29
≥ 6			25	28	32	37	23	25	29	34	21	23	26	31	19	21	24	28

-  Out of prescription (too moist)
  Marginal conditions (moist)
  Regular
  Marginal conditions (dry)
  Out of prescription (too dry)

Table 3.2.3.1 Estimation of surface litter fine fuel moisture content from air temperature, relative humidity, number days since last rainfall and 10-m open wind speed (step 2).

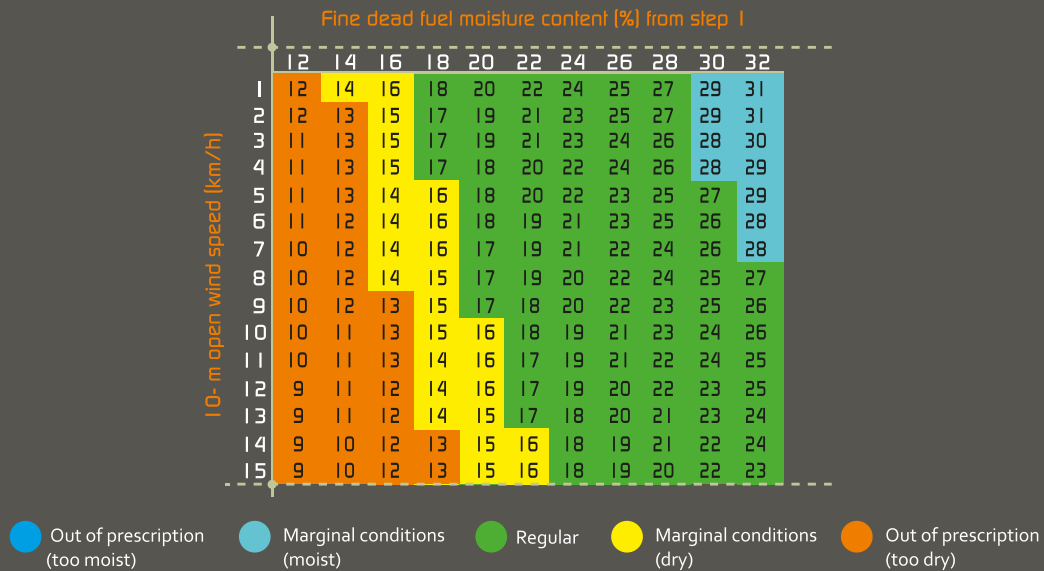
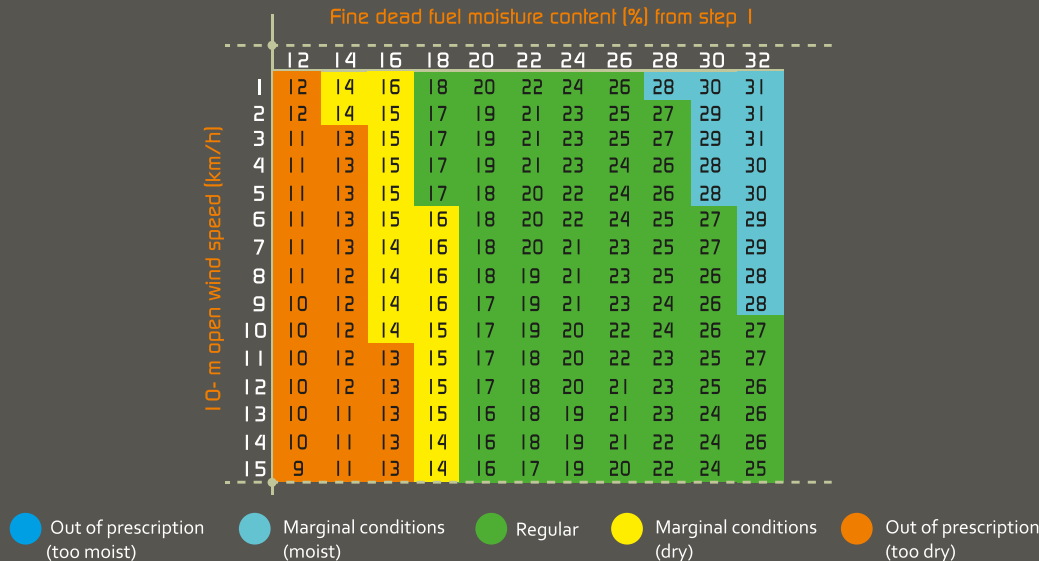


Table 3.2.4. Estimation of fine dead fuel moisture content from air temperature, relative humidity, FFM_C, stand dominant height and 10-m open wind speed (step 1).

	10.0				12.5				15.0				17.5				
	40	50	60	70	40	50	60	70	40	50	60	70	40	50	60	70	
FFMC	38	40	44	48	36	38	41	46	34	36	39	43	32	34	37	41	15
	31	33	36	40	29	31	34	38	28	30	32	36	26	28	30	34	20
70	26	27	30	33	24	26	28	31	23	24	26	29	22	23	25	28	25
	35	37	40	44	33	35	38	42	31	33	35	39	29	31	34	37	15
75	28	30	33	36	27	29	31	34	25	27	29	32	24	26	28	31	20
	23	25	27	30	22	24	25	28	21	22	24	27	20	21	23	25	25
80	31	33	36	40	30	32	34	38	28	30	32	36	26	28	30	34	15
	26	28	30	33	24	26	28	31	23	25	27	29	22	23	25	28	20
85	21	23	25	27	20	21	23	26	19	20	22	24	18	19	21	23	25
	29	30	33	36	27	29	31	34	25	27	29	32	24	26	28	31	15
90	23	25	27	30	22	24	26	28	21	22	24	27	20	21	23	25	20
	19	21	22	25	18	19	21	23	17	18	20	22	16	17	19	21	25
95	26	28	30	33	24	26	28	31	23	25	27	30	22	23	25	28	15
	21	23	25	27	20	21	23	26	19	20	22	24	18	19	21	23	20
	18	19	20	22	17	18	19	21	16	17	18	20	15	16	17	19	25
	24	25	27	30	22	24	26	28	21	22	24	27	20	21	23	25	15
	19	21	22	25	18	20	21	23	17	18	20	22	16	17	19	21	20
	16	17	18	20	15	16	17	19	14	15	16	18	13	14	16	17	25

SDH (m)

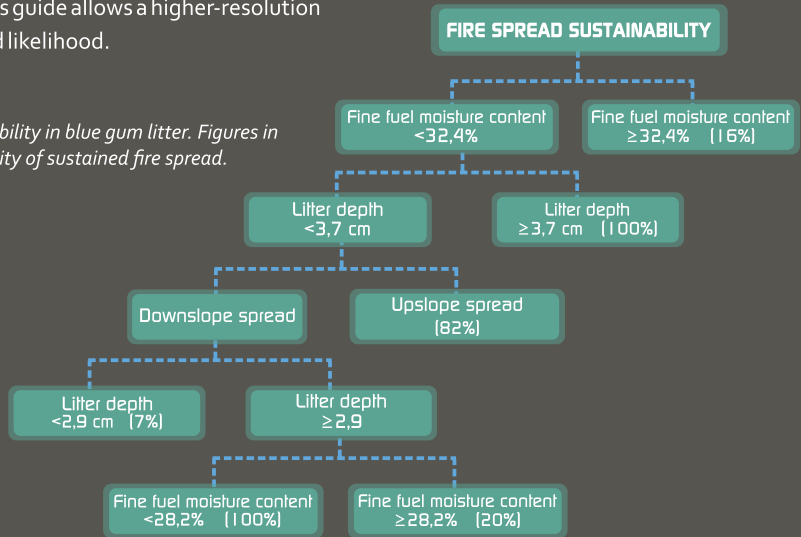
Table 3.2.4.1 Estimation of surface litter fine fuel moisture content from air temperature, relative humidity, FPMC, stand dominant height and 10-m open wind speed (step 2).



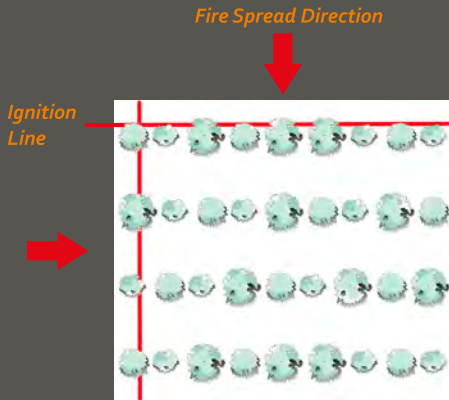
3.3. FIRES SPREAD SUSTAINABILITY

Prescribed fire practitioners should be able to assess in advance (i.e. in a planning context) if a fire will be self-sustained. Figure 4 shows the relevant variables and their thresholds for sustained fire spread. The spreadsheet version of this guide allows a higher-resolution assessment of fire-spread likelihood.

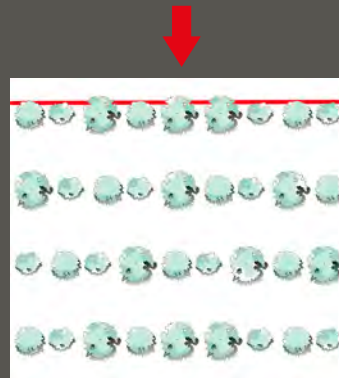
Figure 4 Fire spread sustainability in blue gum litter. Figures in brackets indicate the probability of sustained fire spread.



3.4. IGNITION PATTERNS



3.4.1. Back fire spread



3.4.2. Head fire spread

Important:

When head-firing (forward fire spread driven by the wind, slope, or both), the ignition line should always be established parallel to the plantation rows.

Spot fire ignitions are likely in headfires when $FFMC > 85$ and relative humidity $< 50\%$, or when $FFMC > 87.5$.

3.5. RATE OF FIRES SPREAD

The spread rate of a fire is the most basic descriptor of its behaviour. In association with fine fuel moisture content is used to estimate flame length, which in turn is related to tree stem injury.

3.5.1. BACK FIRES SPREAD

Table 3.5.1. Estimation of fire spread rate ($m h^{-1}$) from litter depth and fine dead fuel moisture content.

- Headfiring or strip-headfiring is recommended because of burn patchiness and low treatment productivity
- Regular

	Litter depth [cm]						
	2	3	4	5	6	7	8
28	1.6	2.3	2.9	3.5	4.1	4.6	5.2
26	1.8	2.5	3.1	3.8	4.4	5.5	5.6
24	1.9	2.7	3.4	4.1	4.8	5.4	6.1
22	2.1	3.0	3.8	4.5	5.3	6.0	6.7
20	2.3	3.3	4.2	5.0	5.8	6.6	7.4
18	2.6	3.7	4.7	5.6	6.5	7.4	8.3
16	3.0	4.2	5.3	6.4	7.4	8.4	9.4
14	3.4	4.8	6.1	7.4	8.5	9.7	10.9

3.5.2. HEAD FIRE SPREAD

Table 3.5.2. Estimation of fire spread rate ($m h^{-1}$) from litter depth and fine dead fuel moisture content and wind speed.

* The ratio of 10-m open wind speed to in-stand surface (1.7-m height) wind speed is 3:1.

Fire spread estimates (Tables 3.5.1 and 3.5.2) are for level terrain. Slope corrections are obtained through Table 3.5.3.

Table 3.5.3. Correction of fire spread rate for slope (Gould et al. 2007).

Slope [°]	Fire spread rate ($m h^{-1}$)				
	10	15	20	25	30
2.5	12	18	24	30	36
5	17	25	34	42	50
7.5	28	42	56	70	84

● Regular
 ● Marginal (faster)
 ● Out of prescription (too fast)

	Litter depth [cm]					
	2	4	6	8	10	
28	9	16	22	28	34	2.5
	16	29	40	51	61	5
	23	41	58	73	88	7.5
26	10	17	24	30	37	2.5
	17	31	43	55	66	5
	25	45	62	79	95	7.5
24	11	19	26	33	40	2.5
	19	34	47	60	72	5
	27	49	68	86	104	7.5
22	12	21	29	36	44	2.5
	21	37	52	66	79	5
	30	53	75	95	114	7.5
20	13	23	32	40	49	2.5
	23	41	57	73	88	5
	33	59	83	105	126	7.5
18	13	25	36	45	54	2.5
	23	46	64	82	98	5
	37	66	93	117	141	7.5
16	16	29	40	51	62	2.5
	29	52	73	93	111	5
	42	75	105	133	160	7.5
14	19	33	47	59	71	2.5
	34	60	84	107	129	5
	49	87	121	154	185	7.5

In-stand 1.7-m wind speed (km/h)*

3.6. FLAME LENGTH

Flame length expresses fireline intensity and can be predicted from the rate of fire spread and fine dead fuel moisture content (Table 3.6.1).

Stem char height is related with stem damage and can be estimated from flame length (Table 3.6.2.).

Table 3.6.1. Estimation of flame length (m) from fire spread rate (m h^{-1}) and fine dead fuel moisture content (%).

Table 3.6.2. Estimation of stem char height (m) from flame length (m).

	Fire spread rate (m h^{-1})							
	6	12	18	24	30	36	42	48
28							0.5	
26								
24	0.5			0.4		0.5		0.6
22		0.3	0.4		0.5			
20							0.6	
18				0.5		0.6		
16	0.3	0.4			0.6			0.7
14			0.5				0.7	

Flame Length (m)	SCH (m)
0.1	0.3
0.2	0.4
0.3	0.5
0.4	0.6
0.5	0.7
0.6	0.7
0.7	0.8
0.8	0.9

Table 4.1.1. Estimation of tree damage and response from DBH, SCH and the decomposing litter (F-layer) moisture content. M = dead; VR = live, sprouting; V – live, no response.

4. FIRE EFFECTS PREDICTION

4.1. TREE DAMAGE

The likelihood of a tree dying (M) or surviving with (VR) or without (V) sprouting is estimated from DBH, SCH and the F-layer moisture content. Depending on the situation (post fire assessment or planning), SCH is predicted respectively from flame length or is measured in the field. F-layer moisture is estimated from the daily DMC (Table 4.1.2.). Tree responses (namely sprouting) are totally visible in spring only.

Table 4.1.2. Daily extremes of the decomposing litter (F-layer) moisture content as a function of daily DMC.

DMC	Max.	HF [%]	Min.
2	205		140
4	164		112
6	132		90
8	106		72
10	85		58
12	68		46
14	54		37
16	43		30
18	35		24

		SCH [m]			DBH [cm]	HF [%]
		0.4	0.6	0.8		
2		VR	M	M		140
		M	M	M		120
		M	M	M		100
		M	M	M		80
		M	M	M		60
		M	M	M		40
4		VR	VR	VR		140
		VR	VR	VR		120
		VR	VR	VR		100
		VR	VR	VR		80
		VR	M	M		60
		M	M	M		40
6		V	V	V		140
		V	V	V		120
		V	V	V		100
		V	VR	VR		80
		VR	VR	VR		60
		VR	VR	VR		40
≥8		V	V	V		140
		V	V	V		120
		V	V	V		100
		V	V	V		80
		V	V	V		60
		V	V	V		40

4.2. FUEL CONSUMPTION

The amount of consumed fuel (as a fraction of the total) does not vary much (Table 4.2.1.) but it depends of the existing loading as well as of the F-layer litter moisture content, which the DMC reflects.

Table 4.2.1. Estimation of fuel loading consumption (%) from litter depth and the DMC.

		Litter depth (cm)			
		2	4	6	8
DMC	2	85	85	85	85
	4				
	6				
	8	90	90	90	90
	10				
	12				
	14	95	95	95	95
	16				
	18				



5. PRESCRIPTION DEVELOPMENT EXAMPLE

Suppose the following situation:

1st rotation blue gum plantation with a mean DBH of 6 cm and an average litter depth of 4 cm.

5.1. FUEL HAZARD ASSESSMENT

Total fuel loading = 11 t ha^{-1}

Fine fuel loading = 9.4 t ha^{-1}

Relative fire behaviour potential = >1

Fuel reduction treatments are advised.

5.2. SPECIFIC BURN OBJECTIVES

Decrease fuel loading in a percentage not lower than 85% of the extant loading (1st restriction), avoiding damage (i.e. stem kill and stem sprouting) to the trees (2nd restriction).

5.3. FUEL CONSUMPTION

A minimum 85% consumption of the existing fuel loading (corresponding to the 4-cm deep litter) is possible for a DMC range of 2–8 (Table 4.2.1).

5.4. TREE DAMAGE EVALUATION

The average tree (DBH = 6 cm) has a lower than 50 % probability of suffering injury (both stem kill and stem sprouting) when (a) or (b) are verified (Table 4.1.1):

(a) SCH = 0.4 m; HF = [140–80], equivalent to DMC = $[2^* - 10^{**}]$ (Table 4.1.2)

(b) SCH = [0.6–0.8] m; HF = [140–100], equivalent to DMC $[2^* - 8^{**}]$ (Table 4.1.2)

* In the afternoon; ** in the morning.

The conditions leading to damage (and the type of damage) of different-size trees in a stand can be explored in the spreadsheet version of the guide.

5.5. FLAME LENGTH

A SCH of 0.4 – 0.8 m is the outcome of a flame length of 0.2 – 0.7 m (Table 3.6.2). This flame length interval results from a fire spread rate of 6 - 36 m h⁻¹ and a fine dead fuel moisture content in the 14-28% range (Table 3.6.1.).

5.6. RATE OF FIRES SPREAD AND IGNITION PATTERNS

There are no restrictions for back fire spread (Table 3.5.1.). If a heading ignition mode is applied then fine dead fuel moisture content should be > 22% if 1.7-m wind speed is 5 km h⁻¹. Lower fuel moisture contents (down to 16%) can be used for winds up to 2.5 km h⁻¹.

5.7. FUEL MOISTURE CONTENT

If the more user-friendly method is used (Tables 3.2.3. and 3.2.3.1), a 16-26% range in fine dead fuel moisture content will result from various combinations of air temperature, time since rain and wind speed when relative humidity ≤ 60 %. As an example, a fuel moisture content of 22% will result from T = 12.5 °C, RH = 40%, 4 days since rain, and a 10-m open wind speed of 4 km h⁻¹ (Table 3.2.3.1.).

5.8. FIRES SPREAD SUSTAINABILITY

Considering that litter depth is > 3.7 cm, sustained fire spread is guaranteed when dead fine fuel moisture content is < 28.2% (Figure 4).

5.9. BURN PRESCRIPTION

Table 5.9.1. Example burn prescription. Two intervals, (1) and (2), are presented for fuel moisture content and wind speed.

Elements	Variables	Range
Weather variables and fuel moisture content	No. days since last rainfall	1-6
	Air temperature (°C)	10-17,5
	Relative humidity (%)	40-50
	Dead fine fuel moisture content (%)	1 26-22
		2 20-16
	10-m wind speed in the open (km h ⁻¹)	1 ≤5
		2 <2,5
	DMC	2-10*
Fire behaviour	Rate of spread (m h ⁻¹)	≤36
	Flame length (m)	≤0,7

* Depending on the daily minimum and maximum value of F-layer moisture content.

6. ANNEXES

6.1. DMC (DUFF MOISTURE CODE) ESTIMATION

The DMC has two roles in the prescription, respectively in relation to fuel consumption and tree injury. Because DMC forecasts may be unavailable we present estimates as a function of weather variables and time since rain (Table 6.1.1.). A base value of six is assumed, three days after forest floor saturation by rainfall. The estimate is corrected as a function of weather and month of the year (by summing Table 6.1.2 values). Finally, if rain occurs its impact is given by Table 6.1.3.



Table 6.1.1. DMC estimation (Canadian Forestry Service, 1987).

		No. days (after 3 days)											
T (°C)	HR (%)	1	2	3	4	5	6	7	8	9	10	11	12
10	40	6.8	7.6	8.5	9.3	10.1	10.9	11.7	12.5	13.4	14.2	15.0	15.2
	50	6.7	7.4	8.1	8.7	9.4	10.1	10.8	11.5	12.1	12.8	13.5	14.1
	60	6.5	7.1	7.6	8.2	8.7	9.3	9.8	10.4	10.9	11.5	12.0	12.6
	70	6.4	6.8	7.2	7.6	8.1	8.5	8.9	9.3	9.7	10.1	10.5	10.9
12.5	40	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.1	18.1
	50	6.8	7.7	8.5	9.3	10.2	11.0	11.9	12.7	13.5	14.4	15.2	16.0
	60	6.7	7.3	8.0	8.7	9.3	10.0	10.7	11.4	12.0	12.7	13.4	14.0
	70	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
15	40	7.2	8.4	9.6	10.8	11.9	13.1	14.3	15.5	16.7	17.9	19.0	20.2
	50	7.0	7.9	8.9	9.9	10.9	11.9	12.9	13.9	14.9	15.9	16.9	17.0
	60	6.8	7.6	8.4	9.2	9.9	10.8	11.6	12.3	13.1	13.9	14.7	15.5
	70	6.6	7.2	7.8	8.4	8.9	9.6	10.2	10.8	11.4	11.9	12.5	13.1
17.5	40	7.4	8.7	10.1	11.5	12.9	14.2	15.6	16.9	18.4	19.7	21.1	22.5
	50	7.1	8.3	9.4	10.6	11.7	12.9	14.0	15.2	16.3	17.4	18.6	19.7
	60	6.9	7.8	8.7	9.6	10.6	11.5	12.4	13.2	14.2	15.2	16.0	16.9
	70	6.7	7.4	8.1	8.7	9.4	10.1	10.8	11.5	12.2	12.9	13.6	14.2

Table 6.1.2. Additive correction to Table 6.1.1. estimates (Canadian Forestry Service, 1987).

T (°C)	HR (%)	February	March	April	October	November - January
5.5 - 10	0-52	1	1	1	1	1
	53-100	0	0	0	0	0
10.5 - 15	0-42	1	2	2	1	1
	43-73	1	1	1	1	1
	74-100	0	0	1	0	0
15.5 - 20	0-32	2	3	4	2	2
	33-52	2	2	3	2	1
	53-73	1	1	2	1	1
	74-100	1	1	1	1	0

Table 6.1.3. Rainfall effect on the DMC (Canadian Forestry Service, 1987).

Previous day DMC	Rainfall (mm)				
	<1.5	1.5-5.1	5.2-8.2	8.3-20.5	>20.5
0-2	*	0	0	0	0
3-5	*	3-2	2	1	1
6-8	*	5-4	4-3	3	3
9-11	*	9-6	6-5	4	4
12-14	*	12-8	7	6	5
15-17	*	15-10	9-8	8-7	7-6
18-20	*	18-12	11-10	10-8	8-7

* Unchanged from previous day.

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