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Canadian Forest Fire Danger Rating System: An Overview[1]

by

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Abstract

Forest fire danger rating research in Canada was initiated by the federal government in 1925. Five different fire danger rating systems have been developed since that time, each with increasing universal applicability across Canada. The approach has been to build on previous danger rating systems in an evolutionary fashion and to use field experiments and empirical analysis extensively. The current system, the Canadian Forest Fire Danger Rating System (CFFDRS), has been under development by Forestry Canada since 1968. The first major subsystem of the CFFDRS, the Canadian Forest Fire Weather Index (FWI) System, provides numerical ratings of relative fire potential based solely on weather observations, and has been in use throughout Canada since 1970. The second major subsystem, the Canadian Forest Fire Behavior Prediction (FBP) System, accounts for variability in fire behavior among fuel types (predicting rate of spread, fuel consumption, and frontal fire intensity), was issued in interim form in 1984 with final production scheduled for 1990. A third major CFFDRS subsystem, the Canadian Forest Fire Occurrence Prediction (FOP) System, is currently being formulated. This paper briefly outlines the history and philosophy of fire danger rating research in Canada discussing in detail the structure of the current CFFDRS and its application and use by fire management agencies throughout Canada.

Key words: fire danger, fire behavior, fire occurrence prediction, fuel moisture, fire danger rating system, fire management.

Résumé

La recherche sur l'évaluation des dangers d'incendie de forêt au Canada a été initiée par le gouvernement fédéral en 1925. Cinq méthodes différentes d'évaluation des dangers d'incendie ont depuis été développées, chacune permettant un nombre croissant d'applications universelles à travers le Canada. L'approche a consisté à construire d'une manière évolutive à partir des méthodes d'évaluation des dangers précédentes, tout en faisant un usage important des expériences de terrain et de l'analyse empirique. La méthode actuelle, la méthode Canadianne d'Evaluation des Dangers d'Incendie de Forêt (MCEDIF), est en développement chez Forêts Canada depuis 1968. La première sous-méthode majeure de la MCEDIF, la Méthode Canadienne de l'Indice Fort-Météo (IFM), qui produit des évaluations numériques du potentiel relatif d'incendie et ce basé uniquement sur des observations météorologiques, est utilisée à travers le Canada depuis 1970. La deuxième sous-méthode majeure, la Méthode Canadienne de Prévision du Comportement des Incendies de Forêt (PCI) qui tient compte de la variabilité du comportement du feu en fonction des différents types de combustibles (prévoyant la vitesse de propagation, la consommation du combustible, l'intensité du front de flammes), a été publiée dans une forme intérimaire en 1984, sa production finale étant prévue pour 1990. Une troisième sous-méthode majeure de la MCEDIF, la Méthode Canadienne de Prévision de la Naissance d'un Incendie de Forêt (PNI), est présentement en préparation. Ce texte souligne brièvement l'histoire et la philosophie de la recherche sur l'évaluation des dangers d'incendie au Canada, abordant en détail la structure de la MCEDIF actuelle ainsi que son application et son utilization par les agences de gestion des feux de forêt à travers le Canada.

Mots clés: danger de feu, comportement du feu, teneur en humidité du comustible, méthode d'évaluation du danger d'incendie, gestion des feux de forêt.

Introduction

The protection of life, property, and forest resources requires increasingly more effective forest fire management. A well-funded fire protection program is fundamental to insuring that investments in intensive forest management reach fruition. Fire managers require some means of judging the various elements affecting ignition potential and probable fire behavior for proper fire control and use decision making. Forest fire danger is defined as "a general term used to express an assessment of both fixed and variable factors

[1]Adapted from a paper presented by the first author on behalf of the Forestry Canada Fire Danger Group, at the Conference on Bushfire Modelling and Fire Danger Rating Systems held July 11-12, 1988, in Canberra, A.C.T., Australia, sponsored by Standing Committee of the Australian Forestry Council in cooperation with the National Bushfire Research Unit of the CSIRO Division of Forestry and Forest Products.

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of the fire environment that determine the ease of ignition, rate of spread, difficulty of control, and fire impact'' (Merrill and Alexander 1987). The process of systematically evaluating and integrating the individual and combined factors influencing fire danger is referred to as fire danger rating. Fire danger rating systems produce qualitative and/or numerical indexes of fire potential that are used as guides in a variety of fire management activities (Fig. 1). A national system

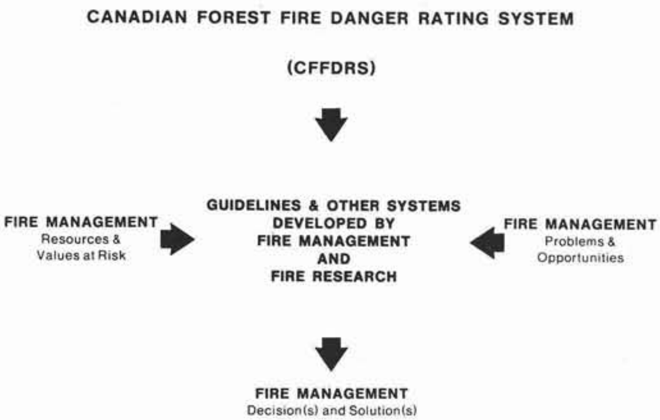

Figure 1. Conseptual framework illustrating the integral role of the Canadian Forest Fire Danger Rating System in fire management actions.

for rating fire danger has been under development by Forestry Canada (formerly Candian Forestry Service) for a number of years, and while developments in the Canadian Forest Fire Danger Rating System (CFFDRS) are expected to continue, its current status and projected structure are presented in this article.

Brief Historical Perspective

Research on forest fire danger rating was initiated in Canada by J.G. Wright in 1925 when he developed a practical research program to investigate the relationship between weather, fuel moisture, and fire behavior (Van Wagner 1987d). Over the next several decades Wright, his primary colleague H.W. Beall, and other successors, developed four different fire danger rating systems which were gradually accepted and widely applied across Canada. A more detailed account of this period is given elsewhere (e.g., Beall's foreword in Canadian Forestry Service 1987 and Service Canadien des Forêts 1987; Van Wagner 1987a,b).

During this period, fire research field stations were established for varying lengths of time across the country from Newfoundland to British Columbia. The primary goal was to investigate the fundamental relationships between the weather elements and fuel moisture, and fuel moisture and fire behavior in important forest fuel types, through the use of field test fires. In reviewing early fire danger research in Canada, two concepts are worth emphasizing. First, the development process was one of evolution in which certain features, even though modified, were retained from system to system. Second, there was a trend toward simplification, both in required weather measurements and in the method of calculation.

Current System Structure and Development

The CFFDRS has been under development by the Forestry Canada (ForCan) since 1968, when ForCan adopted a modular approach to a new national system of fire danger rating. When complete, the CFFDRS will consist of four modules or subsystems: the now familiar Canadian Forest Fire Weather Index (FWI) System, the recently introduced Canadian Forest Fire Prediction (FOP) System and the incomplete Accessory Fuel Moisture System (Fig. 2). The CFFDRS is being documented in a series of reports, in English and French, issued by the national headquarters of ForCan.

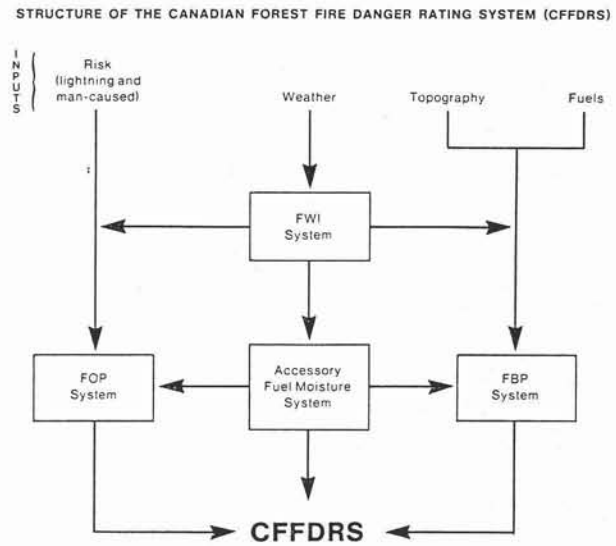

Figure 2. Simplified structure diagram for the Canadian Forest Fire Danger Rating System.

A CFFDRS ''Users' Guide'' has been produced recently that houses all national publications and associated material documenting the technical aspects of the system, including a bibliography[7] of over 300 references (Canadian Forestry Service 1987; Service Canadien des Forêts 1987). Also provision has been made for the inclusion of pertinent regional items related to the System's operational use (e.g., Canadian Forestry Service 1971; Alexander 1983). The CFFDRS is not complete at this stage and, in future years, new component and interpretive publications will be incorporated within the Users' Guide as they are developed, and outdated publications will be revised as necessary.

Canadian Forest Fire Weather Index System

By the late 1960s fire management agencies in Canada had become more sophisticated and were making increasing demands on regional fire danger rating systems developed in the mid-1950s. In response to these demands, ForCan fire researchers began work on a national system for rating fire danger. The result was the Canadian Forest Fire Weather Index (FWI) System, issued provisionally in 1969, the first subsystem of the CFFDRS. Subsequent editions appeared in 1970, 1976, 1978 and 1984. The FWI System is more complex than its predecessors, retaining the best features of earlier systems, but incorporating new components where necessary. The solid link with past systems remains intact.

The FWI System consists of six components that individually and collectively account for the effects of fuel moisture

[7]Alenxander, M.E. 1986, Bibliography on the Canadian Forest Fire Danger Rating System: 1969-85 (with 1986 and 1987 supplements). Can. For. Serv., North, For. Cent., Edmonton, Alta. Study NOR-5-05 File Rep. No. 12. also available in French co-authored with G.P. Delisle).

and wind on fire behavior. The three fuel moisture codes, the Fine Fuel Moisture Code (FFMC), the Duff Moisture Code (DMC), and the Drought Code (DC), are numerical ratings of the fuel moisture content of fine surface litter, loosely compacted duff of moderate depth, and deep compact organic matter, respectively. The three fire behavior indexes, the Initial Spread Index (ISI), the Buildup Index (BUI), and the Fire Weather Index (FWI) component itself, are intended to represent rate of fire spread, fuel available for combustion, and frontal fire intensity.

The FWI System components depend solely on daily measurements of dry-bulb temperature, relative humidity, a 10-m open wind speed, and 24-h cumulated precipitation recorded at noon local standard time. A CFFDRS weather manual published earlier (Turner and Lawson 1978a, b) is currently being revised for publication in the national series of CFFDRS reports for inclusion in the Users' Guide. Codes and indexes may be calculated from tables (Canadian Forestry Service 1984; Service Canadien des Forêts 1984) or from a computer program (Van Wagner and Pickett 1985a, b; McAlpine 1987). Since the FWI System depends solely on weather readings, it can just as easily be calculated from forecast weather to yield a fire danger forecast (e.g., Raddatz and Atkinson 1982).

The three moisture codes are in fact bookkeeping systems that add moisture after rain and subtract some for each day's drying (i.e., today's moisture code is dependent on yesterday's value and present weather). The three fuel moisture codes are expressed on scales related to actual fuel moisture (Van Wagner 1987a, b). Because the three codes react at different rates, timelags, and rain amounts required for saturation of the representative fuel layer, any one of them may be high or low in contrast to the others. For example, two or three good days drying following a heavy rain would produce a high FFMC while the DMC remains low. Conversely, a light rain after a long dry spell will result in a low FFMC while the DMC remains high. Finally, the DC may rise or fall slowly while the FFMC and DMC fluctuate many times.

The three fuel moisture codes plus wind are linked in pairs to form two intermediate indexes and one final index of fire behavior. The ISI, which combines the effects of wind and the fine fuel moisture content represented by the FFMC, represents a numerical rating of fire spread rate without the influence of variable fuel quantity. Because the ISI is dependent solely on weather, actual rate of spread (ROS) can be expected to vary from one fuel type to another over the range of the ISI because of differences in fuel complex characteristics and wind exposure. The BUI, which combines the DMC and DC, represents a numerical rating of the total fuel available for combustion. The BUI was constructed so that when the DMC is near zero the DC would not affect daily fire danger (except for smouldering potential) no matter what the level of DC (i.e., when the DMC is near zero, so is the BUI, no matter what the DC value). The FWI, which combines the ISI and BUI represents a relative measure of the potential intensity of a single spreading fire in a standard fuel complex (i.e., a mature pine stand) on level terrain (Alexander and De Groot 1988). Jack pine and lodgepole pine forest types form a more or less continuous band across Canada (Rowe 1972) so that the concept of a standardized fuel type is reasonably valid.

The FWI is a good indicator of several aspects of fire activity and is best used as a measure of general fire danger for administrative purposes. However, it is impossible to communicate a complete picture of daily fire potential in a single number. The subsidiary components of the FWI System need to be examined as well for proper interpretation of the effects of past and present fire weather on fuel flammability. Each component of the FWI System conveys direct information about certain aspects of wildland fire potential. For example, we know that fires are not likely to spread in surface litter with a FFMC less than about 74, the duff layer does not contribute to frontal fire intensity until the DMC reaches 20, and ground or sub-surface fire activity tends to persist at DC values greater than 400.

The FWI scale is uniform across Canada, but the range of fire weather varies greatly, with the result that each major jurisdiction in the country has developed its own qualitative fire danger classification scheme (Table 1 and Fig. 3). Classes (e.g., Extreme) are derived from regional cumulative frequency distributions of FWI System components, with class limits derived systematically.

Subsequent to the introduction of the FWI System, the analysis of many years of fire weather and fire report information from across Canada showed strong correlations between fire activity (i.e., fire occurrence and area burned) and increasing severity of fire weather as reflected by the components of the FWI System. As a result, System components are well suited to administrative presuppression planning. Studies undertaken in Ontario, Alberta, and British Columbia, analyzing many years of fire weather and fire report information, showed strong correlations between various measures of fire business and an increasing severity of fire weather as reflected by the component codes and indexes

Table 1. The fire danger classification schemes used in Canada, excluding British Columbia, during the 1988 fire season. The numerical class limits associated with the descriptive terms are based on Fire Weather Index (FWI) component values.

Fire danger class	Yukon	Northwest Territories	Alberta	Saskatchewan and Manitoba	Ontario	Quebec	New Brunswick and Prince Edward Is.	Nova Scotia	Newfoundland
Nil or very low	0.1	—	—	—	—	—	—	—	—
Low	2–5	0–4	0–4	0–5	0–3	0–4	0–1	0–1	0–3
Moderate	6–12	5–12	5–10	6–16	4–10	5–10	2–8	2–8	4–7
High	13–18	13–18	11–18	17–30	11–22	11–20	9–15	9–21	8–14
Very High	19–24	19–24	19–29	—	—	—	16–21	—	15–20
Extreme	25+	25+	30+	31+	23+	21+	22+	22+	21+

Source: Alexander, M.E. 1982. Canadian Forest Fire Danger Rating System: an overview. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Study NOR-5-191 File Rep. No. 2. 10 p.

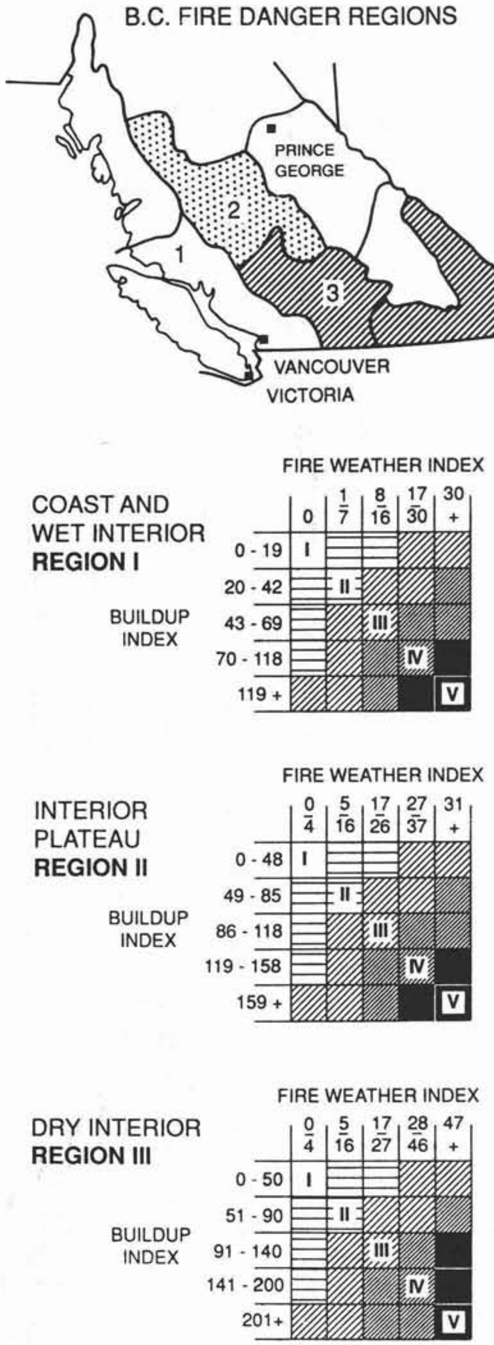

Figure 3. The fire danger classification scheme used in British Columbia during the 1988 fire season (adapted from BC Ministry of Forests 1983). The numerical class limits associated with the five levels in each 'Danger Region' are based on component

of the FWI System. Two obvious examples are the strong relationship between man-caused fire occurrence and the FFMC, and a high correlation between area burned and the ISI (Turner 1973; Stocks 1974; Kiil et al. 1977). The FWI is a good indicator of a variety of aspects of fire activity and is best used as a measure of general fire danger. An overview of FWI severity rating and its application can be found elsewhere (Harvey et al. 1986)

FWI System components and their values have different interpretations in different fuel types, because the System was developed to represent fire behavior in a generalized, standard fuel type. Fire behavior variation with fuel type is addressed by the second major subsystem of the CFFDRS, the FBP System.

Canadian Forest Fire Behavior Prediction System

While the first subsystem of the CFFDRS was being developed in the late 1960s, ForCan fire researchers were already working on the second subsystem, now known as the FBP System. The FBP System was onceived as a series of quantitative fire behavior models for major Canadian fuel types. The FBP System was released in 1984, in interim form[8], to: (1) avoid any further delay in transmittal of the existing information on quantitative prediction of fire spread and growth, and (2) allow field testing and evaluation by fire management agencies prior to formal publication of the complete version of the FBP System in 1990.

Philosophically, the FBP System reflects the long-established ForCan approach to fire behavior research. Field documentation of readily measured variables on experimental fires in natural forest stands (e.g., Lawson 1973; Quintilio *et al.* 1977, 1989; Stocks 1987a, 1987b, 1989; Alexander *et al.* 1989) and clear-cut logging slash (e.g., Stocks and Walker 1972), followed by analysis of the data using simple mathematical models and correlation techniques, are the basis of the ForCan approach. Well-documented prescribed fires and wildfires (e.g., Alexander and Lanoville 1987) 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 provides the models and framework by which field data are analyzed and explained. While the FBP System is empirically based in part, it nevertheless remains a defensible "holding action" until an accepted physically based model for predicting fire behavior is developed. Such a model remains a continuing research challenge.

When complete, the FBP System will consist of four primary components (rate of spread, fuel consumption, frontal fire intensity and type of fire) and three secondary components (fire spread distance, elliptical fire area and perimeter length). In the ROS component, ISI is the primary input variable, along with fuel type and topographic slope. The output is forward, linear, head fire rate of spread on level terrain under equilibrium conditions (units: m/min or km/h). Predicted spread rates are therefore intended to apply to fires that have grown to the point where they are in equilibrium with their environment. Crowning and spotting, and their effect on overall spread rate, are automatically taken into account. The ROS can be adjusted for the mechanical effects of slope steepness (Van Wagner 1977b, 1988). The form of the ROS equations was selected by trial and judgment, with special emphasis on the fit at low ISI values and on the principal that, in the absence of firm data, rate of spread tends to level off at high ISI values. Crowning thresholds were identified for appropriate fuel types, based on informal experience.

Fuel types in the FBP System are described in qualitative rather than quantitative terms. Stand structure and composition, surface and ladder fuels, forest floor cover and the

[8]Alexander, M.E., Lawson, B.D., Stocks, B.J. and Van Wagner, C.E. 1984. User guide to the Canadian Forest Fire Behavior Prediction System: rate of spread relationships. Interim edition. Environ. Can., Can. For. Serv., Ottawa, Ont. 73 p. + Supplements. [First printing July 1984; revision and second printing Sept. 1984.]

organic layer are described with emphasis on properties of importance to fire behavior. Terminology is used that 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 the fuel complex of concern to one of the 16 fuel types provided; no provision is made for adjusting ROS for a fuel type that has characteristics between the discrete fuel types provided. Fuel types will be illustrated with representative color photographs and a composite wall poster (e.g., De Groot 1987; Hirsch 1988a). The number of fuel types currently recognized in the FBP System reflects the amount of empirical fire behavior data available in Canada (the current FBP System data base contains more than 400 fire observations). Eventually other important fuel types will be added as further experimental burning projects are completed. Fire managers must rely upon the fuel type descriptions to equate FBP System fuel types to existing forest inventory/site classification schemes (De Groot 1988), including the production of FBP System fuel type maps.

Fuel consumption (FC)/BUI relationships for the FBP System fuel types are currently under development based primarily on data gathered from experimental and operational prescribed fires. Predicted frontal fire intensity (FFI) (Alexander 1982) will be calculated from the computed ROS and FC (units: kg/m2 or t/ha) for each FBP System fuel type. The type of fire will also be specified (e.g., surface, crown) based on more objective criteria for determining crown fire spread (Van Wagner 1977c). In addition, fire suppression interpretations associated with the FFI component (unit: kW/m) will be offered (e.g., Alexander and De Groot 1988; Alexander and Lanoville 1989). A standard computer program for the FBP System is also under development.

The 1984 interim edition of the FBP System included procedures for projecting fire growth from a single ignition point (McAlpine 1986). Fire area and perimeter calculations are derived from a simple elliptical fire growth model that utilizes the predicted ROS, elapsed time since ignition, 10-m open wind speed and fuel type group. The fire size and shape computations are described in detail elsewhere (Alexander 1985). A method of adjusting the predicted forward spread distance for acceleration from a point ignition is also being investigated (McAlpine 1988).

The general response to the 1984 interim edition of the FBP System has been positive. Excellent results with the system have been reported. Verifiable after-the-fact predictions have shown quite acceptable agreement between observed versus predicted values given the resolution of the inputs (e.g., Stocks and Flannigan 1987; Stocks 1988; Hirsch 1989).

Canadian Forest Fire Occurrence Prediction System

The development of a Canadian Forest Fire Occurrence Prediction (FOP) System, as shown in Figure 2, is currently under consideration. The fire occurrence prediction subsystem in the CFFDRS is envisioned as a national framework consisting of both lightning and man-caused fire components. Several approaches to predicting area- specific numbers of lightning and man-caused fires, that rely in one way or another on the FWI System components are now being used on an operational and/or experimental basis in several Canadian provinces (e.g., Kourtz 1984; Martell *et al.* 1987).

Accessory Fuel Moisture System in the CFFDRS

The primary role of the Accessory Fuel Moisture System in the CFFDRS (Fig. 2) is to supplement or support special applications and requirements of the three major systems. The Accessory Fuel Moisture System is currently incomplete and will remain so for some time, given the variety of fuel situations and fire danger rating requirements in Canada. This subsystem is intended to include: (1) fuel-specific moisture codes not represented by the standard fuel moisture codes in the FWI System, such as cured grass, exposed ground lichen, roundwood slash and deciduous leaf litter (e.g., Van Wagner 1987c), and (2) corrections/adjustments for landform characteristics, latitude, season (e.g., live surface vegetation and spring foliar moisture content effects), time of day, etc. An example of the latter is the hourly version of the FFMC (Van Wagner 1977a).

Fire Management Applications

The CFFDRS remains one of the few nationally-implemented fire danger rating systems in the world. This fact is testimony to the quality of fire research and the technology transfer efforts of ForCan (Kiil *et al.* 1986). Daily calculations of CFFDRS components are made from data recorded at more than 1 000 weather stations throughout Canada. The level of CFFDRS application in fire management varies with the user agency (Fig. 1). The agency mandate, scope of the problem, size and operating budget of the organization, and land area to be managed, all contribute to the sophistication of CFFDRS application. Some of these uses are:

- fire behavior training;
- prevention planning (e.g., informing the public of impending fire danger, regulating access and risk associated with public and industrial forest use);
- preparedness planning (level of readiness and pre-positioning of suppression resources);
- detection planning (e.g., lookout manning and aircraft routing);
- initial attack dispatching;
- suppression tactics and strategies on active wildfires; and
- prescribed fire planning and execution.

Relevant examples illustrating these wildfire and prescribed fire management applications of the CFFDRS can be found in BC Ministry of Forests and Lands (1983 and 1987), Gorley (1985), Lawson (1977), Gray and Janz (1985), Lanoville and Mawdsley (1989), Martell et al. (1984), Ontario Ministry of Natural Resources (1984), Hirsch (1988b) Martell (1978), and Muraro (1975). Prescribed fire applications of quantitative fire behavior prediction in the context of the CFFDRS are limited, since ignition patterns influence the resulting fire behavior and impact (Hawkes and Lawson 1986). However, other components of the CFFDRS dealing with fuel moisture relations are directly applicable to the safe and effective use of prescribed fire (e.g., Chrosciewicz 1978; McRae 1985). Quantitative fire behavior predictions in fuel types adjacent to treatment areas are an important part of prescribed fire planning for prevention and control of escaped fires.

Conceptually, the CFFDRS deals with the prediction of fire behavior from point-source weather measurement (i.e., a single fire weather network station). The System deals primarily with variation in weather from day to day, but will accomodate diurnal variation as well. The System does not account for spatial variation in weather elements between

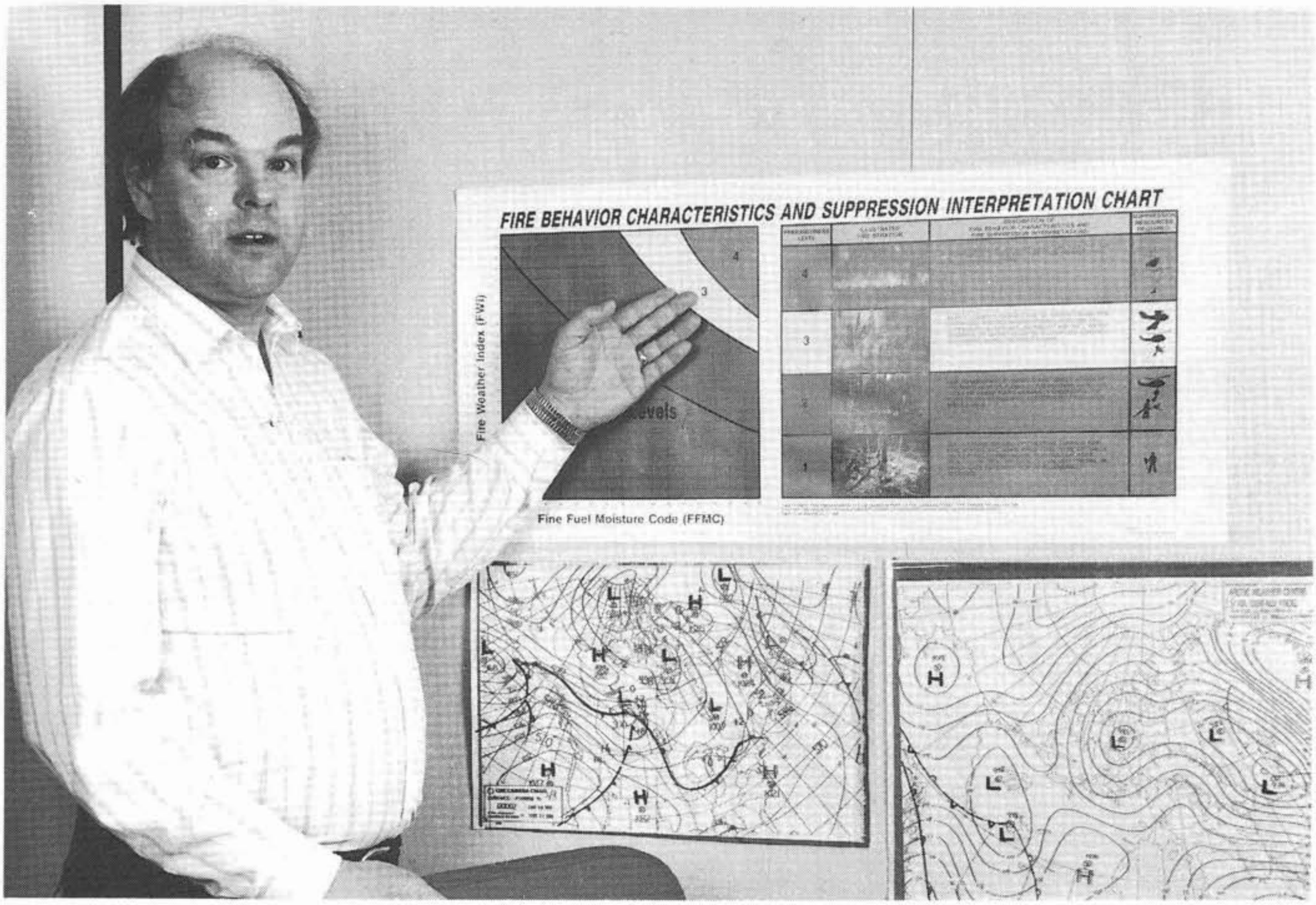

Figure 4. Fire management staff in the Northwest Territories have developed an initial attack preparedness system which is based to a large extent on the Canadian Forest fire Danger Rating System.

points of measurement; such interpolation must be handled by models and guidelines external to the CFFDRS. In operational practice, fire weather and fire danger forecasting procedures have been devised to integrate point-source measurement of CFFDRS components over time and space. Spatial variation in fuels and terrain is a fire management information problem not easily handled by a fire danger rating system unless linked to a geographic information system (GIS) which stores, updates, and displays land base infromation in ways directly usable by the fire manager (Feunekes and Methven 1988). Computer-based information systems for fire management are under development in many regions of Canada. Fire management decision support systems exploit technological advances in computerized information handling, remote automatic collection and transmission of fire weather data, automatic lightning detection and recording networks (e.g., Kourtz 1984). These support systems depend on the CFFDRS to integrate the various information elements, providing the user with real-time fire occurrence and behavior prediction capability.

New approaches to the development and implementation of decision-aids, such as artificial intelligence (AI) and expert systems, will become more prominent in the field of fire management information systems (e.g., Kourtz 1987), but it is certain that outputs from the CFFDRS will become part of any new knowledge-based system. Close interaction among workers in both these research and development fields is required for the most effective progress.

Future Developments

The responsibility for continued development of the CFFDRS rests with the ForCan Fire Danger Group, which presently consists of one or more representatives from each of the four CFS establishments maintaining a fire research program. This group maintains liaison with regional, national and international fire organizations, committees and agencies, including annual reporting to the Canadian Committee on Forest Fire Management (the national body responsible for advising the Government of Canada on fire research needs), to ensure research, development and application of the CFFDRS continues in a timely and relevant manner.

The recent expansion of the CFFDRS provides Canadian fire managers with site-specific fire behavior information for a number of important fuel types. Continued monitoring and documentation of wildfires by user agencies will verify existing relationships (e.g., Hirsch 1989) and provide key information for new model development. Further additions and improvements to the System will require continued research and testing, but feedback from the field also contributes to the development of the System. Effective use of quantitative fire behavior prediction and probabilistic fire occurrence prediction requires improvements in fire weather forecasting, fire weather data collection and information- handling capability. The CFFDRS will continue to evolve in future years to reflect the needs of fire management agencies and the result will be demonstrable progress in improving the effectiveness of fire management in Canada.

Completion of the goals now envisioned for the CFFDRS will mark the end of a major phase in the System's development; however, the system will never be finished, as this type of decision-aid system requires continuous revision and updating. Fire management agencies will expand their application and training programs based upon advances in the CFFDRS.

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