Field Guide for Predicting Fire Behaviour in Ontario's Tallgrass Prairie

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This guide is dedicated to Tom Leblanc, whose 35 year career in fire management in Ontario included the delivery of tallgrass prairie burns as well as the training and mentoring of many of today's prescribed burn practitioners.

Partners

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TABLE OF CONTENTS

Disclaimers and acknowledgements....vi
Cautions....vii
Introduction....1
Use of the guide....3
Procedures used in the guide....7

Fuel Load
Robel pole fuel load graph....8
Litter layer fuel load graph....8
Tallgrass prairie photo series....9

Fuel Moisture
Effective solar radiation....30
Temperature of the fuel....31
Relative Humidity of the fuel....32
Moisture content after rain....33
Moisture content of the fuel....34

Fire Behaviour
Equilibrium rate of spread
Matted grass....42
Standing grass....43
Rate of spread curing conversions....44
Slope equivalent rate of spread....45
Fire intensity....46
Spread distance....47
Fire area and perimeter....48
Perimeter growth rate....49

Appendix
Abbreviations....50
Glossary....50
Selected unit conversions....52
Wind conversions....53
Beaufort scale for estimating 10 m open wind speeds....54
Robel pole construction and instructions....55
Time until burnable....57
Starting moisture contents....61
Equilibrium moisture contents....62
Fuel load worksheet....63
Fire behaviour worksheet....64
Bibliography....65

Disclaimer and limitation of liability

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For consistency in operational use throughout Canada, we have tried to follow the general look and feel of the "Red Book" (Field Guide to the Canadian Forest Fire Behaviour and Prediction System).

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Caution

Fire behaviour models and the predictions derived from them are intended to be used as tools to assist in decision making; such tools are not a substitute for experience, sound judgement, or observation of actual fire behaviour. Almost any fire can be hazardous in some circumstances. Fire behaviour can change rapidly due to changes in fuel condition, slope, and exposure to wind and rapid drying effects of solar radiation. No system can ever fully account for all of the variables that affect fire behaviour. This field guide attempts to provide users with basic information on potential fire behaviour in certain circumstances and is not intended to be a guide to safe working conditions. Operational personnel must be aware of the limitations of the system and be able to recognize unique or unusual situations.

Assumptions

Users must be careful not to apply the models beyond their useful range. With the fire behaviour models used, predictions are limited to a fire spreading during one burning period from a point or line ignition, assuming that:

- All fuels are grasses or forbs.
- Fuel moisture contents are representative of the site conditions.
- Fuels are uniform and continuous, topography is simple and homogeneous, and wind is constant and unidirectional.
- The fire is wind or wind/slope driven, and spread is not affected by a convection column. Wind is represented by the 10m open wind.
- The fire is unaffected by suppression activities (free burning).
- A fire starting from a point ignition will have an elliptical shape under the above conditions.
- The effect of firebrands on spread rate is accounted for.

Introduction

This field guide was created to address the need for a more accurate estimate of fire behaviour in the tallgrass prairie of southern Ontario. Actual fire behaviour in tallgrass prairies consistently exceeded Canadian Forest Fire Behaviour Prediction (FBP) predictions in the matted and standing grass fuel types (O-1a and O-1b) leading prescribed burn practitioners to under-predict expected fire behaviour as well as limiting the conditions under which tallgrass species can be expected to burn. The models used in this guide are not tallgrass fuel type specific and therefore the authors believe that this guide can be used for all grass types in Ontario, however this assumption has not been tested.

The new rate of spread model for tallgrass prairies detailed in this field guide is based on models developed in Australian grasslands and requires an estimate of actual fuel moisture of the grass fuels and thus a tabular method for estimating grass moisture content has also been introduced. Fuel layers in typical tallgrass sites are much more exposed than the shaded litter fuels modelled by the Canadian Forest Fire Weather Index (FWI) System's Fine Fuel Moisture Code (FFMC) and grass itself has a shorter response time that needle litter; response times in grasses have been found to be on the order of one hour. This increased exposure and lower characteristic response time leads to a very fast reacting fuel layer, one for which once daily moisture indices such as the FFMC are of little value. Indeed, even the hourly calculated FFMC reacts too slowly to track moisture content in exposed fields of grasses. Because of its quick reaction time, grass moisture content is very sensitive to changes in temperature, relative humidity and wind speed and is strongly influenced by the amount of solar radiation received. As a result, it is important to track the hourly changes in these conditions in order to calculate an accurate moisture content value - a key factor in determining rate of spread.

Because grass moisture does change quickly with environmental conditions, it is possible however to reasonably estimate moisture content by tracking changing weather conditions for just a few hours prior to the time when a moisture content is needed. If a reasonable estimate of starting moisture content can be made, tracking weather conditions and calculating fuel moisture content for the 3 hours prior to the burn should be sufficient in most cases to make a reasonable estimate of moisture content for the rate of spread prediction.

The fuel moisture model used in this guide has been developed using observations from matted grasses. Matted and standing grasses respond differently to wetting and drying; matted grasses absorb more precipitation than standing grasses and will therefore contain more moisture after a precipitation event than standing grasses. Similarly, matted grasses will absorb more incident solar radiation than standing grasses and will therefore dry more dramatically than standing grasses under sunny conditions. For the range of fuel moistures relevant for fire prediction in this guide (fuel moisture < 20%), the difference between fuel moisture in matted and standing grass is relatively small, so the fuel moisture model can be used for both grass conditions.

The indices used in the FBP System, such as the Fine Fuel Moisture Content (FFMC) and Initial Spread Index (ISI), have been abandoned in favour of direct inputs such as wind speed and fuel moisture content. The Equilibrium Moisture Content (EMC, see Appendix 9) is representative of the fuel moisture content of grasses during the peak burning period on days when weather is relatively stable and can be used as a surrogate for the FFMC in prescribed burn planning.

Use of the Guide

All wind speeds used in this guide are 10 m open wind speed. See Appendix 4 for a wind speed conversion table.

Fuel Load

Fuel load is essential in making accurate fire intensity estimates. Before beginning the fire behaviour prediction process, visit the site the fall before the burn while the grass is still standing to make fuel load estimates. The field guide provides two methods for estimating fuel load in standing grass: a visual obstruction method using a device called the Robel pole and a tallgrass prairie fuel load photo series.

A Robel pole can be used on site to estimate fuel load See Appendix 6 for information on the construction and use of the Robel pole. If your burn area contains distinct sub-areas where, because of species composition or density fuel loads are expected to be different, you should measure fuel load independently in each of these regions. For each relatively uniform area, after taking a minimum of 10 Robel pole measurements, take the average of these measurements and find the corresponding fuel load in Figure 1. A site with greater fuel load variability will require more measurements. If there is a litter layer present at the site, take measurements of the depth of the litter layer at the Robel pole measurement site. Average these litter layer depth measurements and, using Figure 2, find the appropriate fuel load of the litter layer. Add the standing fuel load and the litter layer fuel load to get a total fuel load.

If the Robel pole is not available, the Tallgrass Prairie Fuel Load Photo Series can be used to estimate fuel load.

Moisture Content

1. Determine a starting grass moisture content value based on conditions approximately 4 hours before the burn based on time of day and effective solar radiation (see Table 1). If it has recently rained, refer to Table 4 to determine appropriate starting moisture content based on the amount of rain received. If it has not rained overnight, but did recover, a reasonable approximation is that the grass layer is at its fibre saturation point, ~35% in the early morning (~8 am) as grasses won't exceed 35-40% moisture content in the absence of rain or heavy dew or frost. In the case of frost or heavy dew, a starting moisture content between 100%-150% can be used, and after a heavy rain, a starting

moisture content of 250% can be used. See Appendix 8 for approximate starting moisture content values for other times during the day.

If significant precipitation has occurred (fuel moisture ~ 250%), refer to Appendix 7 for a quick guide to estimating how long it will take for fuels to become burnable (fuel moisture ~ 20%).

2. Determine the most appropriate effective solar radiation (SOL_{ef}) value based on cloud cover and time of day (Table 1).

   Increased cloud cover means less radiation will be received by fuels; the sun low in the sky (during early morning or evening) also means less radiation is received by fuels. Peak solar radiation during the month of April in south-western Ontario occurs around 1400h. An effective solar radiation (SOL_{ef}) value of 1 corresponds to conditions during peak solar radiation on a cloud-free day while a value of 0 corresponds to conditions when less than 10% of peak solar radiation makes it to the fuels as a result of cloud cover and/or time of day. For the sake of simplicity in this tabular method for estimating grass moisture we equate the reduced radiation received when the sun is lower in the sky with scattered (SCT) ,or broken (BKN) or even overcast (OVC) cloud conditions. For example, effective solar radiation in the early morning (8:00 am) of a cloud free day will be equivalent to radiation received during peak solar radiation hours (~2:00 pm) on a day with broken cloud conditions.

3. Calculate fuel temperature using air temperature, wind speed and effective solar radiation (Table 2).

   Fuel temperature is representative of the temperature in the microenvironment of a fully matted fuel layer (grasses become flattened, or matted over winter due to snow compaction). Solar radiation acts to raise fuel temperatures (sometimes very significantly), while wind mixes and moves heat away from the fuel layer microenvironment decreasing fuel temperatures.

4. Calculate the relative humidity at the fuel by using relative humidity, air temperature and fuel temperature (Table 3).

   Relative humidity of the fuel represents the relative humidity in the microenvironment of a fully matted fuel layer. Increased temperature

of the fuel leads to a lower relative humidity in the fuel microenvironment.

5. Find the appropriate Moisture Content Table to use based on fuel temperature (Table 5.x). For the first hour's calculation, use your starting moisture content value from step 1 as the previous hour's moisture content. In subsequent hours, skip step 1 and use the value found previously in this step as the previous hour's moisture content.

6. Repeat steps 2-5 using the appropriate hourly weather predictions until a final moisture content value has been calculated for the desired time (e.g. either the current time or the forecasted ignition time). This final moisture content value will be used in subsequent rate of spread prediction calculations.

7. For a quick estimate of the minimum moisture content that would be reached on a given day, Appendix 9 can be used with that day's forecasted value of maximum air temperature and minimum relative humidity. An estimate of forecasted effective solar radiation of the peak burning period (late afternoon) is also needed. Using these inputs, Appendix 9 gives the user the equilibrium moisture content (EMC) of the fuel. Assuming forecasted conditions are correct, this will be the minimum fuel moisture achievable. In the new grass moisture model this value is essentially the analogue of the FWI System's daily FFMC output.

Primary Fire Behaviour Estimates

8. Find the equilibrium rate of spread for the condition where grass curing is 100% and slope is 0 using the final grass moisture content calculated in Step 6 and the 10 m open forestry wind speed (Table 6.1 or 6.2). If grass curing is less than 100%, then continue to Step 9 to modify this spread rate value based on percent cured. If there is a slope, then continue with step 10 to determine the appropriate rate of spread value based on slope. If grasses are 100% cured and slope is 0, skip to Step 11.

9. Estimate grass curing percentage. Using the rate of spread value calculated in Step 8, find the appropriate rate of spread for the degree of curing of the grass (Table 7).

10. Determine the slope at your site. Using the appropriate rate of spread based on curing from either Step 8 or 9, determine the rate of spread with the effect of slope added (Table 8). If the fire is going upslope, use a positive slope and if fire is going downslope, use a negative slope. Note that only scenarios where wind is driving a fire directly upslope or directly downslope can be evaluated explicitly in this guide.

11. Using the appropriate rate of spread value (based on curing and slope) and the average fuel load at the site, determine the fire intensity class (Table 9).

Secondary Fire Behaviour Estimates

12. Enter the elapsed time corresponding to the prediction time interval. Determine head fire spread distance, backfire spread distance and total spread distance (head fire + back fire spread distance) from Table 10. Distances are given for two spread functions: equilibrium rate of spread and accelerating rate of spread.

    Use the equilibrium rate of spread function for fires spreading from an active fire perimeter or other line ignition. Use the accelerating function for fires spreading from a point ignition type. Determine the backfire spread distances only if there are no barriers to backfire spread. Note: accelerating rate of spread follows the standard FBP System acceleration rate for open fuels, where 90% of equilibrium rate of spread is reached after 20 minutes.

13. For fires starting from a point source, determine the elliptical fire area, elliptical fire perimeter and the length to breadth ratio (LB) from the total spread distance and effective wind speed during the prediction interval (Table 11).

14. The perimeter growth rate can be determined from the head fire and back fire rate of spread and effective wind speed in Table 12. An elliptically shaped fire's maximum width or breadth can be calculated by dividing the total spread distance by the LB ratio (Table 11).

Procedures used in the guide

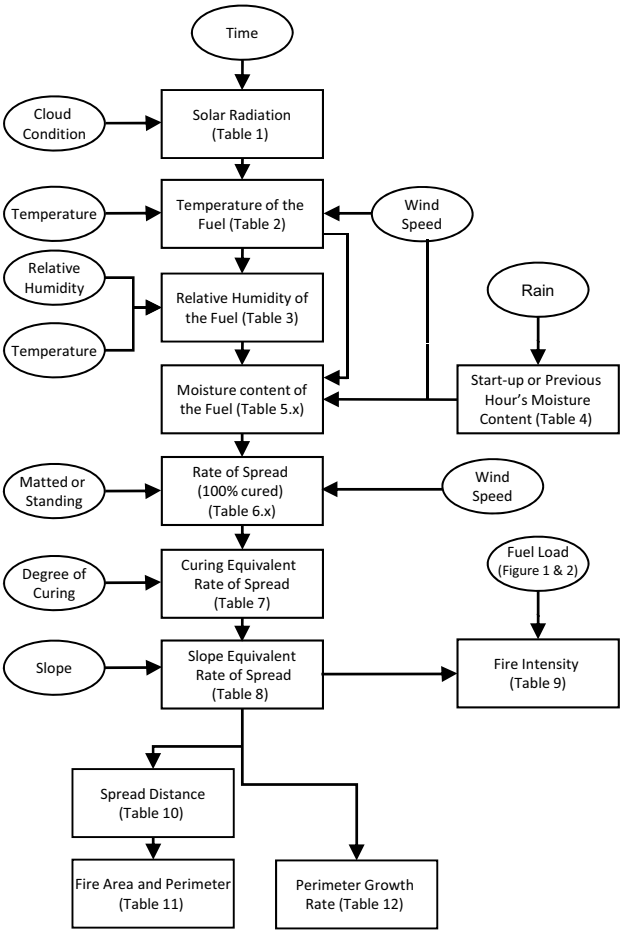
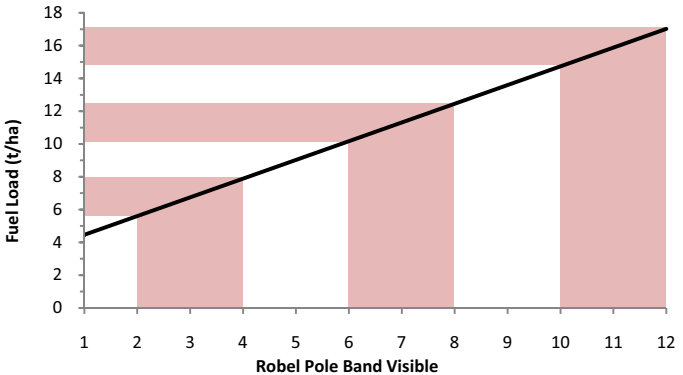


FIGURE 1

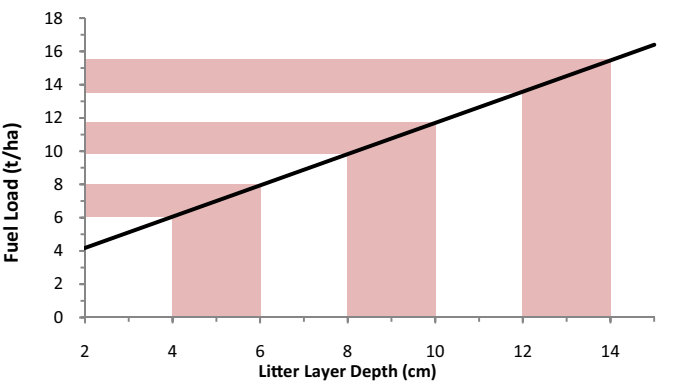
Robel pole and fuel load relationship



Robel pole band visible refers to lowest band of colour visible when viewed from 3 m away from poleand a height of 1 m above the ground. See Appendix 6 for more details.

FIGURE 2

Litter layer depth and fuel load relationship



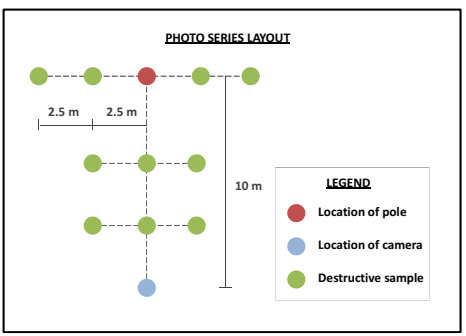
The litter layer is the matted, decomposing layer of previous year's growth.

Tallgrass Prairie Photo Series

How the photo series was created

Photos were taken in the late autumn when all plants were dormant. The pole in each photograph is 2 m tall and is painted with alternating bands of colour every 10 cm. The pictures were taken 10 m away from the pole from a tripod 1.5 m above the ground.

10 destructive fuel samples were taken to determine fuel load at each site (see picture below for layout of destructive sampling). Each sample consisted of the standing vegetation from a 0.46 m x 0.46 m square (matted grass was not included in this total, since it is not visible in the pictures. If a site contains matted grass, please refer to Table 2 to determine the matted layer fuel load). The average fuel load is the average of all 10 samples . The minimum fuel load is the single sample with the lowest fuel load and the maximum fuel load is the single sample with the greatest fuel load. All values have been rounded to the nearest whole integer.



Sites have been assigned codes based on their average fuel load. For example, sites with average fuel loads between 2.5 t/ha – 3.5 t/ha have been assigned codes TGP-3a, TGP-3b, TGP-3c, etc. Sites with average fuel loads between 9.5 t/ha to 10.5 t/ha have been assigned codes TGP-10a, TGP-10b, TGP-10c, etc. This is done so that sites may be easily added in the future while keeping the guide labelled and ordered by increasing fuel load.

Tallgrass Prairie Photo Series

Fuel Type: **EXAMPLE**

Soil: *Describes the soil*

Drainage: *How well water drains through the soil*

County site is located in

Average fuel load: *Average, min and max of destructive samples*

Minimum fuel load:

Maximum fuel load:

Dominant grass species: Lists t*he most abundant grass species at the site*

Height of dominant grass species: (in meters)

Other species present: *Lists all other species at the site*

Site history:

1. When the prairie was last burned with respect to when the picture was taken

2. How frequently the site is burned- ***frequently*** *(more than three times in the past 10 years),* ***infrequently*** *(less than three times in the past 10 years), and* ***never***

3. Type of prairie - ***remnant prairie*** *(a natural prairie that has never been disturbed),* ***restored prairie*** *(a site that has been reverted from anthropogenic uses back to a prairie, site retained prairie seed bed) and* ***planted prairie*** *(a site that has been converted into a prairie by actively planting prairie species)*

Fuel Type: **TGP - 1a**

Soil: **Sandy (and shallow)**
Drainage: **Good**
Wentworth County

Average fuel load: **1 t/ha**
Minimum fuel load: **0.5 t/ha**
Maximum fuel load: **3 t/ha**

Dominant grass species: **Little bluestem**
Height of dominant grass species: **0.75 m - 1.0 m**

Other species present: **Fescue and timothy grass**

Site history: Burned spring previous to picture being taken
Burned frequently
Restored prairie, no significant planting done
Little bluestem very clumpily distributed

Fuel Type: **TGP - 2a**

Soil: **Sandy with gravel**
Drainage: **Good**
Northumberland County

Average fuel load: **2 t/ha**
Minimum fuel load: **1 t/ha**
Maximum fuel load: **3 t/ha**

Dominant grass species: **Big bluestem, Indian grass and little bluestem**

Height of dominant grass species: **1.5 m - 2.0 m**

Other species present: **Mixture of prairie forbs**

Site history: Burned spring previous to picture being taken
Burned frequently
Remnant prairie

Fuel Type: **TGP - 2b**

Soil: **Sandy and rocky**	Average fuel load: **2 t/ha**
Drainage: **Good**	Minimum fuel load: **1 t/ha**
Elgin County	Maximum fuel load: **2 t/ha**

Dominant grass species: **Indian grass**

Height of dominant grass species: **1.0 m - 1.5 m**

Other species present: **Grey headed coneflower**

Site history: Burned two springs previous to picture being taken
Burned frequently
Remnant prairie (along old railway track)

Fuel Type: **TGP - 2c**

Soil: **Sandy (rocky and shallow)**
Drainage: **Good**
Wentworth County

Average fuel load: **2 t/ha**
Minimum fuel load: **1 t/ha**
Maximum fuel load: **3 t/ha**

Dominant grass species: **Little bluestem**
Height of dominant grass species: **0.75 m - 1.0 m**

Other species present: **Minimal forbs interspersed**

Site history: Burned spring previous to picture being taken
Burned frequently
Restored prairie, no significant planting done

Fuel Type: **TGP - 2d**

Soil: **Clay**	Average fuel load: **2 t/ha**
Drainage: **Poor**	Minimum fuel load: **2 t/ha**
Essex County	Maximum fuel load: **3 t/ha**

Dominant grass species: **None**

Height of dominant grass species: **n/a**

Other species present: **Golden rod, Queen Anne's lace, sunflowers**

Site history: Burned spring previous to picture being taken
Burned infrequently
Remnant prairie

Fuel Type: **TGP - 3a**

Soil: **Clay**	Average fuel load: **3 t/ha**
Drainage: **Poor**	Minimum fuel load: **1 t/ha**
Essex County	Maximum fuel load: **5 t/ha**

Dominant grass species: **Switch grass and Indian grass**

Height of dominant grass species: **1.0 m - 1.75 m**

Other species present: **Mixture of forbs**

Site history: Last burn unknown
Burned infrequently
Remnant prairie

Fuel Type: **TGP - 3b**

Soil: **Sandy loam**	Average fuel load: **3 t/ha**
Drainage: **Moderate**	Minimum fuel load: **1 t/ha**
Northumberland County	Maximum fuel load: **5 t/ha**

Dominant grass species: **Big bluestem**

Height of dominant grass species: **1.5 m - 2.0 m**

Other species present: **Sunflower, New Jersey tea, bracken fern, Pennsylvania sedge**

Site history: Burned spring previous to picture being taken
Burned frequently
Remnant prairie

Tallgrass Prairie Photo Series

Fuel Type: **TGP - 3c**

Soil: **Clay**	Average fuel load: **3 t/ha**
Drainage: **Moderate**	Minimum fuel load: **3 t/ha**
Lambton County	Maximum fuel load: **4 t/ha**

Dominant grass species: **Indian grass**

Height of dominant grass species: **1.25 m**

Other species present: **Golden rod, foxglove beard tongue**

Site history: Burned spring previous to picture being taken
Burned frequently
Planted five years before picture was taken
(previously farmland and borrow pit)

Fuel Type: **TGP - 3d**

Soil: **Clay**	Average fuel load: **3 t/ha**
Drainage: **Poor**	Minimum fuel load: **2 t/ha**
Essex County	Maximum fuel load: **5 t/ha**

Dominant grass species: **Little bluestem**

Height of dominant grass species: **1.0 m**

Other species present: **Indian grass, golden rod, sunflower and thistle**

Site history: Last burn unknown
Burned infrequently
Remnant prairie

Fuel Type: **TGP - 3e**

Soil: **Clay**	Average fuel load: **3 t/ha**
Drainage: **Moderate**	Minimum fuel load: **0 t/ha**
Lambton County	Maximum fuel load: **10 t/ha**

Dominant grass species: **Big bluestem**

Height of dominant grass species: **1.5 m - 1.75 m**

Other species present: **Golden rods, cone flowers and clover**

Site history: Burned spring previous to picture being taken
Burned frequently
Planted seven years before picture was taken
(previously used as farmland)

Fuel Type: **TGP - 3f**

Soil: **Sandy**	Average fuel load: **3 t/ha**
Drainage: **Good**	Minimum fuel load: **1 t/ha**
Kent County	Maximum fuel load: **6 t/ha**

Dominant grass species: **Big bluestem and Indian grass**

Height of dominant grass species: **1.75 m - 2.0 m**

Other species present: **Little bluestem and forbs**

Site history: Burned spring previous to picture being taken
Burned frequently
Previously a recreation area left fallow nine years before picture was taken. Minimal planting done.

Fuel Type: **TGP - 3g**

Soil: **Eroded clay**	Average fuel load: **3 t/ha**
Drainage: **Moderate**	Minimum fuel load: **1 t/ha**
Lambton County	Maximum fuel load: **7 t/ha**

Dominant grass species: **Canadian and Virgina wild rye**

Height of dominant grass species: **1.0 m**

Other species present: **Tall sunflower, Indian grass, big bluestem and switch grass**

Site history: Never burned
Planted five years previous to picture being taken (previously used as farmland)

Fuel Type: **TGP - 4a**

Soil: **Sandy and rocky**	Average fuel load: **4 t/ha**
Drainage: **Good**	Minimum fuel load: **3 t/ha**
Elgin County	Maximum fuel load: **5 t/ha**

Dominant grass species: **Big bluestem and Indian grass**

Height of dominant grass species: **1.0 m - 1.5 m**

Other species present: **None**

Site history: Burned two springs previous to picture being taken
Burned frequently
Remnant prairie
Note: picture taken on slight slope

Fuel Type: **TGP - 4b**

Soil: **Clay**	Average fuel load: **4 t/ha**
Drainage: **Poor**	Minimum fuel load: **0 t/ha**
Lambton County	Maximum fuel load: **7 t/ha**

Dominant grass species: **Big bluestem**

Height of dominant grass species: **1.5 m - 1.75 m**

Other species present: **Golden rod, cone flowers and clover**

Site history: Burned spring previous to picture being taken
Burned frequently
Planted seven years before picture was taken
(previously used as farmland)

Fuel Type: **TGP - 4c**

Soil: **Clay**	Average fuel load: **4 t/ha**
Drainage: **Moderate**	Minimum fuel load: **3 t/ha**
Lambton County	Maximum fuel load: **8 t/ha**

Dominant grass species: **Big bluestem and Indian grass**

Height of dominant grass species: **1.6 m - 1.8 m**

Other species present: **Golden rods, tall sunflower and ironweed**

Site history: Burned spring previous to picture being taken
Burned frequently
Planted several years before picture was taken
(was previously used as farmland)

Fuel Type: **TGP - 6a**

Soil: **Clay loam**	Average fuel load: **6 t/ha**
Drainage: **Moderate**	Minimum fuel load: **2 t/ha**
Elgin County	Maximum fuel load: **12 t/ha**

Dominant grass species: **Big bluestem and Indian grass**

Height of dominant grass species: **2.0 m**

Other species present: **None**

Site history: Burned three springs previous to picture being taken
Burned frequently
Plug planted 12 years before picture was taken

Fuel Type: **TGP - 7a**

Soil: **Sandy loam**	Average fuel load: **8 t/ha**
Drainage: **Good**	Minimum fuel load: **5 t/ha**
Lambton County	Maximum fuel load: **11 t/ha**

Dominant grass species: **Indian grass**

Height of dominant grass species: **1.6 m - 2.0 m**

Other species present: **Minimal Queen Anne's lace interspersed**

Site history: Burned spring previous to picture being taken
Burned frequently
Planted as a nursery five years before picture was taken (previously used as farmland)

Fuel Type: **TGP - 10a**

Soil: **Sandy loam**	Average fuel load: **10 t/ha**
Drainage: **Good**	Minimum fuel load: **6 t/ha**
Lambton County	Maximum fuel load: **21 t/ha**

Dominant grass species: **Switch grass**

Height of dominant grass species: **1.6 m - 2.0 m**

Other species present: **None**

Site history: Burned spring previous to picture being taken
Burned frequently
Planted as a nursery five years before picture was taken (previously used as farmland)

Fuel Type: **TGP - 11a**

Soil: **Organic**	Average fuel load: **11 t/ha**
Drainage: **Good**	Minimum fuel load: **5 t/ha**
Lambton County	Maximum fuel load: **14 t/ha**

Dominant grass species: **Big bluestem**

Height of dominant grass species: > **2.0 m**

Other species present: **None**

Site history: Burned spring previous to picture being taken
Burned frequently
Planted six years before picture was taken
(previously used as farmland)

TABLE 1

Effective Solar Radiation (SOL_{ef}) Conversion Table

	Cloud Conditions			
Time	Clear (CLR)	Scattered (SCT)	Broken (BKN)	Overcast (OVC)
7:30 AM	0	0	0	0
7:45 AM	0	0	0	0
8:00 AM	1/3	0	0	0
8:30 AM	1/3	1/3	0	0
9:00 AM	1/3	1/3	0	0
9:30 AM	2/3	1/3	1/3	0
10:00 AM	2/3	1/3	1/3	0
10:30 AM	2/3	2/3	1/3	0
11:00 AM	1	2/3	1/3	0
11:30 AM	1	2/3	1/3	0
12:00 PM	1	2/3	1/3	0
12:30 PM	1	2/3	1/3	0
1:00 PM	1	2/3	1/3	0
1:30 PM	1	2/3	1/3	0
2:00 PM	1	2/3	1/3	0
2:30 PM	1	2/3	1/3	0
3:00 PM	1	2/3	1/3	0
3:30 PM	1	2/3	1/3	0
4:00 PM	2/3	2/3	1/3	0
4:30 PM	2/3	1/3	1/3	0
5:00 PM	2/3	1/3	1/3	0
5:30 PM	2/3	1/3	0	0
6:00 PM	1/3	1/3	0	0
6:30 PM	1/3	1/3	0	0
7:00 PM	1/3	0	0	0
7:30 PM	0	0	0	0

Note: Clear= sky is clear of all clouds, scattered = cloud cover is less than 50%, broken= cloud cover is greater then 50% of sky, but blue sky is still visible, overcast=complete cloud cover

All conditions before 7:30AM and after 7:30PM have an SOL_{ef} of 0.

This table is designed for use in south-western Ontario in mid-April.

TABLE 2

Fuel Temperature, T_f (°C)

		Wind Speed (km/h)							
Air Temp. (°C)	SOL_{ef}	2.5	5	7.5	10	15	20	25	30
5	0	5	5	5	5	5	5	5	5
	1/3	13	12	11	10	9	8	7	6
	2/3	21	19	17	15	12	10	9	8
	1	29	26	23	20	16	13	11	9
10	0	10	10	10	10	10	10	10	10
	1/3	18	17	16	15	14	13	12	11
	2/3	26	24	22	20	17	15	14	13
	1	34	31	28	25	21	18	16	14
15	0	15	15	15	15	15	15	15	15
	1/3	23	22	21	20	19	18	17	16
	2/3	31	29	27	25	22	20	19	18
	1	39	36	33	30	26	23	21	19
20	0	20	20	20	20	20	20	20	20
	1/3	28	27	26	25	24	23	22	21
	2/3	36	34	32	30	27	25	24	23
	1	44	41	38	35	31	28	26	24
25	0	25	25	25	25	25	25	25	25
	1/3	33	32	31	30	29	28	27	26
	2/3	41	39	37	35	32	30	29	28
	1	49	46	43	40	36	33	31	29
30	0	30	30	30	30	30	30	30	30
	1/3	38	37	36	35	34	33	32	31
	2/3	46	44	42	40	37	35	34	33
	1	54	51	48	45	41	38	36	34

Note: Air temperature is to be measured on site or at the nearest weather station.

TABLE 3

Relative Humidity (%) of the Fuel (RH_f)

Air Temp. (°C)	T_f (°C)	Relative Humidity (%)							
		10	20	30	40	50	60	80	100
5	5	10	20	30	40	50	60	80	100
	10	7	14	21	28	36	43	57	71
	15	5	10	15	20	26	31	41	51
	20	4	7	11	15	19	22	30	37
	25	3	5	8	11	14	16	22	27
10	10	10	20	30	40	50	60	80	100
	15	7	14	22	29	36	43	58	72
	20	5	10	16	21	26	31	42	52
	25	4	8	12	15	19	23	31	39
	30	3	6	9	12	14	17	23	29
15	15	10	20	30	40	50	60	80	100
	20	7	15	22	29	36	44	58	73
	25	5	11	16	22	27	32	43	54
	30	4	8	12	16	20	24	32	40
	35	3	6	9	12	15	18	24	30
20	20	10	20	30	40	50	60	80	100
	25	7	15	22	30	37	44	59	74
	30	6	11	17	22	28	33	44	55
	35	4	8	12	17	21	25	33	42
	40	3	6	10	13	16	19	25	32
25	25	10	20	30	40	50	60	80	100
	30	7	15	22	30	37	45	60	75
	35	6	11	17	23	28	34	45	56
	40	4	9	13	17	21	26	34	43
	45	3	7	10	13	17	20	26	33
30	30	10	20	30	40	50	60	80	100
	35	8	15	23	30	38	45	60	75
	40	6	11	17	23	29	34	46	57
	45	4	9	13	18	22	27	35	44
	50	3	7	10	14	17	21	27	34

Note: Air temperature and relative humidity are to be measured on site or at the nearest weather station.

TABLE 4

Moisture Content After Rain (MC_r)

	Rain (mm)								
Starting MC (%)	0.1	0.2	0.3	0.4	0.5	0.75	1	1.5	2
4	21	37	54	71	87	129	171	250	250
6	23	39	56	73	89	131	173	250	250
8	25	41	58	75	91	133	175	250	250
10	27	43	60	77	93	135	177	250	250
12	29	45	62	79	95	137	179	250	250
14	31	47	64	81	97	139	181	250	250
16	33	49	66	83	99	141	183	250	250
18	35	51	68	85	101	143	185	250	250
22	39	55	72	89	105	147	189	250	250
24	41	57	74	91	107	149	191	250	250
30	47	63	80	97	113	155	197	250	250
35	52	68	85	102	118	160	202	250	250
40	57	73	90	107	123	165	207	250	250
45	62	78	95	112	128	170	212	250	250
50	67	83	100	117	133	175	217	250	250
55	72	88	105	122	138	180	222	250	250
60	77	93	110	127	143	185	227	250	250
65	82	98	115	132	148	190	232	250	250
70	87	103	120	137	153	195	237	250	250
75	92	108	125	142	158	200	242	250	250
80	97	113	130	147	163	205	247	250	250
85	102	118	135	152	168	210	250	250	250
90	107	123	140	157	173	215	250	250	250
100	117	133	150	167	183	225	250	250	250

Moisture content after rain varies slightly with fuel load. The above table assumes a constant fuel load of 6 t/ha, but can be used for all fuel loads

If rain exceeds 2mm, all moisture contents go to 250%.

TABLE 5.1

Moisture content (%) of a matted grass layer with a T_f of 5°C

RH_f (%)	Wind Speed (km/h)	Last hour's moisture content (%)																						
		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50	60	75	100	150	200	250
5	5	3	4	5	6	7	7	8	8	9	10	12	13	14	16	19	24	30	35	43	57	84	110	137
	10	3	4	5	6	7	7	8	8	9	10	11	12	13	16	18	23	28	33	41	53	78	104	129
	15	3	4	5	6	7	7	8	8	9	10	11	12	13	15	18	22	27	32	39	51	75	98	122
	20	3	4	5	6	7	7	8	8	9	10	11	12	13	15	17	22	26	31	38	49	72	94	117
	25	3	4	5	6	7	7	8	8	9	10	11	11	12	15	17	21	25	30	36	47	69	91	113
10	5	4	5	6	6	7	8	9	10	11	12	13	14	15	18	21	26	31	37	45	58	86	113	140
	10	4	5	6	7	7	8	9	10	11	12	13	14	15	17	20	25	30	35	43	55	80	106	131
	15	4	5	6	7	7	8	9	10	11	12	13	14	15	17	19	24	29	34	41	53	77	101	125
	20	4	5	6	7	7	8	9	10	11	12	12	13	14	17	19	23	28	33	39	51	74	97	120
	25	4	5	6	7	7	8	9	10	11	11	12	13	14	16	19	23	27	32	38	49	71	93	115
20	5	5	6	7	7	8	9	10	10	12	14	15	16	17	20	23	28	34	39	47	61	89	116	144
	10	6	6	7	8	8	9	10	11	12	14	15	16	17	19	22	27	32	37	45	58	84	109	135
	15	6	7	7	8	9	9	10	11	12	14	15	16	17	19	21	26	31	36	43	56	80	105	129
	20	6	7	7	8	9	9	10	11	12	14	15	15	16	19	21	26	30	35	42	54	77	101	124
	25	6	7	8	8	9	9	10	11	12	14	14	15	16	19	21	25	30	34	41	52	75	97	120
30	5	6	7	8	8	9	10	11	11	13	14	16	17	18	21	24	29	35	41	49	64	92	120	149
	10	7	8	8	9	9	10	11	11	13	14	16	17	18	21	23	29	34	39	47	60	87	113	140
	15	7	8	8	9	10	10	11	12	13	14	16	17	18	20	23	28	33	38	46	58	83	108	134
	20	7	8	9	9	10	10	11	12	13	14	16	17	18	20	23	27	32	37	44	56	80	104	128
	25	8	8	9	9	10	11	11	12	13	14	16	17	18	20	22	27	32	36	43	55	78	101	124
50	5	8	9	10	10	11	11	12	13	14	15	16	18	20	23	26	32	38	44	54	69	100	131	162
	10	9	10	10	11	11	12	12	13	14	15	16	18	20	23	25	31	37	43	51	66	95	123	152
	15	9	10	10	11	12	12	13	13	14	15	17	18	20	22	25	31	36	41	50	63	91	118	145
	20	10	10	11	11	12	12	13	13	14	15	17	18	20	22	25	30	35	40	48	61	88	114	140
	25	10	11	11	12	12	13	13	14	15	16	17	18	20	22	25	30	35	40	47	60	85	110	135
75	5	11	12	12	13	14	14	15	15	16	17	19	20	21	25	28	36	43	50	61	79	115	151	187
	10	12	13	13	14	14	15	15	16	17	18	19	20	21	25	28	35	42	48	59	75	109	143	177
	15	12	13	13	14	14	15	15	16	17	18	19	20	21	25	28	34	41	47	57	73	105	138	170
	20	13	13	14	14	15	15	16	16	17	18	19	20	21	25	28	34	40	46	56	71	102	133	164
	25	13	14	14	15	15	16	16	16	17	18	19	20	21	25	28	34	40	46	55	70	99	129	159

TABLE 5.2

Moisture content (%) of a matted grass layer with a T_f of 10°C

RH_f (%)	Wind Speed (km/h)	Last hour's moisture content (%)																											
		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50	60	75	100	150	200	250					
5	5	3	4	5	6	6	7	7	8	9	10	11	12	13	15	17	22	27	32	39	51	74	98	122					
	10	3	4	5	6	6	7	7	8	9	9	10	11	12	14	16	21	25	29	36	47	69	91	112					
	15	3	4	5	6	6	7	7	8	8	9	10	11	12	14	16	20	24	28	34	44	65	85	106					
	20	3	4	5	6	6	7	7	7	8	9	10	11	11	13	15	19	23	27	33	42	62	81	101					
	25	3	4	5	6	6	7	7	7	8	9	10	10	11	13	15	18	22	26	31	41	59	78	96.3					
10	5	4	5	6	6	7	8	9	9	10	11	12	13	14	16	19	24	28	33	40	52	76	100	124					
	10	4	5	6	6	7	8	9	9	10	11	12	13	14	16	18	22	27	31	38	49	71	93	115					
	15	4	5	6	6	7	8	9	9	10	11	12	12	13	15	17	22	26	30	36	46	67	88	108					
	20	4	5	6	6	7	8	9	9	10	11	12	12	13	15	17	21	25	29	35	44	64	84	103					
	25	4	5	6	7	7	8	9	9	10	11	11	12	13	15	17	20	24	28	33	43	61	80	98.7					
20	5	5	6	7	7	8	9	10	10	12	13	14	15	16	18	21	26	31	36	43	55	80	104	129					
	10	6	6	7	8	8	9	10	10	12	13	14	15	16	18	20	25	29	34	40	52	74	97	119					
	15	6	7	7	8	8	9	10	10	12	13	14	15	15	18	20	24	28	32	39	49	70	92	113					
	20	6	7	7	8	9	9	10	10	12	13	14	14	15	17	19	23	27	31	37	47	67	87	108					
	25	6	7	7	8	9	9	10	10	12	13	14	14	15	17	19	23	27	30	36	46	65	84	103					
30	5	6	7	8	8	9	10	10	11	12	14	15	16	17	20	22	27	32	38	45	58	83	109	134					
	10	7	8	8	9	9	10	10	11	12	14	15	16	17	19	22	26	31	36	43	54	78	101	124					
	15	7	8	8	9	10	10	11	11	12	14	15	16	17	19	21	26	30	34	41	52	74	96	118					
	20	8	8	9	9	10	10	11	11	12	14	15	16	17	19	21	25	29	33	40	50	71	91	112					
	25	8	8	9	9	10	10	11	11	12	14	15	16	17	19	21	24	28	32	38	48	68	88	108					
50	5	9	9	10	10	11	11	12	13	14	15	16	18	19	22	25	30	36	41	50	64	92	120	148					
	10	9	10	10	11	11	12	12	13	14	15	16	18	19	22	24	29	34	40	47	60	86	112	138					
	15	10	10	11	11	12	12	12	13	14	15	16	18	19	21	24	29	33	38	45	58	82	106	130					
	20	10	10	11	11	12	12	13	13	14	15	16	18	19	21	23	28	33	37	44	56	78	101	124					
	25	10	11	11	11	12	12	13	13	14	15	16	18	19	21	23	28	32	36	43	54	76	98	119					
75	5	12	12	13	13	14	14	15	15	16	17	18	19	20	24	28	34	41	48	58	75	109	142	176					
	10	12	13	13	14	14	15	15	16	17	17	18	19	20	24	27	34	40	46	55	71	102	134	165					
	15	13	13	14	14	15	15	16	16	17	18	19	19	20	24	27	33	39	45	54	68	98	128	157					
	20	13	14	14	15	15	15	16	16	17	18	19	19	20	24	27	32	38	44	52	66	94	123	151					
	25	14	14	14	15	15	16	16	16	17	18	19	19	20	24	27	32	37	43	51	64	91	118	146					

TABLE 5.3

Moisture content (%) of a matted grass layer with a T_f of 15°C

RH_f (%)	Wind Speed (km/h)	Last hour's moisture content (%)																						
		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50	60	75	100	150	200	250
5	5	3	4	5	6	6	6	7	7	8	9	10	10	11	13	15	19	24	28	34	44	64	85	105
	10	3	4	5	5	6	6	7	7	8	8	9	10	11	13	14	18	22	25	31	40	59	77	96
	15	3	4	5	5	6	6	7	7	8	8	9	10	10	12	14	17	21	24	29	38	55	72	89
	20	3	4	5	5	6	6	6	7	7	8	9	9	10	12	13	16	20	23	28	36	52	68	84
	25	3	4	5	5	6	6	6	7	7	8	8	9	10	11	13	16	19	22	26	34	49	64	80
10	5	4	5	5	6	7	8	8	9	9	10	11	12	13	15	17	21	25	29	35	46	66	87	108
	10	4	5	5	6	7	8	8	9	9	10	11	12	12	14	16	20	23	27	33	42	61	80	98
	15	4	5	6	6	7	8	8	8	9	10	11	11	12	14	15	19	22	26	31	40	57	74	92
	20	4	5	6	6	7	8	8	8	9	10	10	11	12	13	15	18	21	25	30	38	54	70	86
	25	4	5	6	6	7	8	8	8	9	10	10	11	11	13	15	18	21	24	28	36	51	67	82
20	5	5	6	7	7	8	9	9	10	11	12	13	14	15	17	19	23	27	32	38	49	70	91	112
	10	6	6	7	7	8	9	9	10	11	12	13	14	14	16	18	22	26	30	36	45	64	84	103
	15	6	6	7	8	8	9	9	10	11	12	13	13	14	16	18	21	25	28	34	43	60	78	96
	20	6	7	7	8	8	9	9	10	11	12	13	13	14	16	17	21	24	27	32	41	57	74	91
	25	6	7	7	8	8	9	9	10	11	12	12	13	14	15	17	20	23	26	31	39	55	71	86
30	5	6	7	8	8	9	9	10	11	12	13	14	15	16	18	21	25	29	34	40	52	74	96	118
	10	7	7	8	8	9	10	10	11	12	13	14	15	16	18	20	24	28	32	38	48	68	88	108
	15	7	8	8	9	9	10	10	11	12	13	14	15	16	17	19	23	27	30	36	45	64	83	101
	20	7	8	8	9	9	10	10	11	12	13	14	15	15	17	19	22	26	29	35	43	61	78	96
	25	8	8	9	9	9	10	10	11	12	13	14	15	15	17	19	22	25	28	33	42	58	75	91
50	5	9	9	10	10	11	11	12	12	13	14	16	17	18	21	23	28	33	38	46	58	83	108	133
	10	9	10	10	11	11	12	12	12	13	14	16	17	18	20	23	27	32	36	43	54	77	99	122
	15	10	10	10	11	11	12	12	13	13	14	16	17	18	20	22	26	30	35	41	51	72	93	114
	20	10	10	11	11	12	12	12	13	13	14	16	17	18	20	22	26	30	34	39	49	69	89	108
	25	10	11	11	11	12	12	12	13	14	14	16	17	18	20	21	25	29	33	38	47	66	85	103
75	5	12	13	13	13	14	14	15	15	16	17	18	19	20	24	27	33	39	45	55	70	102	133	164
	10	13	13	14	14	14	15	15	16	16	17	18	19	20	23	26	32	38	43	52	66	95	123	152
	15	13	14	14	14	15	15	15	16	17	17	18	19	20	23	26	31	37	42	50	63	90	117	143
	20	14	14	14	15	15	15	16	16	17	17	18	19	20	23	26	31	36	41	48	61	86	111	136
	25	14	14	15	15	15	16	16	16	17	17	18	19	20	23	25	30	35	40	47	59	83	107	131

TABLE 5.4
Moisture content (%) of a matted grass layer with a T_f of 20°C

RH_f (%)	Wind Speed (km/h)	Last hour's moisture content (%)																						
		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50	60	75	100	150	200	250
5	5	3	4	5	5	5	6	6	6	7	8	9	9	10	12	13	17	20	24	29	37	54	71	89
	10	3	4	5	5	5	6	6	6	7	7	8	9	9	11	12	15	18	21	26	34	49	64	79
	15	3	4	5	5	5	6	6	6	7	7	8	8	9	10	12	14	17	20	24	31	45	59	73
	20	3	4	5	5	5	5	6	6	7	7	8	8	9	10	11	14	16	19	23	29	42	55	67
	25	3	4	5	5	5	5	6	6	6	7	7	8	8	9	11	13	15	18	21	27	39	51	63
10	5	4	4	5	6	7	7	8	8	9	9	10	11	11	13	15	18	22	25	30	39	56	74	91
	10	4	5	5	6	7	7	7	8	8	9	10	10	11	12	14	17	20	23	28	35	51	66	81
	15	4	5	5	6	7	7	7	8	8	9	9	10	10	12	13	16	19	22	26	33	47	61	75
	20	4	5	5	6	7	7	7	8	8	9	9	10	10	11	13	15	18	21	24	31	44	57	70
	25	4	5	5	6	7	7	7	8	8	9	9	9	10	11	12	15	17	20	23	29	41	54	66
20	5	5	6	6	7	8	8	9	10	10	11	12	13	13	15	17	21	24	28	33	42	60	78	96
	10	5	6	6	7	8	8	9	10	10	11	12	12	13	15	16	19	22	26	30	38	54	70	86
	15	6	6	7	7	8	8	9	10	10	11	11	12	13	14	16	18	21	24	29	36	50	65	79
	20	6	6	7	7	8	8	9	10	10	11	11	12	12	14	15	18	20	23	27	34	47	61	74
	25	6	6	7	7	8	8	9	10	10	11	11	12	12	13	15	17	20	22	26	32	45	57	70
30	5	6	7	7	8	8	9	10	10	12	13	13	14	15	17	19	22	26	30	36	45	64	83	101
	10	7	7	8	8	9	9	10	10	12	12	13	14	14	16	18	21	25	28	33	41	58	75	91
	15	7	7	8	8	9	9	10	10	12	12	13	14	14	16	17	20	23	26	31	39	54	69	84
	20	7	8	8	8	9	9	10	10	12	12	13	13	14	15	17	20	23	25	30	37	51	65	79
	25	7	8	8	9	9	9	10	10	12	12	13	13	14	15	17	19	22	24	28	35	48	61	75
50	5	9	9	10	10	10	11	11	12	13	14	15	16	17	19	22	26	30	35	41	52	74	95	117
	10	9	10	10	10	11	11	12	12	13	14	15	16	17	19	21	25	29	32	38	48	67	86	106
	15	10	10	10	11	11	11	12	12	13	14	15	16	17	19	20	24	27	31	36	45	63	80	98
	20	10	10	10	11	11	11	12	12	13	14	15	16	17	18	20	23	26	30	35	43	59	75	92
	25	10	10	11	11	11	12	12	12	13	14	15	16	17	18	20	23	26	29	33	41	56	71	87
75	5	12	13	13	13	14	14	15	15	16	16	17	18	20	23	26	31	37	43	51	65	94	122	151
	10	13	13	14	14	14	15	15	15	16	17	17	18	20	23	25	30	35	40	48	61	86	112	137
	15	13	14	14	14	15	15	15	15	16	17	17	18	20	22	25	29	34	39	46	58	81	105	128
	20	14	14	14	15	15	15	15	16	16	17	17	18	20	22	24	29	33	37	44	55	77	99	121
	25	14	14	14	15	15	15	16	16	16	17	17	18	20	22	24	28	32	36	43	53	74	94	115

TABLE 5.5

Moisture content (%) of a matted grass layer with a T_f of 25°C

RH_f (%)	Wind Speed (km/h)	Last hour's moisture content (%)																						
		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50	60	75	100	150	200	250
5	5	3	4	4	5	5	5	5	6	6	7	7	8	8	10	11	14	17	19	24	30	44	58	72
	10	3	4	4	4	5	5	5	5	6	6	7	7	8	9	10	13	15	17	21	27	39	51	63
	15	3	4	4	4	5	5	5	5	6	6	7	7	7	9	10	12	14	16	19	25	35	46	57
	20	3	4	4	4	5	5	5	5	6	6	6	7	7	8	9	11	13	15	18	23	32	42	52
	25	3	4	4	4	5	5	5	5	6	6	7	7	8	9	10	12	14	17	21	30	39	48	
10	5	4	4	5	6	6	6	7	7	8	8	9	9	10	11	13	15	18	21	25	32	46	60	74
	10	4	4	5	6	6	6	7	7	7	8	8	9	9	10	12	14	17	19	23	29	41	53	65
	15	4	4	5	6	6	6	7	7	7	8	8	8	9	10	11	13	15	18	21	26	37	48	59
	20	4	4	5	6	6	6	6	7	7	7	8	8	9	10	11	13	15	17	20	24	34	44	54
	25	4	4	5	6	6	6	6	7	7	7	8	8	8	9	10	12	14	16	18	23	32	41	50
20	5	5	5	6	7	7	8	9	9	9	10	11	11	12	13	15	18	21	23	28	35	50	64	79
	10	5	6	6	7	7	8	9	9	9	10	10	11	11	13	14	16	19	21	25	32	44	57	69
	15	5	6	6	7	7	8	9	9	9	10	10	11	11	12	13	16	18	20	23	29	40	52	63
	20	5	6	6	7	7	8	9	9	9	10	10	10	11	12	13	15	17	19	22	27	38	48	58
	25	6	6	6	7	7	8	9	9	9	9	10	10	11	12	13	14	16	18	21	26	35	45	54
30	5	6	7	7	7	8	8	9	10	11	12	12	13	13	15	16	20	23	26	30	38	54	69	85
	10	6	7	7	8	8	8	9	10	11	11	12	12	13	14	16	18	21	24	28	34	48	61	75
	15	7	7	7	8	8	8	9	10	11	11	12	12	13	14	15	18	20	22	26	32	44	56	68
	20	7	7	8	8	8	9	9	10	11	11	12	12	13	14	15	17	19	21	25	30	41	52	63
	25	7	7	8	8	8	9	9	10	11	11	12	12	12	13	14	16	18	20	23	28	39	49	59
50	5	9	9	9	10	10	10	11	11	12	14	15	15	16	18	20	23	27	31	36	45	64	82	101
	10	9	9	10	10	10	11	11	11	12	14	14	15	16	17	19	22	25	28	33	41	57	73	89
	15	9	10	10	10	10	11	11	11	12	14	14	15	16	17	18	21	24	27	31	38	53	67	81
	20	9	10	10	10	10	11	11	11	12	14	14	15	15	17	18	21	23	26	30	36	49	62	75
	25	10	10	10	10	11	11	11	11	12	14	14	15	15	16	18	20	22	25	28	34	46	58	70
75	5	12	13	13	13	14	14	14	14	15	16	16	18	19	22	24	29	35	40	47	60	85	111	136
	10	13	13	13	14	14	14	14	15	15	16	16	18	19	21	24	28	33	37	44	55	77	99	122
	15	13	14	14	14	14	14	15	15	15	16	16	18	19	21	23	27	31	35	41	51	72	92	112
	20	14	14	14	14	14	15	15	15	15	16	16	18	19	21	23	27	30	34	40	49	67	86	105
	25	14	14	14	14	15	15	15	15	16	16	16	18	19	21	23	26	29	33	38	47	64	81	98

TABLE 5.6
Moisture content (%) of a matted grass layer with a T_f of 30°C

RH_f (%)	Wind Speed (km/h)	Last hour's moisture content (%)																						
		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50	60	75	100	150	200	250
5	5	3	4	4	4	4	4	5	5	5	6	6	7	7	8	9	11	13	15	19	24	35	45	56
	10	3	4	4	4	4	4	4	5	5	5	6	6	6	7	8	10	12	14	16	21	30	39	48
	15	3	4	4	4	4	4	4	4	5	5	5	6	6	7	8	9	11	12	15	19	26	34	42
	20	3	4	4	4	4	4	4	4	5	5	5	5	6	6	7	9	10	11	13	17	24	31	38
	25	3	4	4	4	4	4	4	4	5	5	5	5	6	6	7	8	9	11	13	16	22	28	35
10	5	3	4	5	5	5	6	6	6	6	7	7	8	8	9	10	13	15	17	20	26	36	47	58
	10	3	4	5	5	5	5	6	6	6	7	7	7	8	9	9	11	13	15	18	22	31	40	50
	15	3	4	5	5	5	5	6	6	6	6	7	7	7	8	9	11	12	14	16	20	28	36	44
	20	4	4	5	5	5	5	6	6	6	6	7	7	7	8	9	10	11	13	15	18	26	33	40
	25	4	4	5	5	5	5	5	6	6	6	6	7	7	8	8	9	11	12	14	17	24	30	37
20	5	4	5	5	6	7	7	8	8	8	9	9	10	10	11	12	15	17	19	23	28	40	51	63
	10	5	5	6	6	7	7	8	8	8	9	9	9	10	11	12	13	15	17	20	25	35	44	54
	15	5	5	6	6	7	7	8	8	8	8	9	9	9	10	11	13	14	16	19	23	31	40	48
	20	5	5	6	6	7	7	7	8	8	8	9	9	9	10	11	12	14	15	17	21	29	36	44
	25	5	5	6	6	7	7	7	8	8	8	8	9	9	10	10	12	13	14	16	20	27	33	40
30	5	6	6	6	7	7	8	9	9	10	10	11	11	12	13	14	17	19	22	25	31	44	56	68
	10	6	6	7	7	7	8	9	9	10	10	11	11	11	12	13	15	18	20	23	28	38	48	59
	15	6	6	7	7	7	8	9	9	10	10	10	11	11	12	13	15	16	18	21	26	35	44	53
	20	6	7	7	7	7	8	9	9	10	10	10	11	11	12	12	14	16	17	20	24	32	40	48
	25	6	7	7	7	7	8	9	9	10	10	10	10	11	11	12	14	15	17	19	22	30	37	44
50	5	8	8	9	9	9	10	10	10	12	13	13	14	15	16	18	21	24	27	31	39	54	69	84
	10	9	9	9	9	10	10	10	10	12	13	13	14	14	16	17	19	22	24	28	35	47	60	73
	15	9	9	9	9	10	10	10	10	12	13	13	14	14	15	16	19	21	23	26	32	43	54	65
	20	9	9	9	10	10	10	10	10	12	13	13	14	14	15	16	18	20	22	25	30	40	50	60
	25	9	9	9	10	10	10	10	10	12	13	13	13	14	15	16	17	19	21	24	28	37	46	55
75	5	12	12	13	13	13	13	14	14	14	15	16	18	18	21	23	27	32	36	43	54	76	98	120
	10	13	13	13	13	13	14	14	14	14	15	16	18	18	20	22	26	30	33	39	49	68	87	106
	15	13	13	13	13	14	14	14	14	15	15	16	17	18	20	22	25	28	32	37	45	62	79	96
	20	13	13	13	14	14	14	14	14	15	15	16	17	18	20	21	24	27	30	35	42	58	73	88
	25	13	13	14	14	14	14	14	14	15	15	16	17	18	19	21	24	26	29	33	40	54	68	82

TABLE 5.7

Moisture content (%) of a matted grass layer with a T_r of 40°C

RH_f (%)	Wind Speed (km/h)	Last hour's moisture content (%)																						
		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50	60	75	100	150	200	250
5	5	2	2	3	3	3	3	3	3	3	4	4	4	4	5	5	6	7	8	10	13	18	24	29
	10	2	2	2	3	3	3	3	3	3	3	3	4	4	4	5	5	6	7	8	10	15	19	23
	15	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	5	6	6	7	9	13	16	19
	20	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	5	6	7	8	11	14	17
	25	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	5	5	6	7	10	12	15
10	5	3	3	3	3	4	4	4	4	4	4	5	5	5	5	6	7	8	9	11	14	19	25	30
	10	3	3	3	3	3	3	4	4	4	4	4	4	5	5	5	6	7	8	9	11	16	20	24
	15	3	3	3	3	3	3	3	4	4	4	4	4	4	5	5	6	6	7	8	10	14	17	21
	20	3	3	3	3	3	3	3	3	4	4	4	4	4	4	5	5	6	7	7	9	12	15	18
	25	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	5	6	6	7	8	11	13	16
20	5	3	4	5	5	5	5	5	5	6	6	6	6	7	7	8	9	10	11	13	16	22	28	34
	10	3	4	5	5	5	5	5	5	5	6	6	6	6	7	7	8	9	10	11	14	18	23	27
	15	3	4	5	5	5	5	5	5	5	5	6	6	6	6	7	7	8	9	10	12	16	20	24
	20	3	4	5	5	5	5	5	5	5	5	6	6	6	6	6	7	8	8	9	11	14	18	21
	25	3	4	5	5	5	5	5	5	5	5	5	6	6	6	6	7	7	8	9	10	13	16	19
30	5	4	5	5	6	7	7	7	7	7	7	8	8	8	9	10	11	12	14	16	19	25	32	39
	10	4	5	5	6	7	7	7	7	7	7	7	8	8	8	9	10	11	12	14	16	21	26	32
	15	5	5	5	6	7	7	7	7	7	7	7	7	8	8	8	9	10	11	12	14	19	23	27
	20	5	5	5	6	7	7	7	7	7	7	7	7	7	8	8	9	10	10	11	13	17	20	24
	25	5	5	5	6	7	7	7	7	7	7	7	7	7	8	8	9	9	10	11	12	16	19	22
50	5	7	7	7	7	8	8	9	10	10	10	11	11	12	12	13	15	17	19	21	26	35	43	52
	10	7	7	7	7	8	8	9	10	10	10	11	11	11	12	13	14	15	17	19	22	29	36	43
	15	7	7	7	7	8	8	9	10	10	10	10	11	11	11	12	13	14	15	17	20	26	31	37
	20	7	7	7	8	8	8	9	10	10	10	10	11	11	11	12	13	14	15	16	19	23	28	33
	25	7	7	7	8	8	8	9	10	10	10	10	10	11	11	11	12	13	14	15	17	22	26	30
75	5	11	11	11	12	12	12	12	12	12	14	15	16	16	18	19	22	26	29	33	41	56	72	87
	10	11	12	12	12	12	12	12	12	12	14	15	15	16	17	18	21	23	26	29	36	48	60	73
	15	12	12	12	12	12	12	12	12	12	14	15	15	16	17	18	20	22	24	27	32	43	53	64
	20	12	12	12	12	12	12	12	12	12	14	15	15	16	16	17	19	21	23	25	30	39	48	57
	25	12	12	12	12	12	12	12	12	12	14	15	15	15	16	17	19	20	22	24	28	36	44	52

TABLE 5.8
Moisture content (%) of a matted grass layer with a T_f of 50°C

RH_f (%)	Wind Speed (km/h)	Last hour's moisture content (%)																						
		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50	60	75	100	150	200	250
5	5	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	4	5	7	9	11
	10	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	4	5	7	8
	15	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3	4	5	6
	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	4	4	5
	25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	4	5
10	5	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	4	4	5	7	10	12
	10	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	4	6	7	8
	15	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	5	6	7
	20	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	4	5	6
	25	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	4	5
20	5	2	2	2	3	3	3	3	3	3	3	3	3	3	3	4	4	5	5	6	7	9	12	14
	10	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	5	6	7	9	10
	15	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	5	6	7	8
	20	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	5	6	7
	25	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	5	5	6
30	5	3	4	4	4	4	4	4	4	4	4	5	5	5	5	5	6	6	7	8	9	12	14	17
	10	3	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	6	6	7	7	9	11	13
	15	3	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	6	7	8	9	11	
	20	3	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	6	7	8	9	
	25	3	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	6	7	8	8	
50	5	5	5	5	6	7	7	7	7	7	8	8	8	8	8	9	10	11	11	13	15	19	23	27
	10	5	5	5	6	7	7	7	7	7	7	8	8	8	8	8	9	9	10	11	12	15	18	21
	15	5	5	5	6	7	7	7	7	7	7	7	7	8	8	8	8	9	9	10	11	13	16	18
	20	5	5	5	6	7	7	7	7	7	7	7	7	7	8	8	8	9	9	9	10	12	14	16
	25	5	5	5	6	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	10	11	13	14
75	5	9	9	9	9	10	10	10	10	12	12	13	13	13	14	15	17	19	21	23	28	37	47	56
	10	9	9	9	10	10	10	10	10	12	12	12	13	13	14	14	16	17	18	20	24	30	37	44
	15	9	10	10	10	10	10	10	10	12	12	12	12	13	13	14	15	16	17	18	21	26	31	37
	20	10	10	10	10	10	10	10	10	12	12	12	12	13	13	13	14	15	16	17	19	24	28	32
	25	10	10	10	10	10	10	10	10	12	12	12	12	12	13	13	14	15	15	16	18	22	25	29

TABLE 6.1

Equilibrium rate of spread (m/min)
Matted grass (100% curing, no slope)

	Wind Speed (km/h)									
MC (%)	0*	5	10	15	20	25	30	35	40	50
24	0	0	0	0	0	0	0	0	0	0
23	0	0	1	2	3	4	4	5	6	7
22	0	0	3	5	6	8	9	10	12	14
21	0	0	4	7	9	11	14	16	18	21
20	0	0	6	9	12	15	18	21	23	29
19	< 0.1	0.6	7	12	15	19	23	26	29	36
18	< 0.1	1	9	14	19	23	27	31	35	43
17	0.1	2	10	16	22	27	32	36	41	50
16	0.1	3	12	19	25	31	36	42	47	57
15	0.2	3	13	21	28	34	41	47	53	64
14	0.2	4	15	23	31	38	45	52	59	72
13	0.2	4	16	25	34	42	50	57	65	79
12	0.2	5	18	28	37	46	54	63	71	86
11	0.3	6	20	31	41	51	61	70	79	96
10	0.3	6	22	34	46	57	67	78	88	107
9	0.3	7	24	38	51	63	75	87	98	119
8	0.4	8	27	43	57	71	84	96	109	133
7	0.4	9	30	48	64	79	93	107	121	148
6	0.5	10	34	53	71	88	104	120	135	164
5	1	11	38	59	79	98	116	133	150	183
4	1	12	42	66	88	109	129	148	167	204
3	1	13	47	73	98	121	144	165	187	227

For **back fire rate of spread** use 0 wind speed and appropriate moisture content

* Fires burning under light winds (< 5km/h) tend to spread erratically as they respond to gusts and lulls caused by localized thermal activity.

TABLE 6.2

Equilibrium rate of spread (m/min)
Standing grass (100% curing, no slope)

	Wind Speed (km/h)									
MC (%)	0*	5	10	15	20	25	30	35	40	50
24	0	0	0	0	0	0	0	0	0	0
23	0	0	2	3	4	4	5	6	7	8
22	0	0	4	5	7	9	11	12	14	17
21	0	0	5	8	11	14	16	18	21	25
20	0	0	7	11	15	18	21	25	28	34
19	< 0.1	0.8	9	14	18	23	27	31	35	42
18	< 0.1	2	11	17	22	27	32	37	42	51
17	0.1	2	12	19	26	32	37	43	48	59
16	0.1	3	14	22	29	36	43	49	55	67
15	0.2	4	16	25	33	41	48	55	62	76
14	0.2	5	18	28	37	45	53	61	69	84
13	0.2	6	19	30	40	50	59	68	76	93
12	0.2	6	21	33	44	54	64	74	83	101
11	0.3	7	24	37	49	60	72	82	93	113
10	0.3	8	26	41	55	67	80	92	103	126
9	0.3	9	29	46	61	75	89	102	115	140
8	0.4	10	33	51	68	84	99	114	128	156
7	0.4	11	36	57	75	93	110	127	143	174
6	0.5	12	41	63	84	104	123	141	159	194
5	1	14	45	70	94	116	137	157	177	216
4	1	15	50	78	104	129	152	175	197	240
3	1	17	56	87	116	143	170	195	220	268

For **back fire rate of spread** use 0 wind speed and appropriate moisture content

* Fires burning under light winds (< 5km/h) tend to spread erratically as they respond to gusts and lulls caused by localized thermal activity.

TABLE 7

Rate of spread (m/min) for different degrees of curing

	Curing (%)							
$ROS_{100\% Cured}$*	25	50	60	70	80	90	95	100
0.1	0	<0.1	<0.1	<0.1	0.1	0.1	0.1	0.1
0.3	<0.1	<0.1	<0.1	0.1	0.2	0.2	0.3	0.3
0.5	<0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.5
1	<0.1	0.1	0.2	0.4	1	1	1	1
2	<0.1	0.2	0.4	1	1	2	2	2
3	0.1	0.3	1	1	2	2	3	3
4	0.1	0.4	1	2	2	3	4	4
5	0.1	0.5	1	2	3	4	5	5
6	0.1	0.6	1	2	4	5	5	6
7	0.1	1	1	3	4	6	6	7
8	0.1	1	2	3	5	6	7	8
9	0.2	1	2	4	5	7	8	9
10	0.2	1	2	4	6	8	9	10
15	0.3	2	3	6	9	12	14	15
20	0.4	2	4	8	12	16	18	20
25	0.4	3	5	10	15	20	23	25
30	0.5	3	6	12	18	24	27	30
35	0.6	4	7	14	21	28	32	35
40	1	4	8	16	24	32	36	40
45	1	5	9	18	27	36	41	45
50	1	5	10	20	30	40	45	50
60	1	6	12	24	36	48	54	60
70	1	7	14	28	42	56	63	70
80	1	8	16	32	48	64	72	80
90	2	9	18	36	54	72	81	90
100	2	10	20	40	60	80	90	100
125	2	13	25	50	75	100	113	125
150	3	15	30	60	90	120	135	150
175	3	18	35	70	105	140	158	175
200	4	20	40	80	120	160	180	200

* This is the rate of spread value for fully cured grass (Table 6.1 or 6.2)

TABLE 8

Slope equivalent rate of spread (m/min)

	Slope (%)						
$ROS_{no\ slope}$*	-40	-20	-10	0	10	20	40
0.1	0	0	0.1	0.1	0.1	0.2	0.5
0.3	0	0.1	0.2	0.3	0.4	0.7	1
0.5	0.1	0.2	0.3	0.5	0.7	1	2
1	0.2	0.5	0.7	1	1	2	5
2	0.4	0.9	1	2	3	4	9
3	0.7	1	2	3	4	7	14
4	0.9	2	3	4	6	9	18
5	1	2	3	5	7	11	23
6	1	3	4	6	9	13	27
7	2	3	5	7	10	15	32
8	2	4	5	8	12	17	36
9	2	4	6	9	13	20	41
10	2	5	7	10	15	22	45
15	3	7	10	15	22	33	68
20	4	9	13	20	30	44	90
25	6	11	17	25	37	55	113
30	7	14	20	30	44	65	135
35	8	16	24	35	52	76	158
40	9	18	27	40	59	87	180
45	10	21	30	45	67	98	203
50	11	23	34	50	74	109	225
60	13	27	40	60	89	131	270
70	16	32	47	70	104	153	315
80	18	37	54	80	119	175	360
90	20	41	61	90	133	196	405
100	22	46	67	100	148	218	450
125	28	57	84	125	185	273	563
150	33	69	101	150	222	327	675
175	39	80	118	175	260	382	788
200	44	92	135	200	297	436	900

Based on McArthur (1967) and Cheney and Sullivan (2008)

* This value comes from Table 6.1 or 6.2, or Table 7 if curing is less than 100%

TABLE 9

Head fire intensity (kW/m) for different fuel loadings

Intensity Class

1	<10 kW/m
2	10-500
3	500-2000
4	2000-4000
5	4000-10000
6	>10000

ROS	Fuel Load (t/ha)				
(m/min)	1	3	6	10	15
0.1	3	9	18	30	45
0.3	9	27	54	90	135
0.5	15	45	90	150	225
1	30	90	180	300	450
2	60	180	360	600	900
3	90	270	540	900	1350
4	120	360	720	1200	1800
5	150	450	900	1500	2250
6	180	540	1080	1800	2700
7	210	630	1260	2100	3150
8	240	720	1440	2400	3600
9	270	810	1620	2700	4050
10	300	900	1800	3000	4500
15	450	1350	2700	4500	6750
20	600	1800	3600	6000	9000
25	750	2250	4500	7500	11250
30	900	2700	5400	9000	13500
35	1050	3150	6300	10500	15750
40	1200	3600	7200	12000	18000
45	1350	4050	8100	13500	20250
50	1500	4500	9000	15000	22500
60	1800	5400	10800	18000	27000
70	2100	6300	12600	21000	31500
80	2400	7200	14400	24000	36000
90	2700	8100	16200	27000	40500
100	3000	9000	18000	30000	45000
125	3750	11250	22500	37500	56250
150	4500	13500	27000	45000	67500
175	5250	15750	31500	52500	78750
200	6000	18000	36000	60000	90000

TABLE 10

Spread distances (m) for line ignition (equilibrium ROS) and point ignition (accelerating ROS)

Equilibrium ROS (m/min)	Elapsed Time											
	15 min		30 min		45 min		1 h		2 h		3 h	
0.2	3	2	6	4	9	7	12	10	24	22	36	34
0.4	6	3	12	9	18	15	24	21	48	45	72	69
0.6	9	5	18	13	27	22	36	31	72	87	108	103
0.8	12	6	24	17	36	29	48	41	96	89	144	137
1	15	8	30	22	45	36	60	51	120	111	180	171
2	30	16	60	43	90	73	120	103	240	223	360	343
3	45	24	90	65	135	109	180	154	360	334	540	514
4	60	31	120	86	180	145	240	205	480	445	720	685
5	75	39	150	108	225	182	300	257	600	557	900	857
6	90	47	180	129	270	218	360	308	720	668	1080	1028
7	105	55	210	151	315	254	420	359	840	779	1260	1199
8	120	63	240	173	360	291	480	411	960	890	1440	1370
9	135	71	270	194	405	327	540	462	1080	1002	1620	1542
10	150	79	300	216	450	364	600	513	1200	1113	1800	1713
12	180	94	360	259	540	436	720	616	1440	1336	2160	2056
14	210	110	420	302	630	509	840	718	1680	1558	2520	2398
16	240	126	480	345	720	582	960	821	1920	1781	2880	2741
18	270	141	540	388	810	654	1080	924	2160	2003	3240	3083
20	300	157	600	432	900	727	1200	1026	2400	2226	3600	3426
25	375	196	750	540	1125	909	1500	1283	3000	2783	4500	4283
30	450	236	900	647	1350	1091	1800	1539	3600	3339	5400	5139
35	525	275	1050	755	1575	1272	2100	1796	4200	3896	6300	5996
40	600	314	1200	863	1800	1454	2400	2053	4800	4452	7200	6852
45	675	353	1350	971	2025	1636	2700	2309	5400	5009	8100	7709
50	750	393	1500	1079	2250	1818	3000	2566	6000	5565	9000	8565
55	825	432	1650	1187	2475	1999	3300	2822	6600	6122	9900	9422
60	900	471	1800	1295	2700	2181	3600	3079	7200	6678	10800	10278
65	975	510	1950	1403	2925	2363	3900	3335	4800	7235	11700	11135
70	1050	550	2100	1511	3150	2545	4200	3592	8400	7791	12600	11991
75	1125	589	2250	1619	3375	2727	4500	3848	9000	8348	13500	12848
80	1200	628	2400	1726	3600	2908	4800	4105	9600	8904	14400	13704
85	1275	668	2550	1834	3825	3090	5100	4362	10200	9461	15300	14561
90	1350	707	2700	1942	4050	3272	5400	4618	10800	10017	16200	15417
95	1425	746	2850	1942	4275	3454	5700	4875	11400	10574	17100	16417
100	1500	785	3000	2168	4500	3635	6000	5131	12000	11130	18000	17130

Red figures are distance for equilibrium rate of spread. Black figures are for accelerating rate of spread.

TABLE 11

Elliptical Fire area (ha) and perimeter (m)

Spread Distance (m)	Effective Wind Speed (km/h)									
	0	5	10	15	20	25	30	35	40	50
25	< 0.1 79	< 0.1 58	< 0.1 55	< 0.1 54	< 0.1 53	< 0.1 52	< 0.1 52	< 0.1 52	< 0.1 52	< 0.1 51
50	0.2 157	0.1 117	0.1 110	0.1 107	< 0.1 106	< 0.1 105	< 0.1 104	< 0.1 104	< 0.1 103	< 0.1 103
100	0.8 314	0.3 234	0.2 220	0.2 215	0.2 212	0.2 210	0.1 208	0.1 207	0.1 206	0.1 205
150	1.8 471	0.8 350	0.6 330	0.5 322	0.4 318	0.4 315	0.3 312	0.3 311	0.3 309	0.3 308
200	3 628	1 467	1 440	0.8 430	0.7 423	0.6 419	0.6 417	0.5 414	0.5 413	0.5 410
250	5 785	2 584	2 550	1 537	1 529	1 524	0.9 521	0.9 518	0.8 516	0.7 513
300	7 942	3 701	2 661	2 644	2 635	1 629	1 625	1 622	1 619	1 615
400	13 1256	5 934	4 881	3 859	3 847	3 839	2 833	2 829	2 825	2 820
500	20 1570	8 1168	6 1101	5 1074	4 1059	4 1048	4 1041	3 1036	3 1032	3 1025
600	28 1884	12 1401	9 1321	7 1289	6 1270	6 1258	5 1250	5 1243	5 1238	4 1230
800	50 2512	22 1868	16 1761	13 1718	11 1694	10 1678	9 1666	9 1657	8 1651	7 1640
1000	79 3140	34 2335	25 2202	20 2148	18 2117	16 2097	15 2083	14 2072	13 2063	12 2051
1200	113 3768	49 2802	35 2642	29 2577	26 2540	23 2516	21 2499	20 2486	19 2476	17 2461
1500	177 4710	76 3503	55 3303	46 3221	40 3176	36 3145	33 3124	31 3108	29 3095	26 3076
2000	314 6280	135 4670	98 4404	81 4295	71 4234	64 4194	59 4165	55 4144	52 4127	46 4101
3000	707 9420	304 7006	221 6605	183 6443	160 6351	144 6291	133 6248	123 6215	116 6190	105 6152
4000	1256 12560	541 9341	392 8807	325 8590	284 8468	256 8388	236 8331	219 8287	206 8253	186 8202
5000	1963 15700	845 11676	613 11009	508 10738	444 10585	401 10485	368 10413	343 10359	322 10316	290 10253
LB	1.0	2.3	3.2	3.5	4.4	4.9	5.3	5.7	6.1	6.8

Red figures are area (ha). Black Figures are perimeter length (m).

48

TABLE 12

Perimeter growth rate (m/min)

	Wind Speed (km/h)										
Equilibrium ROS*	0	5	10	15	20	25	30	35	40	45	50
0.5	2	1	1	1	1	1	1	1	1	1	1
1	3	2	2	2	2	2	2	2	2	2	2
2	6	5	4	4	4	4	4	4	4	4	4
3	9	7	7	6	6	6	6	6	6	6	6
4	13	9	9	9	8	8	8	8	8	8	8
5	16	12	11	11	11	10	10	10	10	10	10
6	19	14	13	13	13	13	12	12	12	12	12
7	22	16	15	15	15	15	15	15	14	14	14
8	25	19	18	17	17	17	17	17	17	16	16
9	28	21	20	19	19	19	19	19	19	19	18
10	31	23	22	21	21	21	21	21	21	21	21
12	38	28	26	26	25	25	25	25	25	25	25
14	44	33	31	30	30	29	29	29	29	29	29
16	50	37	35	34	34	34	33	33	33	33	33
18	57	42	40	39	38	38	37	37	37	37	37
20	63	47	44	43	42	42	42	41	41	41	41
25	79	58	55	54	53	52	52	52	52	51	51
30	94	70	66	64	64	63	62	62	62	62	62
35	110	82	77	75	74	73	73	73	72	72	72
40	126	93	88	86	85	84	83	83	83	82	82
45	141	105	99	97	95	94	94	93	93	93	92
50	157	117	110	107	106	105	104	104	103	103	103
60	188	140	132	129	127	126	125	124	124	123	123
70	220	163	154	150	148	147	146	145	144	144	144
80	251	187	176	172	169	168	167	166	165	165	164
90	283	210	198	193	191	189	187	186	186	185	185
100	314	234	220	215	212	210	208	207	206	206	205
125	393	292	275	268	265	262	260	259	258	257	256
150	471	350	330	322	318	315	312	311	309	308	308
175	550	409	385	376	370	367	364	363	361	360	359
200	628	467	440	430	423	419	417	414	413	411	410

* sum of the equilibrium head fire rate of spread and the back fire rate of spread

APPENDIX 1
Abbreviations

BKN	Broken cloud cover
CLR	Clear (no cloud cover)
SOL_{ef}	Effective solar radiation
MC	Fuel moisture content (%)
MC_r	Fuel moisture content after rain (%)
OVC	Overcast (complete cloud cover)
RH_f	Relative humidity of the fuel (%)
ROS	Rate of spread (m/min)
$ROS_{100\% \text{ cured}}$	Rate of spread of 100% cured fuels (m/min)
$ROS_{\text{ no slope}}$	Rate of spread on ground with no slope (m/min)
SCT	Scattered cloud cover
T_f	Temperature of the fuel (°C)

APPENDIX 2
Glossary

Degree of curing: The proportion of cured and/or dead plant material in a grassland fuel complex.

Effective solar radiation (SOL_{ef}): The proportion of peak expected cloud-free solar radiation received by fuels based on cloud cover and time of day.

Elliptical fire growth model: Theory: a free-burning point ignition grows like an ellipse when fuels are uniform and continuous, topography is homogeneous, wind speed is constant and unidirectional, and the fire is unaffected by suppression activities. The length of the ellipse is the sum of the head fire spread distance and the back fire spread distance. Fire shape or length-to-breadth ratio (LB) is determined by the wind speed. Fire area and perimeter length are calculated from the total spread distance and the LB ratio.

Fibre saturation: The moisture content of a fuel when all free water is gone but cell walls remain saturated with bound water. In this guide, grasses are assumed to have a fibre saturation moisture content of 35%.

Fire intensity: The rate of heat energy release per unit time per unit length of fire front. Frontal fire intensity is a major determinant of certain fire effects and difficulty of control. Numerically, it is equal to the product of the net heat of combustion, the quantity of fuel consumed in the flaming front and the linear rate of spread.

Fire perimeter: The entire outer edge or boundary of a fire. See elliptical fire growth model.

Fuel temperature: The temperature of a fully matted grass fuel microclimate as a function of the air temperature around the fuel, the amount of solar radiation received by the fuel and the wind speed.

Full saturation: The moisture content at which cells can absorb no more water. In this guide, grasses are assumed to have a full saturation moisture content of 250%

Length to breadth ratio (LB): See elliptical fire growth model.

Litter layer: In the absence of fire and/or grazing, growth from previous year's accumulate forming a layer of decomposing organic material.

Rate of spread (ROS): The speed at which a fire extends its horizontal dimensions, expressed in terms of distance per unit time. Generally thought of in terms of a fire's forward movement, or head fire rate of spread, but also applicable to back fire and flank fire rate of spread.

Relative humidity of the fuel: The relative humidity of the fuel microclimate as a function of the relative humidity of the surrounding air, the temperature of the fuel microclimate (see fuel temperature above) and the temperature of the surrounding air.

Robel pole: A non-destructive method of estimating fuel load in grasslands. The Robel pole is a 2m tall pole painted with bands of alternating colour. An observer stands a set distance from the pole and from a set height observes the lowest band of colour visible through the vegetation. This measurement (which is a function of the density of the vegetation between the observer and the pole) is used to estimate fuel load in that area based on previously developed models.

Slope equivalent rate of spread: An approach originally used in the FBP System where-by the effect of slope on fire spread with zero wind is given a value in units of wind speed.

APPENDIX 3

Selected unit conversion factors

If the SI units are	Multiply by	To obtain	Inverse Factor
hectares (ha)	2.4711	acres (ac)	0.40469
kilometers per hour (km/h)	0.62137	miles per hour (mi/h)	1.6093
kilowatts per meter (kW/m)	0.28909	Btu per second per foot	3.4592
meters (m)	0.049709	chains (ch)	20.117
meters (m)	3.2808	feet (ft)	0.3048
meters per minute (m/min)	3.2808	feet per minute (ft/min)	0.3048
meters per minute (m/min)	2.9826	chains per hour (ch/h)	0.33528
meters per minute (m/min)	60.0	meters per hour (m/h)	0.016667
meters per minute (m/min)	0.06	kilometers per hour (km/h)	16.667
tonnes per hectare (t/ha)	0.44609	tons per acre (T/ac)	2.2417
tonnes per hectare (t/ha)	0.1	kilogram per meter squared	10

Note: all factors are given to five significant digits. If fewer, the value is exact. To convert Imperial or old metric unit values to the International System of Units (SI) multiply by the inverse factor given in the right-hand column. Btu= British thermal unit.

APPENDIX 4

Wind Conversions

Forestry 10 m winds (km/h)	Height of wind measurement (m)										Airport 10 m winds (km/h)
	1	2	3	4	5	6	7	8	9	10	
1	1	1	1	1	1	1	1	1	1	1	2
2	1	2	2	2	2	2	2	2	2	2	3
3	2	2	2	3	3	3	3	3	3	3	5
4	3	3	3	3	4	4	4	4	4	4	7
5	3	4	4	4	5	5	5	5	5	5	8
6	4	5	5	5	5	5	6	6	6	6	10
7	5	5	6	6	6	6	7	7	7	7	12
8	5	6	7	7	7	7	8	8	8	8	13
9	6	7	7	8	8	8	9	9	9	9	15
10	7	8	8	9	9	9	10	10	10	10	17
12	8	9	10	10	11	11	12	12	12	12	20
14	9	11	11	12	13	13	14	14	14	14	23
16	11	12	13	14	15	15	16	16	16	16	27
18	12	14	15	16	16	16	17	17	18	18	30
20	14	15	16	17	18	18	19	19	20	20	33
25	17	19	20	22	23	23	24	24	25	25	42
30	20	23	25	26	27	27	29	29	30	30	50
35	24	27	29	30	32	32	34	34	35	35	58
40	27	31	33	34	36	36	39	39	40	40	67
45	30	34	37	39	41	41	44	44	45	45	75
50	34	38	41	43	45	45	49	49	50	50	83

APPENDIX 5

Beaufort scale[1] for estimating 10-m open wind speeds

Force or number	Wind speed (km/h)		Description	Observed wind effects
	Range	Mean		
0	<1	0	Calm	Smoke rises vertically
1	1-5	3	Light air	Direction of drift shown by smoke drift but not by wind rise
2	6-11	9	Light breeze	Wind felt on face; leaves rustle; vanes moved by wind
3	12-19	16	Gentle breeze	Leaves and twigs in constant motion; wind extends light flag
4	20-28	24	Moderate breez	Raises dust and loose paper; small branches are moved
5	29-38	34	Fresh breeze	Small trees in leaf begin to sway; crested wavelets on inland waters
6	39-49	44	Strong breeze	Large branches in motion; whistling in telephone wires; umbrellas used with difficulty
7	50-61	55	Moderate gale	Whole trees in motion; resistance felt when walking against wind
8	62-74	68	Fresh gale	Breaks twigs of trees; generally impedes progress
9	75-88	82	Strong gale	Slight structural damage occurs
10	89-102	96	Whole gale	Seldom experienced inland; trees uprooted considerable structural damage
11	109-117	110	Storm	Very rarely experienced; wide-spread damage
12 or above	118+	>125	Hurricane	

[1] Adapted from List, R.J. 1951. Smithsonian meteorological tables. 6th rev. Ed. Smithsonian Inst. Press, Washington D.C.

Appendix 6

Robel pole construction

These instructions are borrowed from Toledo, Abbott and Herrick (2008).

Materials

1 piece of schedule 40 polyvinyl chloride (PVC) pipe, 2 m long, 2.54 cm diameter
1 threaded male PVC connector, 2.54 cm diameter
2 threaded female PVC connectors, 2.54 cm diameter
1 threaded male plug, 2.54 cm diameter
1 flat headed spike, 20 cm long, 1.3 cm diameter
1 PVC cap, 2.54 cm diameter
PVC cleaner, primer and glue
Epoxy
Enamel or PVC paint in black, white and red

Instructions

1. Cut the PVC pipe into two 1-m-long pieces.
2. Use the PVC cleaner and primer on the inside walls of the unthreaded male and female connectors.
3. Use the PVC cleaner and primer to prepare one end of one piece of PVC pipe and both ends of the other piece of the PVC pipe. These pieces will become the top and bottom halves of the Robel pole respectively.
4. Glue a female connector to a prepared end of each piece of pipe.
5. Glue the male connector to the remaining prepared end of the bottom pipe.
6. Drill a 1.3 cm hole in the center of the flat end of the threaded male plug. Insert the spike through the hole until the spike head is firmly seated against the inside of the plug. Inject epoxy into the plug, covering the spike head and filling the plug. Ensure that the spike is straight, and allow the epoxy to harden.
7. Assemble the Robel pole by screwing the top and bottom halves together, and screw the plug with the spike into the female end of the bottom pipe. Tighten connections until they are snug, but do not over tighten. Attach the remaining PVC cap (unglued) to the open end of the top of the pole.
8. Measure the cover pole and mark the top end at the 2-m mark.
9. Remove the cap and trim the open end of the top pipe to produce a 2-m-long (cap to plug) pole.
10. Reassemble the pole. Paint alternating 10-cm white and black segments, with every fifth segment painted red as depicted in the diagram to the left.

Appendix 6

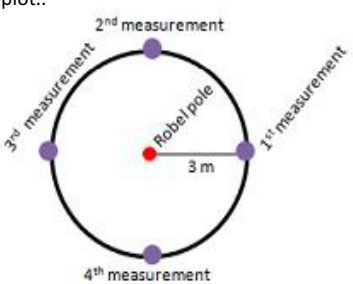
How to use the Robel Pole

Materials

Robel pole (instructions on previous page)
Wooden meter stick (with a 1 cm diameter hole drilled in top 2 cm of stick)
3 m long piece of rope
10 m long retractable tape measure

Instructions

1. Assemble the Robel pole.
2. Chose a random starting point and drive the stake at the bottom of the pole into the ground.
3. Have someone hold one end of the 3 m rope against the pole, and with the meter stick, walk straight away from the pole holding the other end of the rope until the rope is taut. With the hole facing up, hold the meter stick vertical against the ground where the rope ends.
4. Looking through the hole in the meter stick, record the lowest painted band that is visible on the pole through the grass using a worksheet similar to that in Appendix 10.
5. Walk in a clockwise or counter clockwise direction 90° from your current spot, still holding the rope taut. Put the meter stick down and looking through the hole, record the lowest band visible through the grass from this new location.
6. Repeat step 5 twice continuing around the pole in 90° increments. You will then have four observations of highest visible band height for this one point in your plot..



7. Standing at the pole, determine a random transect direction for the remaining Robel pole measurements. Have someone hold one end of the measuring tape at the original site of the pole and lift the pole from the ground. With the pole, walk 10 m along the transect placing the pole in the ground at the 10 m mark.
8. Repeat Steps 3 to 6 at this new robel pole site, then move another 10 m along the original transect and repeat until you have reached the desired number of sample points.
9. After all the measurements have been taken, determine the average band visible from all measurements. Refer to Figure 1 in this guide to determine the average fuel load using this value.

APPENDIX 7.1

Time (h) to burnable (MC=20%) from saturation (MC=250%)

Full Effective Solar Radiation

		Relative Humidity (%)							
Temp. (°C)	Wind Speed (km/h)	10	20	30	40	50	60	80	100
5	5	2	2	2	2	2	2	2	3
	10	2	2	2	3	3	3	3	3
	15	3	3	3	3	3	3	4	4
	20	3	3	3	3	4	4	5	6
	25	3	3	3	4	4	4	6	-
10	5	2	2	2	2	2	2	2	2
	10	2	2	2	2	2	2	2	3
	15	2	2	2	2	3	3	3	3
	20	2	2	3	3	3	3	4	5
	25	2	3	3	3	3	3	4	7
15	5	1	1	1	1	2	2	2	2
	10	2	2	2	2	2	2	2	2
	15	2	2	2	2	2	2	2	3
	20	2	2	2	2	2	2	3	4
	25	2	2	2	2	3	3	3	5
20	5	1	1	1	1	1	1	1	1
	10	1	1	1	1	1	1	2	2
	15	1	1	2	2	2	2	2	2
	20	1	2	2	2	2	2	2	3
	25	2	2	2	2	2	2	3	4
25	5	1	1	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1
	15	1	1	1	1	1	1	2	2
	20	1	1	1	1	2	2	2	2
	25	1	1	1	2	2	2	2	3

See Table 1 for calculation of effective solar radiation

APPENDIX 7.2

Time (h) to burnable (MC=20%) from saturation (MC=250%)

2/3 Effective Solar Radiation

		Relative Humidity (%)							
Temp. (°C)	Wind Speed (km/h)	10	20	30	40	50	60	80	100
5	5	3	3	3	3	3	3	4	4
	10	3	3	3	3	4	4	4	5
	15	3	3	3	4	4	4	5	7
	20	3	3	4	4	4	5	7	-
	25	3	3	4	4	5	5	10	-
10	5	2	2	2	3	3	3	3	3
	10	2	2	3	3	3	3	4	4
	15	2	3	3	3	3	3	4	5
	20	3	3	3	3	3	4	5	11
	25	3	3	3	3	4	4	6	-
15	5	2	2	2	2	2	2	2	3
	10	2	2	2	2	2	2	3	3
	15	2	2	2	2	3	3	3	4
	20	2	2	2	3	3	3	4	6
	25	2	2	2	3	3	3	4	-
20	5	2	2	2	2	2	2	2	2
	10	2	2	2	2	2	2	2	3
	15	2	2	2	2	2	2	3	3
	20	2	2	2	2	2	2	3	4
	25	2	2	2	2	2	3	3	8
25	5	1	1	1	1	1	1	2	2
	10	1	1	1	1	2	2	2	2
	15	1	1	1	2	2	2	2	3
	20	1	1	2	2	2	2	2	3
	25	1	1	2	2	2	2	3	5

See Table 1 for calculation of effective solar radiation

APPENDIX 7.3

Time (h) to burnable (MC=20%) from saturation (MC=250%)

1/3 Effective Solar Radiation

		Relative Humidity (%)							
Temp. (°C)	Wind Speed (km/h)	10	20	30	40	50	60	80	100
5	5	4	4	4	5	5	6	7	11
	10	4	4	4	5	5	6	8	-
	15	4	4	4	5	5	6	-	-
	20	3	4	4	5	6	7	-	-
	25	3	4	4	5	6	7	-	-
10	5	3	3	3	4	4	4	5	8
	10	3	3	3	4	4	5	6	-
	15	3	3	3	4	4	5	7	-
	20	3	3	3	4	4	5	11	-
	25	3	3	3	4	4	5	-	-
15	5	2	3	3	3	3	4	4	6
	10	2	3	3	3	3	4	5	8
	15	2	3	3	3	3	4	5	-
	20	2	3	3	3	3	4	6	-
	25	2	3	3	3	3	4	7	-
20	5	2	2	2	2	3	3	3	5
	10	2	2	2	2	3	3	4	6
	15	2	2	2	2	3	3	4	-
	20	2	2	2	2	3	3	4	-
	25	2	2	2	2	3	3	5	-
25	5	2	2	2	2	2	2	3	4
	10	2	2	2	2	2	2	3	4
	15	2	2	2	2	2	2	3	6
	20	2	2	2	2	2	2	3	-
	25	2	2	2	2	2	2	4	-

See Table 1 for calculation of effective solar radiation

APPENDIX 7.4

Time (h) to burnable (MC=20%) from saturation (MC=250%)

0 Effective Solar Radiation

		Relative Humidity (%)							
Temp. (°C)	Wind Speed (km/h)	10	20	30	40	50	60	80	100
5	5	5	6	7	9	12	-	-	-
	10	5	5	6	8	10	-	-	-
	15	4	5	6	7	9	-	-	-
	20	4	5	5	7	9	-	-	-
	25	4	4	5	6	8	-	-	-
10	5	4	5	5	6	8	12	-	-
	10	4	4	5	6	7	10	-	-
	15	3	4	5	5	6	9	-	-
	20	3	4	4	5	6	8	-	-
	25	3	4	4	5	6	8	-	-
15	5	3	4	4	5	6	8	-	-
	10	3	3	4	4	5	7	-	-
	15	3	3	4	4	5	6	-	-
	20	3	3	3	4	4	6	-	-
	25	3	3	3	4	4	5	-	-
20	5	3	3	3	4	5	6	-	-
	10	2	3	3	3	4	5	-	-
	15	2	3	3	3	4	4	-	-
	20	2	2	3	3	3	4	-	-
	25	2	2	3	3	3	4	-	-
25	5	2	2	3	3	4	4	-	-
	10	2	2	2	3	3	4	-	-
	15	2	2	2	3	3	3	-	-
	20	2	2	2	2	3	3	-	-
	25	2	2	2	2	3	3	-	-

See Table 1 for calculation of effective solar radiation

APPENDIX 8

Average starting moisture content values

Time	Clear (CLR)	Scattered (SCT)	Broken (BKN)	Overcast (OVC)
8:00 AM	35	35	35	35
9:00 AM	24	25	26	29
10:00 AM	16	17	20	25
11:00 AM	11	14	17	22
12:00 PM	9	12	15	21
1:00 PM	9	12	15	20
2:00 PM	9	11	15	19
3:00 PM	8	11	14	19
4:00 PM	8	11	13	19
5:00 PM	9	11	14	19
6:00 PM	10	12	14	19
7:00 PM	12	13	15	19

Values were estimated by using historic weather data from two southern Ontario cities for the month of April.
This chart assumes there has been no significant precipitation in the past 24 hours.

APPENDIX 9

Equilibrium Moisture Content (%)

		Relative Humidity (%)							
Temp (°C)	SOL_{ef}	10	20	30	40	50	60	80	100
5	0	10	13	16	17	19	21	25	38
	1/3	7	10	12	14	15	16	19	21
	2/3	5	8	10	11	12	13	15	17
	1	4	6	7	8	9	10	12	13
10	0	9	12	14	16	18	19	24	37
	1/3	6	9	11	13	14	15	18	20
	2/3	5	7	9	10	11	12	14	15
	1	3	5	6	7	8	9	11	12
15	0	8	11	13	15	16	18	23	36
	1/3	6	8	10	11	13	14	16	19
	2/3	4	6	7	9	10	11	13	14
	1	3	4	5	6	7	8	9	11
20	0	7	10	12	13	15	17	21	34
	1/3	5	7	9	10	12	13	15	18
	2/3	4	5	6	8	9	10	11	13
	1	3	4	4	5	6	7	8	10
25	0	6	8	10	12	14	15	20	33
	1/3	4	6	8	9	10	11	14	17
	2/3	3	4	5	6	7	8	10	12
	1	2	3	4	4	5	6	7	9
30	0	5	7	9	11	12	14	19	32
	1/3	3	5	6	8	9	10	13	16
	2/3	2	3	4	5	6	7	9	11
	1	2	2	3	3	4	5	6	7

Note: A constant 10m open wind speed of 10 km/h is assumed.

APPENDIX 10

Robel Pole - fuel load worksheet

Site name:	Date:

Site notes:

Pole site	Lowest band visible on pole (from four points around the pole)				Average	Litter Layer Depth (cm)
	1	2	3	4		
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
			Site Average			
			Fuel Load (t/ha)*			

Total Fuel Load	t/ha

*See Figures 1 and 2 to convert Robel pole band measurement and litter layer depth to a fuel load value.

APPENDIX11

Fire Behaviour Prediction Worksh

Fire no./Name				
Prediction date and start time	Date		Time	

Pg. #		Area 1	Area 2	Area 3	Area 4
8	Fuel load				
-	Ground slope (%)				

		Hours previous to burn (h)			
		3	2	1	0
-	Observed wind speed (km/h)				
53	10 m open wind speed (km/h)				

30	Effective solar radiation				
-	Relative humidity (%)				
-	Temperature (°C)				

31	Temperature of the fuel (°C)				
32	Relative humidity of the fuel (%)				
33-41	Moisture content of the fuel (%)				

		Area 1	Area 2	Area 3	Area 4
-	Degree of curing (%)				
42 -	Equil. ROS (m/min) - head				
45	- back				
46	Fire intenisity class - head/back				

-	Elapsed time (min)				
47	Head fire spread distance (m)				
47	Back fire spread distance (m)				
47	Total spread distance (m)				
48	Elliptical fire area (ha)				
48	Elliptical fire perimeter (m)				
48	LB ratio				
49	Perimeter growth rate (m/min)				

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