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A SYSTEM FOR PREDICTING FIRE BEHAVIOR IN CANADIAN FORESTS[1]

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ABSTRACT.--The Canadian Forest Fire Danger Rating System (CFFDRS) consists of two major sub-systems. The Canadian Forest Fire Weather Index (FWI) System provides numerical ratings of relative fire potential in a standard fuel type, based solely on weather observations. The other major sub-system of the CFFDRS, the Canadian Forest Fire Behavior Prediction (FBP) System, consists of three components as primary outputs: rate of spread, fuel consumption, and line- or frontal fire intensity. An interim version of the rate of spread (ROS) component was produced in 1984 and is described here. The principal input variable is the Initial Spread Index (ISI), a component of the FWI System. Head fire ROS/ISI equations were developed for 14 major Canadian fuel types from a data base consisting of 245 experimental/operational prescribed fire and 45 wildfire observations. Procedures for projecting fire growth are illustrated using a documented wildfire example.

INTRODUCTION

The Canadian Forest Fire Danger Rating System (CFFDRS) has been under development in its present form since 1968. The first major sub-system of the CFFDRS, the Canadian Forest Fire Weather Index (FWI) System, was initially completed in 1970 (Van Wagner 1974). FWI System components, calculated from tables or computer program (Can. For. Serv. 1984, Van Wagner and Pickett 1985), provide numerical ratings of relative fire potential in a standard fuel type on level terrain, based solely on weather observations. The other major sub-system of the CFFDRS was conceived originally as a series of regionally developed guides to actual fire behavior in specific fuel types (Lawson 1977). This concept has now been replaced by the Canadian Forest Fire Behavior Prediction (FBP) System, the subject of this paper.

The FBP System consists of three primary output components: rate of spread, fuel consumption, and frontal fire intensity. To date, only the rate of spread (ROS) component has been completed and subjected to user trials. An interim user guide[6] was prepared in 1984 in order to present to users without further delay existing ROS predictive equations for 14 Canadian fuel types. Fuel types are organized into five major groups (Table 1).

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[1]A paper presented at the 8th National Conference on Fire and Forest Meteorology, held at Detroit, Michigan, April 29-May 2, 1985.

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[6]Alexander, M.E., B.D. Lawson, B.J. Stocks, and C.E. Van Wagner. 1984. User guide to the Canadian Forest Fire Behavior Prediction System: rate of spread relationships. Interim edition. Can. For. Serv. Fire Danger Group. 73 p. + Supplements.

TABLE 1.--List of fuel types in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System.

Group	Identifier	Descriptive name
Coniferous	C-1	Spruce - Lichen Woodland
	C-2	Boreal Spruce
	C-3	Mature Jack or Lodgepole Pine
	C-4	Immature Jack or Lodgepole Pine
	C-5	Red and White Pine
	C-6	Red Pine Plantation[1]
	C-7	Ponderosa Pine - Douglas-fir
Deciduous	D-1	Leafless Aspen
Mixedwood	M-1	Boreal Mixedwood - leafless[2]
	M-2	Boreal Mixedwood - summer[2]
Slash	S-1	Jack or Lodgepole Pine Slash
	S-2	Spruce - Balsam Slash
	S-3	Coastal Cedar - Hemmlock - Douglas-fir Slash
Open	O-1	Grass[3]

[1]Rate of spread relationships available for three mean stand height ranges: < 10 m, 10-20, and > 20 m.

[2]Must specify percent softwood (S) and hardwood (H) species composition. Three commonly accepted combinations have been included in the User Guide Rate of Spread Tables and Graphs: 75S:25H, 50S:50H, and 25S:75H.

[3]Must specify percent cured or dead material. Standard fuel load is 3 t/ha. Variable fuel weight/rate of spread relationship available.

Structurally, the principal input variable is Initial Spread Index (ISI), a component of the FWI System that combines the effects of wind and Fine Fuel Moisture Code (FFMC). Fuel type and topographic slope are the other primary FBP System inputs (fig. 1). The output from the spread

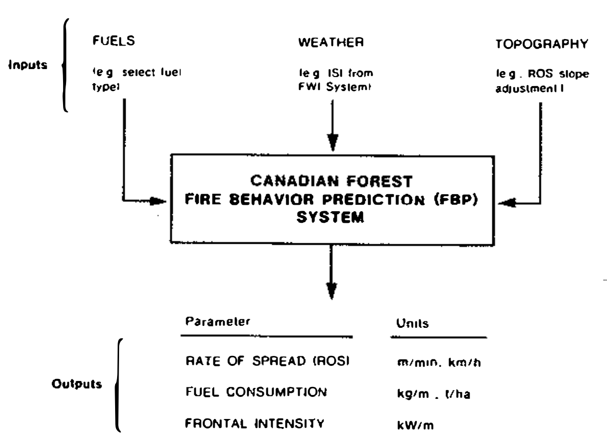

FIGURE 1.--Simplified structure of the Canadian Forest Fire Behavior Prediction (FBP) System.

component is forward, linear, head fire rate of spread on level terrain under equilibrium conditions. By defining ROS as the forward movement of the fire front per unit time after having reached a "quasi" steady-state, crowning and spotting are automatically accounted for, in terms of their influence on the overall spread rate in fuel types subject to these fire behavior phenomena. Crown fire thresholds are indicated as part of the basic ROS output of the system.

Philosophically, the FBP System reflects the long-established Canadian Forestry Service (CFS) approach to fire behavior research, as described by Van Wagner (1971) and Stocks and Alexander (1980). Field documentation of readily measured variables on experimental fires, followed by analysis of the data using simple mathematical models and correlation techniques, are the basis of the CFS approach. Well-documented operational prescribed fires and wildfires have been used as well, the latter being particularly useful to quantify the extreme end of the fire behavior scale where experimental fires are difficult to schedule and manage. Laboratory-based fire research in moisture physics and heat transfer theory provide the models and framework by which field data are analyzed and explained.

TECHNICAL DERIVATION

ROS equations for most fuel types were developed by grouping into appropriate subsets data from a larger data set consisting of 290 fire observations for which spread rate and necessary weather information were available. This data base comprises 245 experimental and operational prescribed fire observations and 45 wildfire observations from all available Canadian sources (e.g., Stocks and Walker 1972, Lawson 1973, Van Wagner 1973, Stocks 1975, Quintilio et al. 1977, Alexander 1983) and some from adjacent U.S. states (e.g., Randall 1966, Dyrness and Norum 1983, Alexander 1984). Some large wildfires known to have burned through several forest types were included in more than one fuel type subset.

For all equations derived directly from the data base, the independent variable is the ISI. Because this index comprises functions of fine fuel moisture and wind, all fuel type subsets were tested for multiple correlation of ROS with these two variables expressed separately. No advantage was found over ISI alone.

Final equation forms were chosen after some trial and judgment. Special attention was paid to reasonable fit with data at low ISI (fig. 2), and for consistency among fuel types. The principle that ROS probably levels off at very high ISI was adopted as an appropriate conservative approach in the absence of firm knowledge. Some fuel types are served by two equations for lower and upper ranges of ISI, with a smooth junction at the ISI change-over value. Where data existed for a low range of ISI only, the curves were extrapolated by judgment and informal experience.

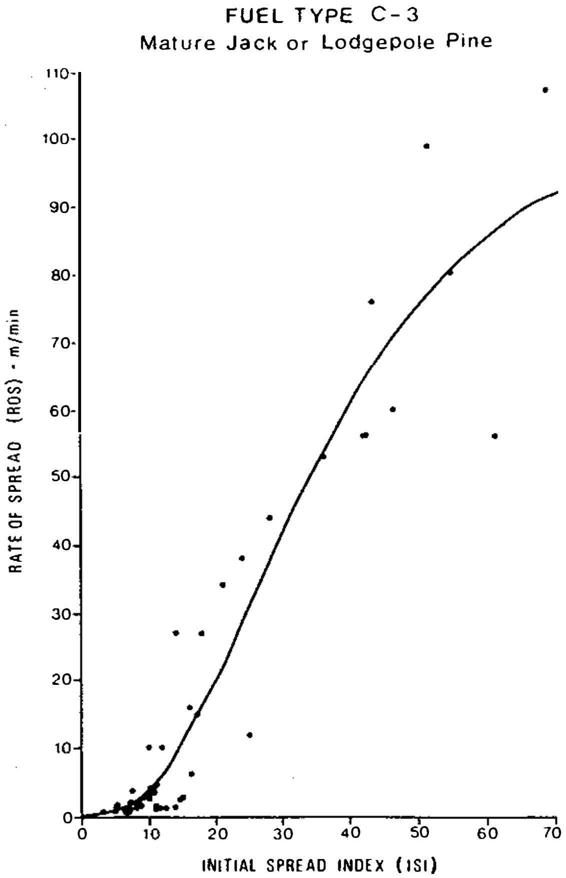

FIGURE 2.--Scattergram of Initial Spread Index (ISI) vs. rate of spread (ROS) observations from experimental and wild fires in the Mature Jack or Lodgepole Pine Fuel Type (C-3) of the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System.

Because of the empirical nature of the data, the transition from surface fire to crown fire among the coniferous fuel types is accounted for automatically in the ROS equations. Among the boreal coniferous fuel types especially (C-1, C-2, C-3, and C-4), the steeper section of the curves at intermediate ISI represents this process. Crowning thresholds on the basis of ISI were set by informal experience (Table 2). All ROS curves were forced through the origin, with the exception of type C-4 where the dense nature of the stands precluded fire spread at ISI values less than 4. Figure 3 shows the comparative position of ROS/ISI curves for all 14 fuel types.

Table 3 shows various statistics, including ranges of ROS and ISI, number of fire observations and correlation coefficients (r^2) between actual versus calculated ROS values for all data-based fuel types. Several ROS equations were not derived directly from the data base:

1. The Boreal Mixedwood Fuel Types (M-1 and M-2) are served by a blend of the ROS equations for Boreal Spruce (C-2) and Leafless Aspen (D-1) in proportion to the amount of softwood (S) and hardwood (H).

TABLE 2.--Threshold conditions for crown fire development in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System for fires burning on level to gently undulating ground or downslope in terms of the Initial Spread Index (ISI) and for fires burning upslope in terms of the forward rate of spread (ROS) adjusted for percent ground slope.

Fuel type		ISI	ROS	
			m/min	km/h
C-1		16	15	0.90
C-2		12	14	0.84
C-3		18	17	1.02
C-4		8	9	0.54
C-5		--------crowning unlikely--------		
C-6	<10 m[1]	8	9	0.54
	10-20 m	18	17	1.02
	>20 m	--------crowning unlikely--------		
C-7		25	8	0.48
D-1		--------crowning unlikely--------		
M-1	75S:25H[2]	16	17	1.02
	50S:50S	20	17	1.02
	25S:75H	--------crowning unlikely--------		
M-2	75S:25H[2]	20	21	1.26
	50S:50H	27	21	1.26
	25S:75H	--------crowning unlikely--------		
S-1		N/A	N/A	N/A
S-2		N/A	N/A	N/A
S-3		N/A	N/A	N/A
O-1		N/A	N/A	N/A

[1]Mean stand height.

[2]Percent softwood (S) and hardwood (H) species composition.

2. The Red Pine Plantation Fuel Type (C-6) utilizes the ROS equations of other coniferous fuel types for three mean stand height ranges. This approach was adopted in view of(1) the importance of height to plantation fire behavior, and(2) the limited number of ROS observations in this fuel type.

3. The Grass Fuel Type (O-1) equation is based on the Australian grassland fire behavior research of McArthur (1962, 1977), with supporting evidence from early Canadian grass fire research (Wright and Beall 1938). Proportion of cured or dead fuel is a required input to the ROS equation, whereas fuel loading can be input if known; otherwise a standard fuel load of 3 t/ha is assumed.

DESCRIBING FUEL TYPES

A fuel type is a recognizable fuel complex of sufficient homogeneity of characteristics and horizontal (areal) extent that steady-state equilibrium fire behavior can be predicted and be expected to be maintained over a considerable period of time.

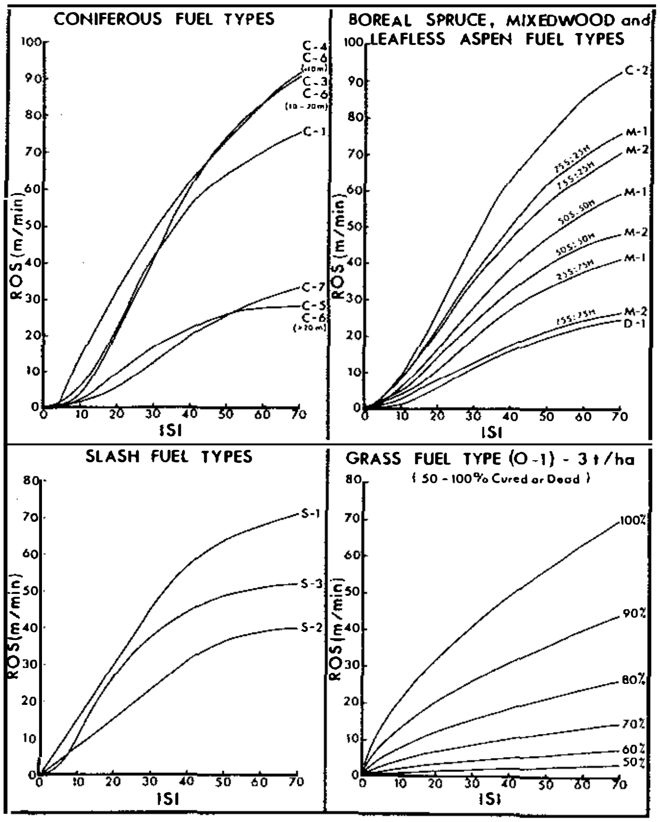

FIGURE 3.--Rate of spread (ROS)/Initial Spread Index (ISI) relationships for the 14 fuel types in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System.

TABLE 3.--Statistics associated with the data base and rate of spread (ROS)/Initial Spread Index (ISI) relationships in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System.

Fuel type	No. of fire obs. (n)	ROS range (m/min)	ISI range	Correlation coefficient[1] (r^2)
C-1	8	0.6- 51.4	3.2-31.1	0.95
C-2	35	0.3-107.0	2.5-68.0	.91
C-3	56	0.4-107.0	3.3-68.0	.91
C-4	29	0.7-107.0	5.8-68.0	.84
C-5	15	0.3- 7.5	3.0-18.0	.91
C-6	12	0.9- 27.4	5.0-13.0	-
C-7	12	0.3- 26.8	7.0-41.0	.92
D-1	34	0.3- 10.7	3.2-28.1	.69
S-1	53	0.6- 31.7	1.0-16.4	.60
S-2	52	0.1- 31.7	1.0-38.8	.74
S-3	12	0.4- 12.0	1.0-11.0	.69

[1]Refers to the correlation between actual and equation spread rates.

Fuel types in the FBP System are described mainly qualitatively, rather than quantitatively, using terms describing stand structure and composition, surface and ladder fuels, and the forest floor cover and organic (duff) layer. The descriptions emphasize obvious properties of importance to fire behavior. Terminology is used which allows semi-quantitative comparison of characteristics among fuel types to assist a user in selecting the most appropriate fuel type. The user is required to fit his fuel complex of concern to one of the 14 fuel types provided; no provision is made for adjusting ROS for a fuel type which has characteristics between the discrete fuel types provided.

An example of a fuel type description from the interim edition of the FBP System illustrates the above principles:

<u>Fuel Type C-3 (Mature Jack or Lodgepole Pine)</u>

This fuel type is characterized by pure, fully-stocked (1000 to 2000 stems/ha) jack pine or lodgepole pine stands that have matured at least to the stage that crown closure is complete and the base of live crowns is substantially separated from the ground. Dead surface fuels are light and scattered. Ground cover is basically feather moss over a moderately deep (approximately 10 cm) compact organic layer. A sparse conifer understory may be present.

Similar written descriptions for the other 13 fuel types and a summary table are provided for comparing and contrasting them.

OUTPUT FORMATS

ROS/ISI relationships for level to gently undulating terrain are presented in equation, graph and table form. An example equation is given below:

<u>Fuel Type C-3 (Mature Jack or Lodgepole Pine)</u>

$$R = 100.3\left(1 - e^{-0.0509\ ISI}\right)^{3.53} \quad (1)$$

where, R is ROS on level ground (m/min) and ISI is Initial Spread Index.

The equations are provided for computer users although no comprehensive FBP System computer program has been included at this stage.

Separate graphs of ROS versus ISI are presented for each fuel type, generated from the equations as above. In the example graph for Fuel Type C-3 (fig. 4), the solid line represents plotted equation values based on observed data, while the dashed line represents an extrapolation beyond our data limit. The shaded area around each curve is a subjective confidence interval within which observed spread rates can be expected to fall approximately two-thirds of the time. Threshold values of ISI, indicating the transition from surface fire to crown fire, are shown for susceptible fuel types. Each graph presents ROS in both m/min and km/h on level ground. The latter unit is more suitable when monitoring fast-spreading fires over long time periods while the former is preferred for general usage, particularly for slow-spreading fires over short periods. All graphs are plotted to a maximum ISI of 70. Extrapolation of ROS beyond this point is not recommended.

FUEL TYPE C-3
Mature Jack or Lodgepole Pine

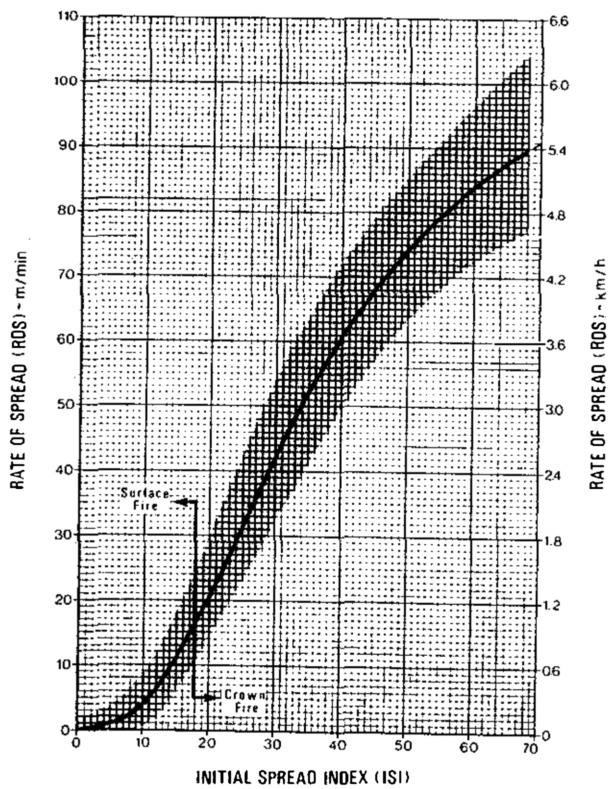

FIGURE 4.--Example of a rate of spread (ROS)/Initial Spread Index (ISI) graph from the 1984 interim edition user guide to the Canadian Forest Fire Behavior Prediction (FBP) System for Fuel Type C-3 (Mature Jack or Lodgepole Pine) with 70% confidence limits (shaded area), crowning threshold, and limit of observed data (dashed line) indicated.

Rate of spread tables for operational field use are presented for all fuel types, with separate versions for ROS in m/min and km/h. Table 4 illustrates one of the four ROS tables, including the coniferous and deciduous fuel types, with ROS in m/min and crown fire spread indicated by shading. Table ROS values were generated from the equations described above and represent head fire rate of spread to be expected on essentially level ground.

USER INSTRUCTIONS

Methods and procedures are suggested in the 1984 interim edition User Guide for adjusting FBP System inputs (Wind, FFMC, and ISI), principal output (ROS), and for calculating and plotting predicted fire sizes. A flow chart of these procedural steps is given in figure 5.

A worksheet has been designed to help the user organize and record step by step input data and results of computations.

It is important when calculating ISI for ROS predictions to determine the most accurate and current 10-m open wind speed measured, estimated or forecasted for the time and area of interest. Methods to correct wind speed observations taken at non-standard heights, as well as guides for estimating wind speeds, are presented in Turner and Lawson (1978).

TABLE 4.--Example of a rate of spread (ROS)/Initial Spread Index (ISI) table from the 1984 interim edition user guide to the Canadian Forest Fire Behavior Prediction (FBP) System for the coniferous and deciduous fuel type groups.

ISI	Fuel Type C-1	C-2	C-3	C-4	C-5	C-6 <10 m	C-6 10-20 m	C-6 >20 m	C-7	D-1
	ROS (m/min)									
0.5	*	0.1	*	0	*	0	*	*	*	*
1.0	0.1	0.2	*	0	*	0	*	*	*	0.1
1.5	0.2	0.4	*	0	*	0	*	*	*	0.1
2.0	0.3	0.6	*	0	0.1	0	*	0.1	0.1	0.2
2.5	0.4	1.0	0.1	0	0.1	0	0.1	0.1	0.1	0.2
3	0.6	1.3	0.1	0	0.2	0	0.1	0.2	0.2	0.3
4	1.1	2.2	0.3	0.8	0.3	0.8	0.3	0.3	0.3	0.5
5	1.6	3.3	0.5	3.1	0.5	3.1	0.5	0.5	0.4	0.7
6	2.3	4.4	0.9	5.4	0.7	5.4	0.9	0.7	0.6	0.9
7	3.1	5.7	1.4	7.6	1.0	7.6	1.4	1.0	0.8	1.1
8	4.0	7.2	2.1	9.7	1.4	9.7	2.1	1.4	1.0	1.4
9	4.9	8.7	2.9	12	1.8	12	2.9	1.8	1.2	1.6
10	6.0	10	3.9	14	2.2	14	3.9	2.2	1.5	1.9
12	8.5	14	6.3	18	3.3	18	6.3	3.3	2.1	2.6
14	11	17	9.3	22	4.6	22	9.3	4.6	2.9	3.3
16	15	21	13	26	6.2	26	13	6.2	3.7	4.1
18	18	25	17	29	7.9	29	17	7.9	4.6	4.9
20	22	28	21	33	9.8	33	21	9.8	5.6	5.8
25	33	38	31	41	14	41	31	14	8.5	8.2
30	42	46	42	49	17	49	42	17	12	11
35	49	55	52	56	20	56	52	20	16	14
40	56	62	61	63	22	63	61	22	20	16
45	61	69	69	69	23	69	69	23	23	18
50	65	75	75	74	25	74	75	25	26	20
55	68	80	80	79	26	79	80	26	28	21
60	71	84	85	84	27	84	85	27	30	22
65	74	88	88	88	27	88	88	27	31	23
70	76	92	91	92	28	92	91	28	33	24

Notes: Shaded area indicates crown fire spread. The three values listed in the column heading under Fuel Type C-6 (Red Pine Plantation) refer to mean stand height ranges. ROS values greater than 0.0 m/min but less than 0.05 m/min are indicated by an asterisk (*).

Fine Fuel Moisture Code Adjustments

A simple approach to FFMC adjustments was chosen to account for the effects on fine fuel moisture of diurnal and topographic differences between weather observation points and fire prediction points. The standard daily FFMC applies to the mid-afternoon fire danger peak on level ground under a forest canopy. One table is used to adjust FFMC for times throughout the afternoon and requires only the FFMC determined from the standard noon weather observations; the table assumes a

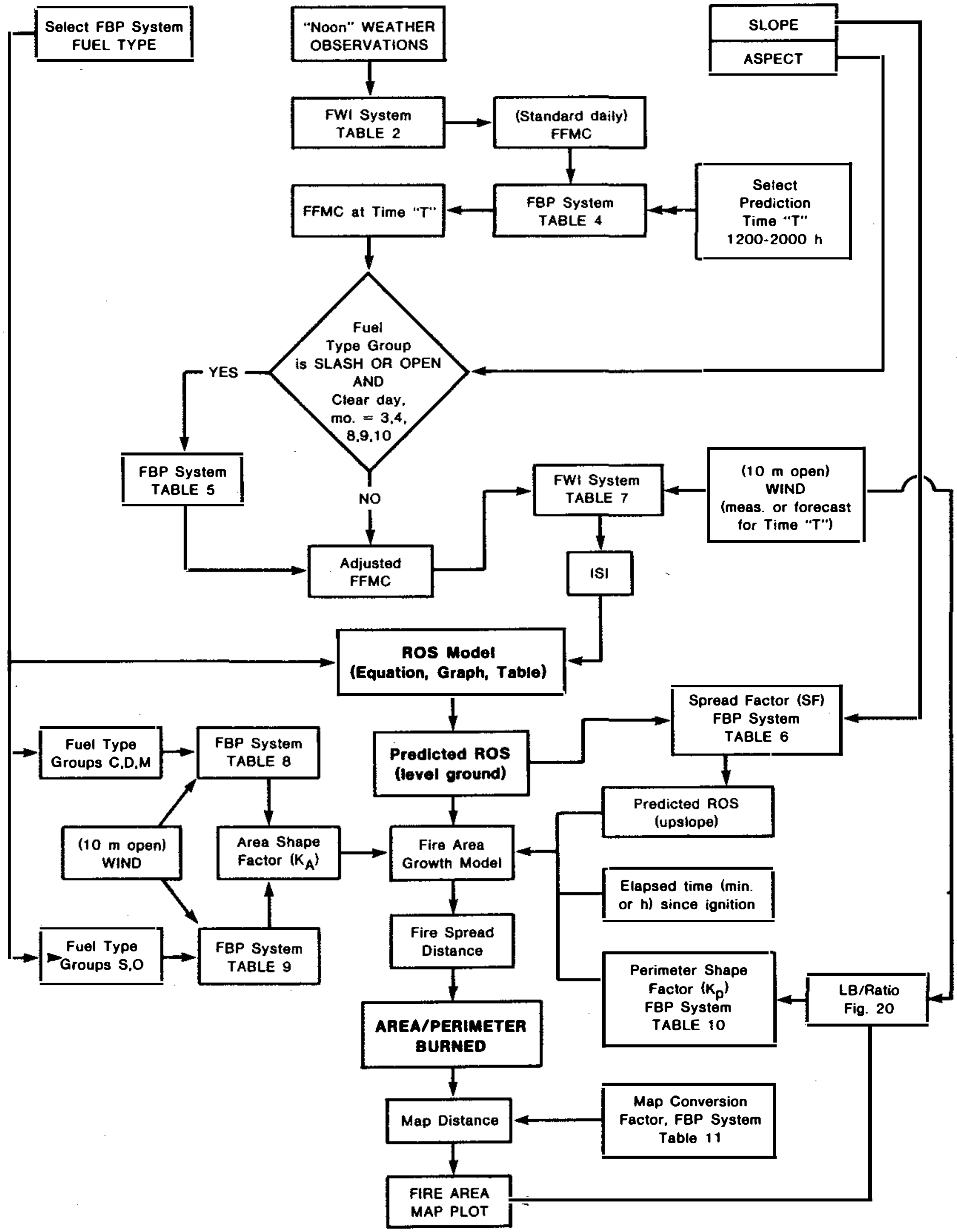

FIGURE 5.--Flow chart of adjustments and procedures in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System.

normal afternoon pattern of change in temperature and relative humidity and was derived from previously published versions (Van Wagner 1972, Alexander 1982b). A second table is used, under restricted circumstances, to adjust FFMC for slope and aspect, if the standard daily FFMC was determined from weather observations taken on different topographic conditions from those at the fire behavior prediction point. This adjustment is applied only to non-forested fuel types (Slash and Open fuel type groups) on clear to partly cloudy afternoons in spring, late summer and fall months, conditions where fuel moisture differences among various slopes and aspects are significant enough to result in expected fire behavior differences of importance to normal FBP System applications. The interim edition of the FBP System utilized an unpublished slope and aspect adjustment procedure developed by S.J. Muraro in 1978, based on the field research findings of Williams (1964) in coastal British Columbia slash. A more comprehensive FFMC adjustment model is under development.

Slope Adjustments

If a ROS prediction is desired for level to gently undulating terrain, the appropriate ROS equation, table or graph for the fuel type best matching the fuels ahead of the prediction point is entered with ISI, and the ROS is read or calculated. However, if terrain is sloping, an appropriate spread factor (SF), a simple multiplier, is required to account for the mechanical effects of slope on fire spread rate (equation 2).

$$(2) \quad SF = e^{3.533 \; (\phi/100)^{1.2}}$$

where, SF = spread factor, ϕ = ground slope (%).

For the simplest case of a fire spreading upslope with the wind, the user must determine the ground slope (percent) on the area of interest and derive the appropriate spread factor (SF) from a table, or calculate a predicted upslope ROS directly from an equation combining SF and ROS predicted for level ground. The SF relationship (fig. 6) was adapted from the work of Van Wagner (1977a) which examined relative fire spread factors from various literature references to fire danger rating systems and to studies of fire behavior on slopes from both field and laboratory. Figure 6 indicates that a fire burning up a 25% slope would spread twice as fast as on flat terrain, for the same fuel and weather conditions. The SF relationship is not regarded as valid to extrapolate to slopes greater than 60 or 70%, because of expected fuel discontinuities common on steeper slopes and the generally unstable nature of fire behavior on very steep slopes.

Instructions are provided for ROS predictions for four possible combinations of fire spread relative to direction of wind and slope. The simplest case (Case 1: fire spread upslope with the wind) was described above, when head fire ROS is reinforced by both wind and slope. Figure 7

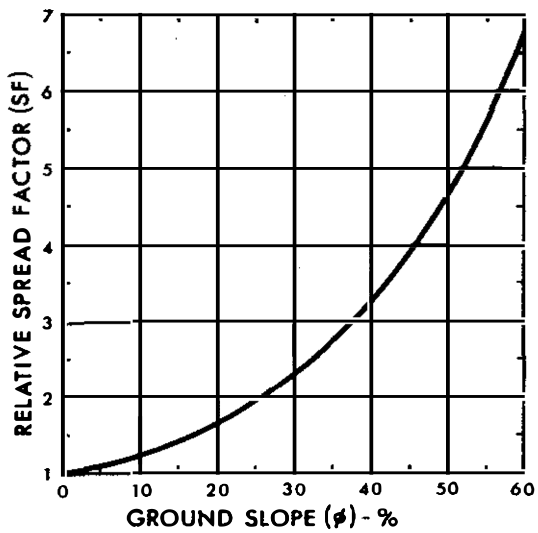

FIGURE 6.--The effect of ground slope on increasing the rate of spread of fires burning upslope according to Van Wagner (1977a).

indicates that for the case of fire spread direction upslope against the wind, in calculating ROS, zero wind speed is used to compute ISI and the given ground slope is used for SF. In this case, the wind effect is cancelled but the slope effect remains. The remaining two cases of fire spread downslope with and against the wind use the given wind speed or zero wind speed, respectively and SF for zero ground slope.

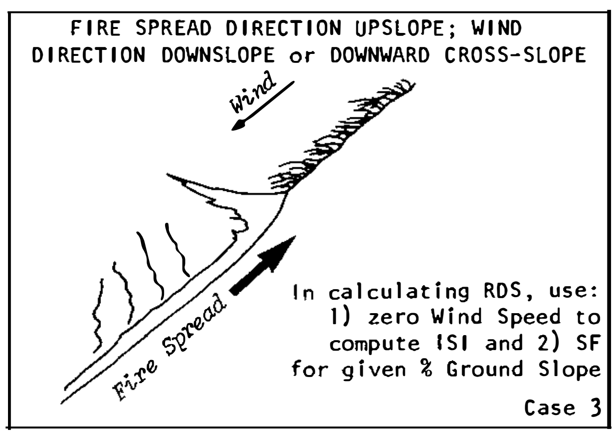

FIGURE 7.--One of four cases of determining rate of spread (ROS) in relation to direction fire is spreading with respect to wind and slope in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System (ISI = Initial Spread Index and SF = relative Spread Factor).

Crown Fire Thresholds

With regard to thresholds for crown fire development given in the ROS graphs and tables in terms of the ISI, and listed here in table 2, it should be noted that these ISI thresholds are applicable to head fires on level ground and to fires burning downslope. However, for fires burning upslope (Cases 1 and 3), the threshold conditions for crowning should be based on the slope-adjusted ROS criteria listed in table 2 rather than ISI.

Fire Size Calculations

The interim edition of the FBP System contains procedures for projecting fire growth from a point ignition. Fire size calculations for point ignitions are based on a simple elliptical fire growth model (e.g. Van Wagner 1969). Area and perimeter computations are described in detail by Alexander (1985).

Fire Area Plotting

Plotting of the projected fire area on a map as a smooth ellipse can be done by following a detailed instructional worksheet. The user guide also offers general guidelines for projecting fire area growth and spread from the active perimeter of a large wildfire. The following section illustrates the technique of using the FBP System to make a series of fire growth projections from point ignitions and plotting the results on a map.

A PRACTICAL EXAMPLE

The procedures illustrated here for calculating and plotting fire growth on a map are applicable to the initial spread pattern of wildfires during their first major burning period, spot or jump fires, or excursion points along the controlled line of a campaign fire (i.e., point ignitions).

An example of a documented wildfire, DND-4-80 in east-central Alberta, is presented to illustrate the computation and display of results from the interim edition of the FBP System. Alexander et al. (1983) fully described the fire behavior and associated environmental conditions for this major fire which made its initial run on May 2, 1980. Figure 8 illustrates fire spread and size projections from ignition over three separate time periods of the fire run. Calculations are shown on a portion of a FBP System worksheet and the results displayed in the form of "nested" ellipses on a map for the three time intervals. Comparison with the plotted actual fire perimeter at the conclusion of the major run is possible from the map.

The fire was detected at 1438 MDT and reported at 1440. FFMC and wind velocity for 1300 MDT were taken from table 2 in Alexander et al. (1983). The fire made an initial run during the afternoon, crowning through continuous stands of jack pine and black spruce on essentially flat terrain. By 1930 when the fire perimeter was mapped by the Alberta Forest Service (AFS) Lac La Biche Forest superintendent (L.G. Huberdeau) and protection officer (E.R. Johnson), the estimated size was 7500 ha, with a total spread distance of 19.8 km, a maximum breadth of 5.1 km (length-to-breadth (L/B) ratio = 3.9), and a perimeter estimated at 48.3 km. The actual fire perimeter as mapped (AFS Forest Cover Series sheet no. 73M S.E.; interpretation based on 1951 aerial photography) is shown on the inset map of fig. 8. (Several water bodies in the fire area facilitated visual mapping of the fire perimeter, but these observations must still be regarded as best estimates).

FBP System calculations were made for the three time intervals shown in order to adjust FFMC for time of day. Fuel Type C-3 was used throughout. Wind speed from the nearest fire weather station (Winefred Lookout) for 1300 MDT was used to calculate ISI for all three intervals, as no additional observations from the lookout were made through the afternoon (towerman evacuated) and the hourly observations from nearby synoptic stations supported the fairly consistent wind velocity throughout the afternoon.

The worksheet (fig. 8) shows that the total predicted spread distance (sum of spread distance predicted for each time interval) was 19.0 km with a perimeter length of 43.9 km and a burned area of 7597 ha. Under prediction of perimeter is due to irregularities in fire edge not accounted for in the simple ellipse formula. Over prediction in area is due to the slight under prediction of L/B ratio (3.7 vs. 3.9 actual).

If backfire spread were taken into account (using wind = 0), total spread distance would be predicted as 19.5 km, perimeter length as 45.1 km, and burned area as 8018 ha.

This example illustrates the importance of accurate fire origin locations when plotting fire growth projections. In this case there was some uncertainty as to the exact origin, as the area was screened from Winefred Lookout by a ridge. Wind direction is a crucial variable in map plotting of fire growth as well, and a 16-point compass is recommended for standard fire weather observations.

PRESENT AND POTENTIAL APPLICATIONS

Application of outputs from the ROS component of the FBP System could include a number of fire presuppression and suppression activities involving a wide range of planning time horizons, from near real-time suppression tactics and strategic planning for a major going fire, to fire control resource allocation and deployment schedules. For example, a presuppression preparedness system is currently under development by the Department of Indian and Northern Affairs for Canada's Northwest Territories which uses in part the ROS and fire growth predictive models of the FBP System[7].

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CANADIAN FOREST FIRE BEHAVIOR PREDICTION (FBP) SYSTEM WORKSHEET

Fire Number/Name DND-4-80 (east-central Alberta) Date & Time 02.05.80 1440

Prediction Date & Time Interval 02.05.80 from 1438 MDT to 1930 MDT

		1438–1600	1600–1800	1800–1930
1	Prediction Point	1 P.I.	1 P.I.	1 P.I.
	Fuel Type Information			
2	FBP System Fuel Type	C-3	C-3	C-3
3	Softwood Species Composition (%)	–	–	–
4	Hardwood Species Composition (%)	–	–	–
5	Cured/Dead Grass (%)	–	–	–
6	Grass Fuel Weight (t/ha)	–	–	–
	Fine Fuel Moisture Code (FFMC) Time & Slope/Aspect Adjustments			
7	Standard Daily FFMC	94	94	94
8	Time "T"	1500	1700	1900
9	FFMC at Time "T"	93	94	93
10	Aspect (N, E, S, or W)	–	–	–
11	Ground Slope (%)	0	0	0
12	Adjusted FFMC	93	94	93
	Rate of Spread (ROS) Calculations			
13	10-m Wind Speed (km/h)	36	36	36
14	Initial Spread Index (ISI)	40*	46*	40*
15	Spread Factor (SF)	1.00	1.00	1.00
16	ROS on Level (m/min or km/h)	3.7	4.2	3.7
17	ROS[16] x SF[15] (m/min or km/h)	3.7	4.2	3.7
	Fire Size Calculations	* – CROWN FIRE		
18	Elapsed Time (min or h)	1.37	2.0	1.5
19	Spread Distance (m or km)	5.07 +	8.4 +	5.55
20	Area Shape Factor (K_A)	0.21	0.21	0.21
21	Area Burned (ha)	540	3810	7597
22	Length/Breadth Ratio (L/B)	3.7	3.7	3.7
23	Perimeter Shape Factor (Kp)	2.31	2.31	2.31
24	Perimeter Length (m or km)	11.7	31.1	43.9
	Fire Area Plotting 1:126 720			
25	Map Conversion Factor (cm/km)	0.79	0.79	0.79
26	Map Distance (cm)	4.0/1.1	10.6/2.9	15.0/4.1
27	Wind Direction	S	S	S

Note: the Area Burned, Perimeter Length, and Map Distance computations for 1600-1800 h and 1800-1930 h are based on the cumulative Spread Distance (i.e., 13.47 km and 19.02 respectively)

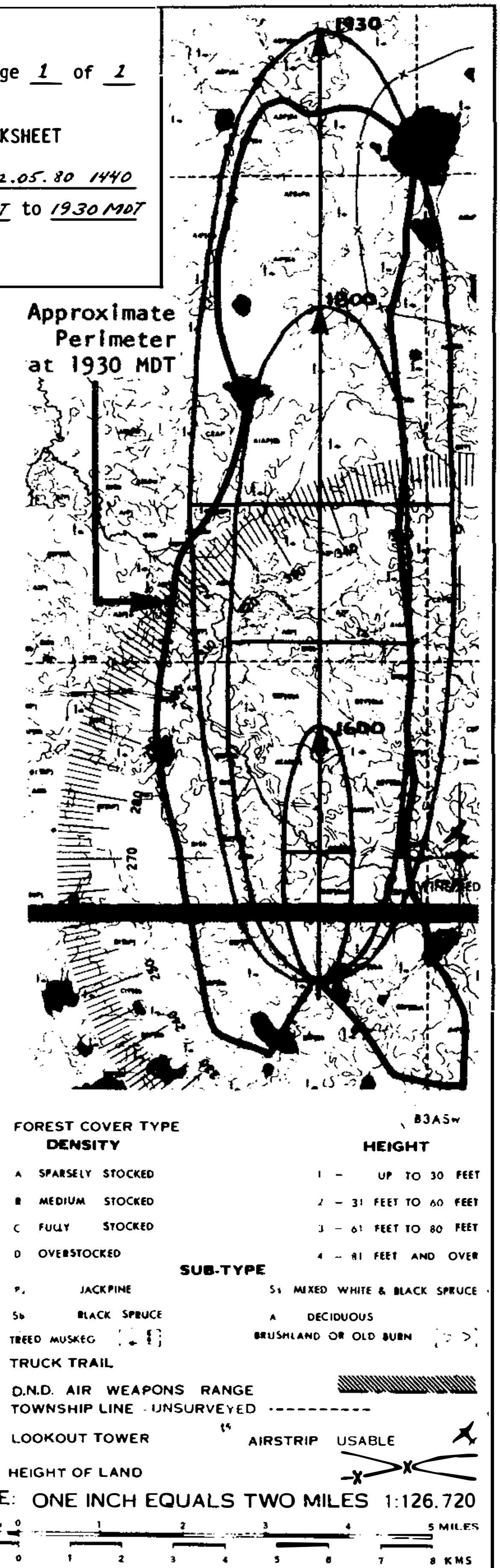

FIGURE 8.--An after-the-fact prediction of an actual wildfire situation illustrating the use of the worksheet and the procedures for plotting fire growth from a point ignition contained in the user guide to the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System.

As part of a computer-based centralized fire management information system to support resource allocation, Kourtz et al. (1977) has developed a fire perimeter location model which simulates fire growth across a grid of cells. Rate of spread across a cell in eight radial directions is calculated according to fuel type, slope, fuel moisture based on indexes from the nearest fire weather station, and forecast wind velocity for the hour (Kourtz 1984). This model has incorporated the rate of spread and related equations from the FBP System, and is in the process of development and demonstration in several provinces of Canada (Quebec, Ontario, British Columbia) as the trend towards regional fire management decision support systems continues.

A pilot study (Dixon et al. 1984) to demonstrate the feasibility of Landsat MSS digital data for fuel type mapping in the boreal forest of Manitoba produced color thematic maps of eight vegetation/cover types and associated FBP System fuel types.

As well, several provinces and territories of Canada have introduced the ROS and fire growth procedures of the FBP System to their fire management staff through fire behavior training courses and field references.

FUTURE DEVELOPMENTS

Response from fire management agencies to the interim edition of the FBP System has been encouraging; the need for quantitative fire behavior prediction models for Canadian forests has been recognized during the years of data collection and development of the system.

Present plans include continued experimental burning programs in critical fuel types not presently or adequately covered, such as the current study in lowland black spruce in northern Alberta. Fire management agency interest in wildfire behavior monitoring for additional high rate of spread data has been spurred by the release of the interim edition of the FBP System and should result in both verification data for existing models and key information for model development for new fuel types of regional interest. Some suggestions are provided in the interim User Guide on documentation of wildfire spread rates.

Revisions to the interim edition are planned with regard to the FFMC adjustment procedures for slope and aspect. A comprehensive, computer-compatible scheme to handle time of day, elevation, latitude, as well as slope and aspect variables is under development.

The effect of available fuel on ROS will be accounted for by introducing a contribution from the Buildup Index (BUI) of the FWI system. The ISI does not account for variable fuel quantity by definition.

A major extension is under development to incorporate fuel consumption and frontal fire intensity outputs, in addition to rate of spread. Surface and aerial fuel consumption predictive equations by fuel type, in terms of the BUI are being investigated. Predictions of frontal fire intensity (Byram 1959, Alexander 1982a) from predicted ROS and fuel consumption by fuel type will probably be presented to the user in the form of fire characteristics and associated suppression interpretations. More rigorous procedures for determining crown fire thresholds using the crown fire theory of Van Wagner (1977b) are being investigated. As well, a comprehensive computer program for the complete FBP System is planned for publication.

Also proposed to assist with user interpretation of fuel type descriptions is a series of color photographs of each FBP System fuel type and a composite photographic wall poster.

CONCLUDING REMARKS

The interim edition of the FBP System, as described in this paper, represents the best available information on fire spread in Canadian forests. Practice and experienced judgment in assessing the fire environment, coupled with a systematic method of calculating expected fire behavior, can yield surprisingly good results. Quantitative prediction of fire behavior characteristics in wildland fuel complexes remains an art. It must be done at the fire site by trained, experienced fire specialists who must observe and evaluate many interacting parameters of the fire environment in terms of existing and forecast changes over time and space.

The FBP System provides Canadian fire managers with site-specific fire behavior information for a number of important fuel types. Other fuel types will be added to the system as fire behavior models are constructed. Future development and effective use of quantitative fire behavior prediction dictate improved weather data collection, fire weather forecasting and information handling capability by operational agencies. Fire management information systems which link site-specific fire predictive tools with decision support guidelines should be of demonstrable value in improving fire management effectiveness.

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