A BRIEF OVERVIEW OF THE CANADIAN FOREST FIRE BEHAVIOR PREDICTION (FBP) SYSTEM

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INTRODUCTION

The Canadian Forest Fire Behavior Prediction (FBP) System is the one of four subsystems of the Canadian Forest Fire Danger Rating System (CFFDRS). It has been under development since 1968 when a modular approach to a national system for fire danger rating was envisioned (Figure 1). Other subsystems of the CFFDRS are the Canadian Forest Fire Weather Index (FWI) System, which was implemented by operational fire management agencies in Canada in the early 1970s; the Canadian Forest Fire Occurrence Prediction (FOP) System and the Accessory Fuel Moisture System, both of which are still in development (Stocks et al. 1989).

The FBP System was developed by the Forestry Canada Fire Danger Group[1] in order to provide a national system for predicting fire behavior. An interim edition of the system was released in 1984 (Alexander et al. 1984) and documentation of the first complete version is now available (Forestry Canada Fire Danger Group 1992). Given that a formal technical report on the FBP System has been published, the purpose of this paper is to provide a brief overview of the system, its key inputs and outputs, and some of its primary operational applications.

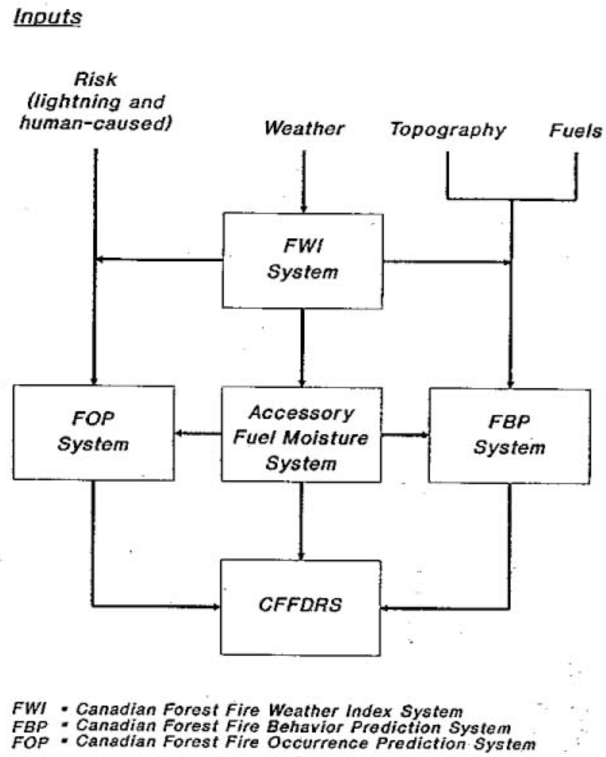

Figure 1. Simplified structure diagram for the Canadian Forest Fire Danger Rating System (adapted from Stocks et. al 1989).

NATURE OF THE FBP SYSTEM AND ITS DEVELOPMENT

The FBP System is primarily empirical in nature; many of the relationships within the system are based on observations of actual fire behavior. Information from a total of 495 fires (409 experimental fires and 86 well-documented wildfires) are included in the FBP System data base (Table 1). The FBP System data base also consists of observations from 345 fires from across Canada as well as 18 fires from six areas in the northern United States and 132 Australian grass fires.

To develop the FBP System the set of empirical fire data was analyzed using simple mathematical models and correlation techniques. Laboratory-based fire research in moisture physics and heat transfer theory was used as a framework for explaining the results of the data analysis. Physical theories of fire behavior were assessed in relation to the actual data to ensure that the most logical predictions were provided by the FBP System. These analysis and modelling activities were conducted jointly by the members of the Fire Danger Group allowing for the discussion of a wide variety of opinions and considerations.

STRUCTURE OF THE FBP SYSTEM

The FBP System has 14 primary inputs that can be divided into five general categories: fuels, weather, topography, foliar moisture content, and type and duration of prediction (Figure 2). In the FBP System these inputs are used to

[1] Current members of the Fire Danger Group are: R.S. McAlpine - Chairman (Petawawa National Forestry Institute), B.J. Stocks and T.J. Lynham (Great Lakes Forestry Centre), M.E. Alexander and B.S. Lee (Northern Forestry Centre), and B.D. Lawson (Pacific Forestry Centre). Also a major contribution to the development of the FBP System was made by C.E. Van Wagner who recently retired from the Petawawa National Forestry Institute.

Table 1. Type and number of fires in the FBP System data base (adapted from Forestry Canada Fire Danger Group 1992).

Fuel type	Experimental	Wildfires[a]	Total
Coniferous			
(C-1) Spruce-Lichen Woodland	7	1	8
(C-2) Boreal Spruce	18	30	48
(C-3) Mature Jack or Lodgepole Pine	41	22	63
(C-4) Immature Jack or Lodgepole Pine	15	20	35
(C-5) Red and White Pine	19	1	20
(C-6) Conifer Plantation	12	0	12
(C-7) Ponderosa Pine/Douglas-fir	8	5	13
Deciduous			
(D-1) Leafless Aspen	32	3	35
Mixedwood			
(M-1) Boreal Mixedwood-leafless[b]	—	—	—
(M-2) Boreal Mixedwood-green[b]	—	—	—
(M-3) Dead Balsam Fir/Mixedwood-leafless	5	0	5
(M-4) Dead Balsam Fir/Mixedwood-green	1	0	1
Slash			
(S-1) Jack or Lodgepole Pine Slash	48	11	59
(S-2) Spruce/Balsam Slash	49	21	70
(S-3) Coastal Cedar/Hemlock/Douglas-fir Slash	28	5	33
Open			
(O-1a) Matted Grass[c]	52	6	58
(O-1b) Standing Grass[c]	74	—	74
TOTAL	409	125	534[d]

[a] The wildfire category also includes a few well-documented operational prescribed burns conducted in the slash fuel types.
[b] The M-1 and M-2 fuel types are derived mathematically from the equations for C-2 and D-1.
[c] The O-1a and O-1b fuel types are based on Australian grass fire data that was analyzed by the Forestry Canada Fire Danger Group.
[d] A total of 39 wildfire observations were used in more than one fuel type (mostly C-2, C-3, and C-4) because a combination of these fuel types were consumed during the major wildfire runs.

calculate four primary and 11 secondary outputs. Primary outputs are based generally on the fire intensity equation developed by Byram (1959), and secondary outputs are derived from a simple elliptical fire growth model (e.g., Van Wagner 1969).

Inputs

(a) Fuel Types - The FBP System has 16 general fuel types (including 7 coniferous, 1 deciduous, 4 mixedwood, 3 slash, and 1 open or grass type) which represent most, but not all, of the major fuel types found in Canada (see Table 1). A poster with representative photographs of each fuel type is also available (De Groot 1992).

(b) Weather - The FBP System uses the Fine Fuel Moisture Code (FFMC), the Initial Spread Index (ISI) and the Buildup Index (BUI) from the FWI System (Van Wagner 1987). These indexes are considered weather inputs because they are calculated from observations of temperature, relative humidity (RH), wind speed and precipitation. The FBP System can also use detailed (e.g., hourly or time of day) observations or forecasts of wind speed (km/h) and wind direction.

(c) Topography - Percent slope and aspect are necessary inputs when the effects of topography on fire behavior are considered. Percent slope directly impacts on the rate of fire spread and the interactive effect of the slope direction (i.e., aspect) and the wind direction are used to predict fire spread direction.

(d) Foliar Moisture Content - The FMC influences calculations related to the prediction of crown fire involvement for coniferous and mixedwood fuel types. It also influences crown fire rate of spread in the Conifer Plantation (C-6) fuel type. The percent foliar moisture content (FMC) is computed using the latitude (°N), longitude (°W), elevation (m) above mean sea level, and the date. Within the FBP System the FMC can vary between 85% and 120%, with the minimum FMC usually occurring between mid-May and mid-June.

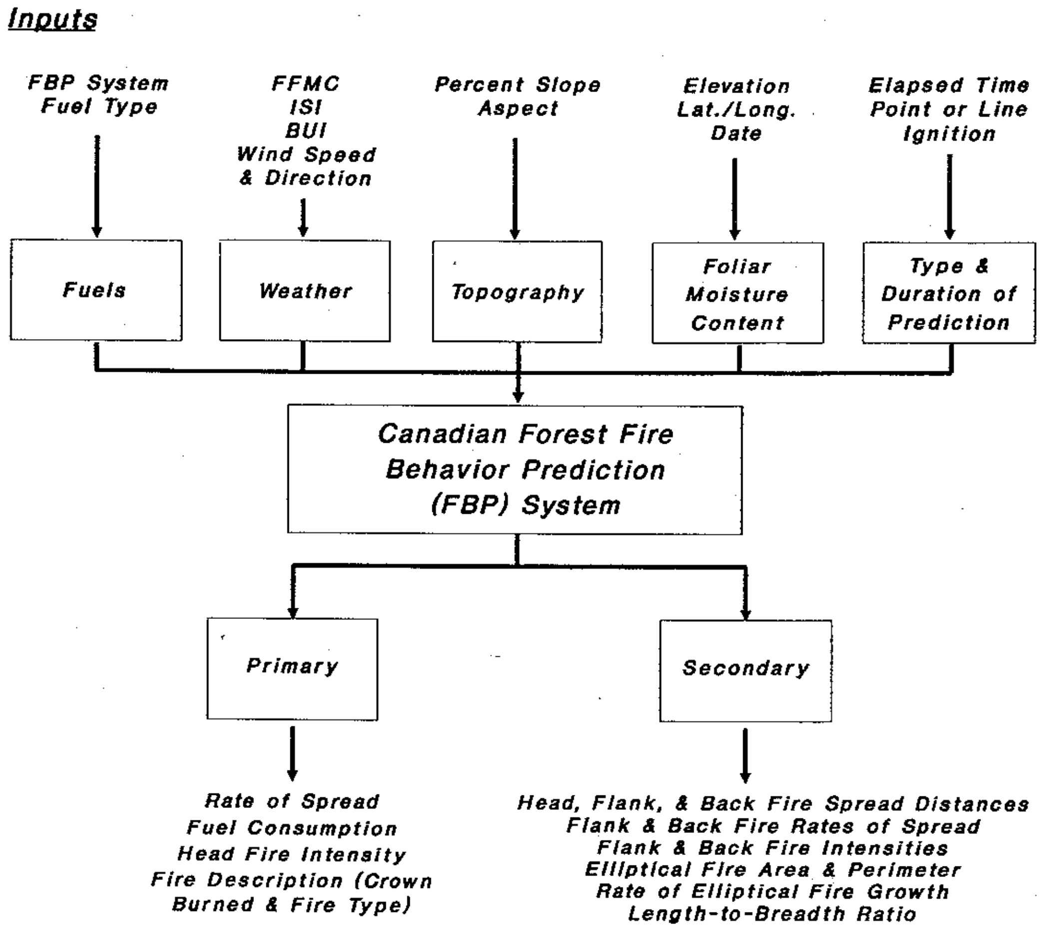

Figure 2. Structure of the Canadian Forest Fire Behavior Prediction (FBP) System (adapted from Forestry Canada Fire Danger Group 1992).

(e) Type and Duration of Prediction - The FBP System allows for two different types of fire behavior predictions depending on whether or not the fire has reached its equilibrium rate of spread. A point source prediction is used for a fire that is in its early stages of fire growth and is still accelerating. A prediction for a line ignition fire is used when a fire has already reached its steady-state rate of spread. For example, a point source prediction would be used for a fire started from a match, campfire, lightning strike, or spot fire occurring a large distance ahead of a spreading fire. On the other hand, a line ignition prediction would be used when a wind shift occurs on a large fire causing the flank fire to become the head fire.

Duration of the prediction or the elapsed time (in minutes) determines the fire behavior characteristics of an accelerating fire starting from a point ignition. It is also necessary for the calculation of many of the fire size components of the secondary outputs.

Outputs

(a) Primary - Three of the four primary outputs in the FBP System (Figure 2) relate directly to Byram's fire intensity equation (Byram 1959). They are rate of spread (m/min), fuel consumption (kg/m^2), and head fire intensity (kW/m). The fourth primary output, fire description, has 3 categories: surface fire, intermittent crown fire, and continuous crown fire. They are defined by the degree of crown involvement or crown fraction burned (Table 2).

Table 2. Fire Description categories used in the FBP System.

Fire type	Crown fraction burned[a]
Surface fire	≤0.1
Intermittent crown fire	0.1-0.89
Continuous crown fire	≥0.9

[a] Crown Fraction Burned (CFB) refers to the proportion of tree crowns in a given area that are involved in the fire.

(b) Secondary - The 11 secondary outputs (Figure 2) are based on the assumption that a fire will grow in an elliptical shape if fuels, weather and topographic conditions remain relatively constant. The secondary outputs and their common units are:
   - Head, flank and back fire spread distances (m),
   - flank and back fire rates of spread (m/min),
   - flank and back fire intensities (kW/m),
   - elliptical fire area (ha),
   - elliptical fire perimeter (m),
   - rate of elliptical perimeter growth (m/min), and
   - elliptical length-to-breadth ratio.

PRINCIPAL CALCULATION PROCEDURES

To produce a fire behavior prediction, the FBP System uses a variety of theoretical and empirical models. It is sufficiently complex that a computer is required in order for all of the FBP System outputs to be calculated. Therefore, understanding why and how a specific calculation is made is crucial to the effective use of the FBP System. A summary of the principal calculation procedures is given below and a more detailed discussion is provided in Forestry Canada Fire Danger Group (1992).

(a) Fire Site FFMC and ISI - The time of day adjusted FFMC and resulting ISI can be calculated using three different methods. Each method requires a different type and amount of information which affects the representativeness of the indexes.

(b) Rate of Spread (ROS) - The ROS is based on the fire site ISI value and can be adjusted for the steepness of a slope, the interaction between slope direction and wind direction, and increasing fuel availability as accounted for through the BUI.

(c) Fuel Consumption - The fuel consumption calculation includes both surface fuel (i.e., down woody and forest floor material) consumption and crown fuel consumption. Surface fuel consumption is based on the BUI for most fuel types, and crown fuel consumption is dependent on the crown fuel load (foliage only) and the degree of crown involvement.

(d) Crown Fire Initiation - The FBP System uses Van Wagner's crown fire theory (Van Wagner 1977) to determine whether the crown fuel layer of a given coniferous or mixedwood stand will become involved in the fire. The theory states that there is a minimum or critical surface fire intensity value that must be exceeded for crowning to occur. Once crowning is initiated, a second assumption is made which assumes that continuous crowning will occur when the critical surface fire rate of spread (which corresponds to the critical surface fire intensity) is exceeded by a value of 10 m/min.

(e) Fire Intensity - The FBP System predictions of fire intensity are modeled after Byram's (1959) fire intensity equation as follows:

$$I = 300 \times FC \times ROS \qquad [1]$$

where I = predicted fire intensity (kW/m),
FC = predicted weight of fuel consumed per unit are in the active fire front (kg/m^2),and
ROS= predicted rate of forward spread (m/min).

Note that the constant value of 300 is derived by dividing an assumed standard value of 18,000 kJ/kg for the low heat of combustion by 60, allowing ROS to be expressed in m/min rather than m/sec.

(f) Elliptical Fire Growth Model - A simple elliptical fire growth model is used to calculate most of the secondary outputs. For example, the prediction of the area or perimeter of a fire is simply the mathematical calculation of the area or perimeter of an ellipse.

(g) Acceleration of Point Source Fires - An acceleration period has been incorporated into fire growth projections for point source ignition fires to account for the time it takes such fires to reach their equilibrium rate of spread. For open-canopy fuel types it is assumed that a fire will achieve 90% of its equilibrium rate of spread after 20 minutes, whereas for a closed-canopy fuel type it will take between 20 and 75 minutes depending on the degree of crown involvement.

(h) Back Fire Rate of Spread - Back fire rate of spread is calculated from the wind speed and the head fire rate of spread and is independent of the length-to-breadth ratio.

(i) Grass Fuels Rate of Spread - The rate of spread in grass fuels is dependent on the degree of curing and the ISI. Grass fuels with less than 50% cured material are considered insufficient to support fire spread. Grass fuel load does not influence rate of spread but it does affect the amount of fuel consumption and therefore the fire intensity.

(j) Conifer Plantation Fuel Type - For the Conifer Plantation (C-6) fuel type, certain fire behavior characteristics, particularly rate of spread, are modeled using a physically-based rather than an empirical model (Van Wagner 1989). A rigorous dual-equation model that predicts rate of spread as a value between two bounding curves for surface fires and crown fires was developed for the typically homogeneous conifer plantation fuel type, whereas a single-equation regression model was used for the other, more variable fuel types.

OPERATIONAL USES OF THE FBP SYSTEM

The FBP System is currently being used for two primary operational activities. First, it is used by many fire management agencies in Canada for the prediction of large fire behavior. For example, fire behavior officers will often attempt to predict the rate of spread, the shape and the fire intensity of a campaign fire at different points on the perimeter so that an overhead team can develop appropriate fire suppression strategies. Second, the FBP System is used in preparedness planning systems that allow fire managers to pre-position their fire suppression resources based on the potential fire behavior. The FBP System is often an integral part of this planning process regardless of whether the preparedness system is a complex computerized fire management system (Lee and Anderson 1991; Kourtz 1984) or a more simplified manual preparedness system (Lanoville and Mawdsley 1990; De Groot 1990; Hirsch 1991).

In the future it is expected that the FBP System will also be related to other aspects of fire and resource management. For example, a strong relationship may exist between certain fire behavior characteristics (e.g., fire intensity, rate of perimeter growth, etc.) and the effectiveness of various types of fire suppression equipment and methods. Also, it may be possible to directly correlate specific fire behavior parameters to post-fire vegetative responses or certain types of environmental impacts such as smoke emissions.

CONCLUDING REMARKS

The FBP System is a systematic method for assessing fire behavior in Canada that integrates many of the major factors that are known to influence fire behavior. It is a complex, mathematical system that can be utilized by fire managers in their decision-making process. However, like any other system that attempts to simulate what occurs in the "real world", the FBP System has its limitations. For this reason, individuals that use the FBP System must not only be familiar with its inputs and outputs but they must be aware of how the system derives fire behavior predictions.

To predict fire behavior accurately requires a great deal of skill and knowledge. It is heavily dependent upon an individual's experience and their understanding of the basic principles of fire behavior. Since no model or system could ever account for all the variables that could affect a fire's behavior, the fire manager must still rely on his or her own ability to cope with unique and unusual situations. Thus, the best possible fire behavior predictions are those that are based on the systematically calculated values of the FBP System in combination with the opinions and assessments of experienced fire management personnel.

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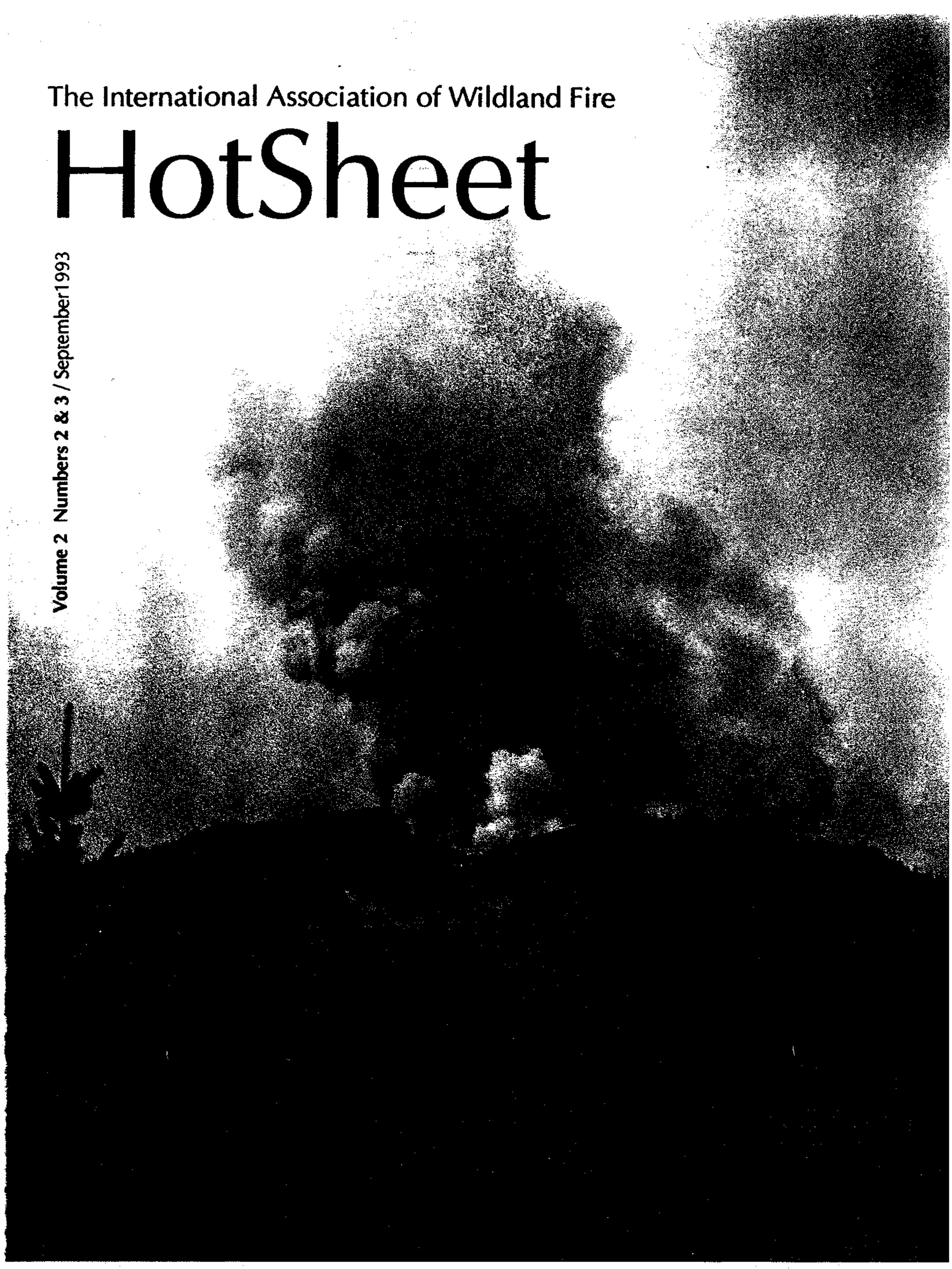

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HotSheet

Contents

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