Systems for Rating Fire Danger and Predicting Fire Behavior Used in Canada[1]

By T.A. Van Nest[2], M.E. Alexander[3]

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 the federal forestry service in Canada since 1968. The CFFDRS presently consists of two major subsystems. The Canadian Forest Fire Weather Index (FWI) System, provides numerical ratings of relative fire potential for a standard fuel type on level terrain based solely on weather observations, and has been used throughout Canada since 1970. The Canadian Forest Fire Behavior Prediction (FBP) System, accounts for variability in fire behavior amongst fuel types for a given slope steepness in quantitative and descriptive terms based on certain FWI System components as inputs. The FBP System was released in interim form in 1984 with final production completed in 1992. This paper provides a brief overview of these systems and their application in Canadian fire management, including a comparison of some of their U.S. counterparts. A selected bibliography is attached.
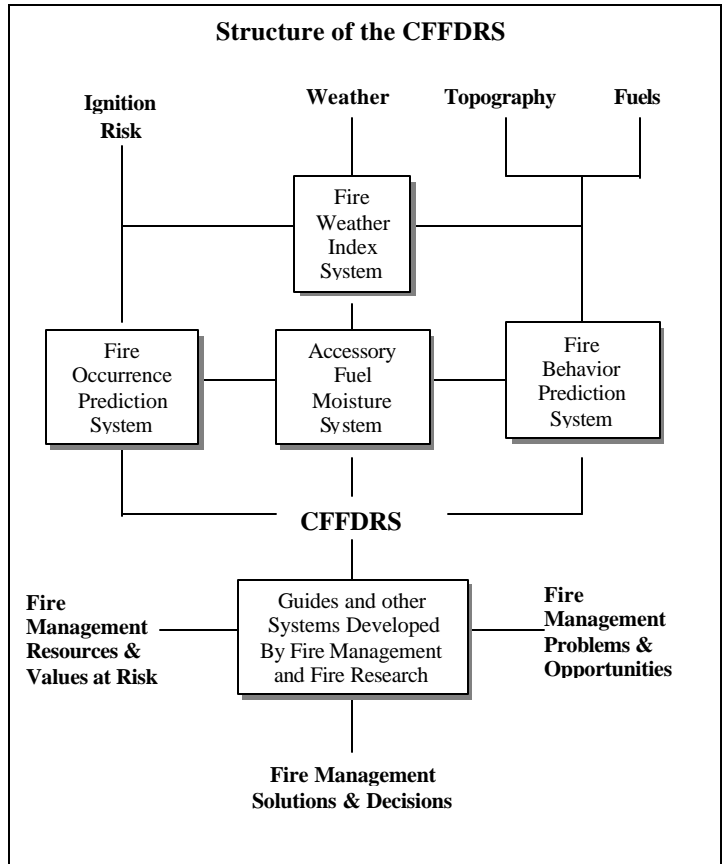

Figure 1 - Simplified structure diagram for the Canadian Forest Fire Danger Rating System (CFFDRS) illustrating the linkage to fire management actions.

[2]Senior Fire Management Instructor, Alberta Environmental Training Centre, 1176 Switzer Drive, Hinton, Alberta T7E 1V3. E-mail: Terry.VanNest@gov.ab.ca

[3] Senior Fire Behavior Research Officer, Canadian Forestry Service, Northern Forestry Centre, Edmonton, Alberta T6H 3S5. E-mail: malexand@nrcan.gc.ca

Introduction

The protection of life, property and natural resources from wildfires requires increasingly effective forest fire management. For effective decision making fire managers require some means of reliably evaluating and integrating the individual factors influencing fire danger – a fire danger rating system. The federal government in 1925 initiated forest fire danger rating research in Canada. Since that time, five different fire danger rating systems have been developed, each with increasing national applicability. The approach has been an evolutionary process, building on previous systems and using field experiments and empirical analysis extensively. Canada's current method of fire danger assessment is known as the Canadian Forest Fire Behavior Danger Rating System (CFFDRS), which took shape in the 1960s when the Canadian Forest Service (CFS) envisioned a modular design for a national fire danger rating system. The CFFDRS currently comprises two major subsystems, namely the Fire Weather Index (FWI) System and the Fire Behavior Prediction (FBP) System.

Weather Input in Fire Danger Rating

The first phase in the development of the national fire danger rating system, the FWI System, provides for the assessment of relative fire potential based solely on weather observations. This has now been in operational use for 25 years.

The FWI System's six components individually and collectively account for the effects of fuel moisture and wind on ignition potential and probable fire behavior in the form of relative numerical ratings.

Three fuel moisture codes reflect the fuel moisture content of fine surface litter (Fine Fuel Moisture Code — FFMC); loosely compacted duff of moderate depth (Duff Moisture Code — DMC); and deep compact organic matter (Drought Code — DC), respectively. The codes are in fact dynamic book-keeping systems that account for each day's precipitation and drying.

The fuel moisture codes plus wind are linked in pairs to form two intermediate and one final index of fire behavior. The Initial Spread Index (ISI) combines the effects of wind and fine fuel moisture content (FFMC). It represents a numerical rating of fire spread rate, without the influence of variable fuel quantity. The Buildup Index (BUI — based on the DMC and DC) represents a measure of the total fuel available for combustion.

The Fire Weather Index (FWI) component itself combines the ISI and BUI to indicate the potential intensity of a fire on level terrain in a stand of mature pine. Because jack pine and lodgepole pine forests form a more or less continuous band across Canada, the concept of a standardized fuel type is reasonable.

FWI System components depend solely on daily measurements of: dry-bulb temperature, relative humidity, a 10-metre open wind speed and 24-hour
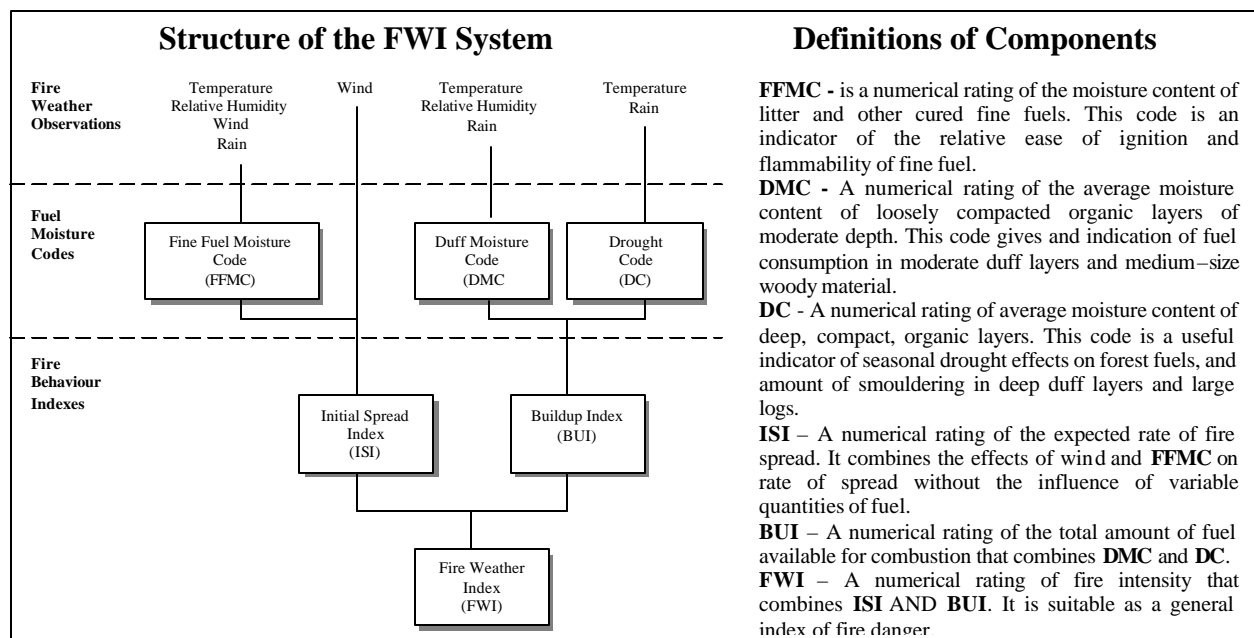

Structure of the FWI System

Definitions of Components

FFMC - is a numerical rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and flammability of fine fuel.

DMC - A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives and indication of fuel consumption in moderate duff layers and medium–size woody material.

DC - A numerical rating of average moisture content of deep, compact, organic layers. This code is a useful indicator of seasonal drought effects on forest fuels, and amount of smouldering in deep duff layers and large logs.

ISI – A numerical rating of the expected rate of fire spread. It combines the effects of wind and **FFMC** on rate of spread without the influence of variable quantities of fuel.

BUI – A numerical rating of the total amount of fuel available for combustion that combines **DMC** and **DC**.

FWI – A numerical rating of fire intensity that combines **ISI** AND **BUI**. It is suitable as a general index of fire danger.

Figure 2 - Structure of the Canadian Forest Fire Weather Index (FWI) System and component definitions.

accumulated precipitation, recorded at noon local standard time. Because calculation of the components depends solely on weather readings, they can just as easily be calculated from forecast weather to yield a fire danger forecast.

The FWI itself 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 need to be examined as well for proper interpretation of past and current weather effects on fuel flammability.

Each component of the FWI System conveys direct information about certain aspects of wildland fire potential. For example, the FFMC is a useful indicator of human-caused ignition probability, as is the DMC for lightning-caused ignitions. The DC and the BUI are excellent indicators of smouldering combustion or fire persistence in deep compact organic layers and hence of mop-up difficulty.

Quantitative Fire Behavior Prediction

The relative numerical values of the FWI System components have different meanings in different fuel types because the system was developed to rate fire potential in a generalized standard fuel type on a relative basis as opposed to an absolute sense. Fire behavior variation with fuel type is addressed, in quantitative terms, by the FBP System.

An incomplete interim edition of the FBP System was released for field testing and evaluation in 1984, although information from experimental burning projects and wildfire investigations was issued as it became available. Fonnal publication of the system was completed in 1992 and represents the latest achievement by the CFS in the practical application of fire behavior knowledge and research experience for the general improvement of forest fire management in Canada.

The technical derivation of the FBP System rests on a sound scientific basis developed from real-world observation and measurement of numerous experimental fires, coupled with many well-documented wildfires and operational prescribed fires, correlated against the weather-based fire danger indices of the FWI System or weather parameters for discrete fuel types. The FBP System is unique in that it incorporates the most extensive crown fire data set available anywhere.

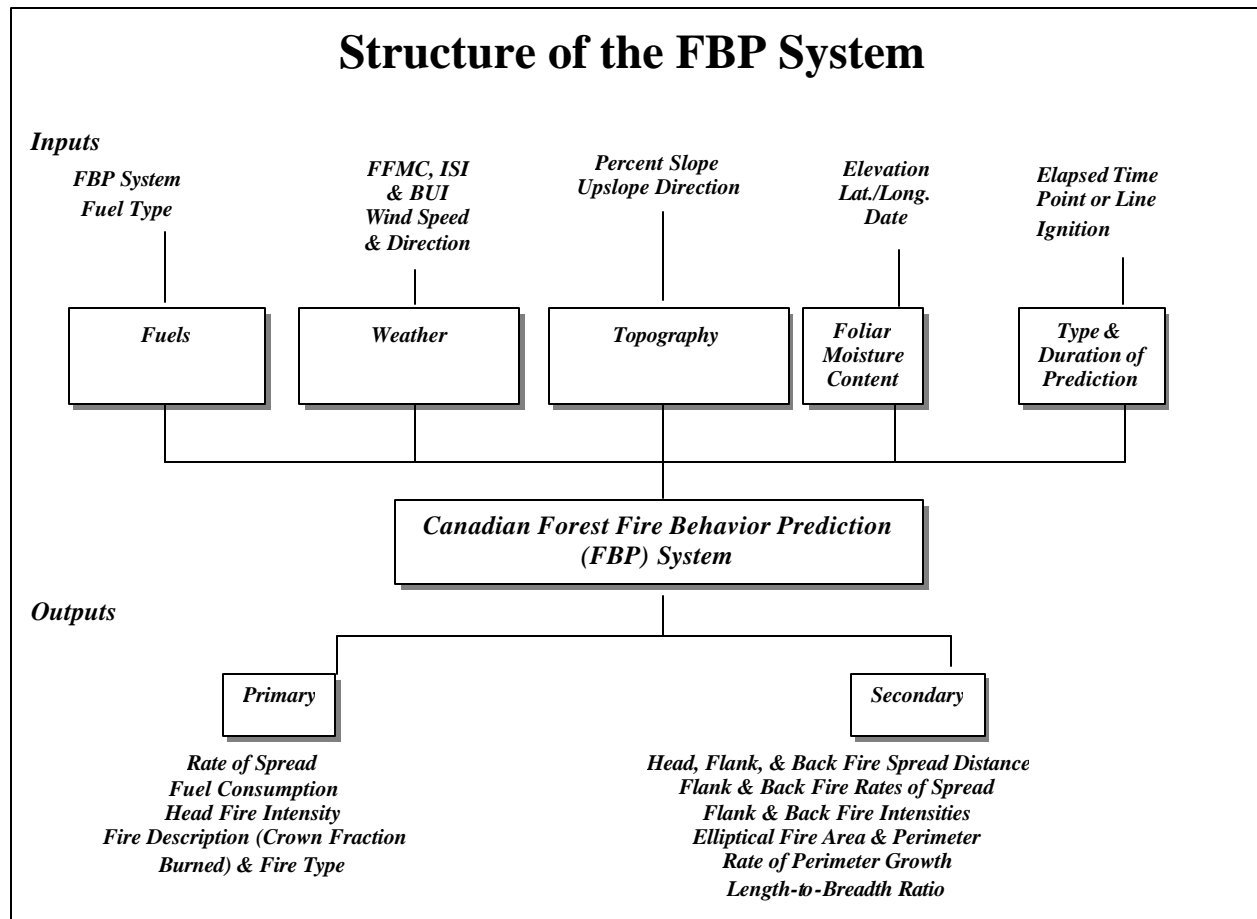The FBP System allows the user to predict the rate of

Figure 3 - Structure of the Canadian Forest Fire Behavior Prediction (FBP) System.

spread (metres/minute), fuel consumption (kilograms/square metre) and intensity (kilowatts/metre) at the head, back or flanks of fires that are still accelerating following ignition or which have reached a steady-state condition with their environment. These characteristics are determined by the prevailing fire weather severity (based on wind velocity and certain FWI System components), fuel type, slope steepness, geographical location, elevation and calendar date. A general description of the type of fire is also given (for instance, surface fire, intermittent crowning or continuous crowning). A simple elliptical fire growth model is employed in estimating the size and shape of fires originating from a single ignition source as opposed to an established line of fire.

The FBP System's operation is based on a small number of readily available inputs. At present, 16 major Canadian benchmark fuel types are recognized in the system, a reflection of the empirical fire behavior data available in Canada.

The FBP System incorporates the best available information on forest fire behavior in Canada. Canadian fire managers are therefore in a good position to predict certain fire behavior characteristics with reasonable assurance for a wide range of burning conditions and excellent results have been reported with the system. The general response to the FBP System has been very positive as reported by nation - wide surveys conducted in 1992 and 1994 by the Canadian Committee on Forest Fire Management, the national body responsible for advising the federal government on wildland fire research needs.

For field use in predicting fire behavior, the FBP System is available in tables or computer program. The table format, "Field Guide to the Canadian Forest Fire Behavior Prediction (FBP) System – 1997 edition", provides a simplified method for assessing wildland fire behavior potential. This guide is intended to assist field staff in making first approximations of FBP System outputs when computer based applications are not available. Quantitative estimates of head fire spread rate, fire intensity, type of fire, and elliptical fire area, perimeter, and perimeter growth rate are provided for sixteen discrete fuel types within five broad groupings (coniferous, deciduous, and mixedwood forests, logging slash, and grass), covering most of the major forest fuel types found in Canada. Computer based programs which provide all the outputs available from the FBP System range from FBP calculators such as the RemSoft DOS based FBP93 or Windows based FBP97 programs to more sophisticated systems linked to GIS systems. The

decision as to which computer program will be used for a specific evaluation of fire behavior normally depends on the following criteria:
- Fire prediction objectives.
- Computing capability.
- Ability to provide sufficient data to run the computer application.

Regardless of the application, operational experience has shown that the underlying FBP system will provide reasonable predictions provided that the user understands the assumptions associated with the FBP System and that reasonably reliable data is used as input for the fire behavior evaluation process. As with all prediction systems, the FBP System is intended to assist in decision-making, and is not a substitute for experience, sound judgement, or observation of actual fire behavior.

Table 1 – List of Canadian Forest Fire Behavior Prediction (FBP) System fuel types.

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	Conifer plantation
C-7	Ponderosa pine-Douglas-fir
Deciduous	
D-1	Leafless aspen
Mixedwood	
M-1	Boreal mixedwood-leafless
M-2	Boreal mixedwood-green
M-3	Dead balsam fir mixedwood-leafless
M-4	Dead balsam fir mixedwood-green
Slash	
S-1	Jack or lodgepole pine slash
S-2	White spruce-balsam slash
S-3	Coastal cedar-hemlock-Douglas-fir slash
Open	
O-1	Grass

Other Subsystems

The development of a Canadian Forest Fire Occurrence Prediction (FOP) System is currently under consideration. This subsystem is envisioned as a national framework of both lightning- and human-caused fire components. Several approaches to predicting area-specific numbers of lightning-and human-caused fires (employing one or more of the FWI System components) are now being used on an operational or experimental basis in several Canadian provinces and territories. Research studies on the fundamentals of ignition and prediction of fire

occurrence have been completed or are nearing completion.

The primary role of the CFFDRS's Accessory Fuel Moisture System (AFMS) is to supplement or support special applications and requirements of the three major subsystems. This subsystem includes fuel-specific moisture codes not represented by the standard codes in the FWI System. Other adjustments for land-form characteristics, latitude, season, time of day and other factors will also be included. Given the variety of fuel situations and fire danger rating requirements in Canada, development of the AFM System is a continuing process.

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 the CFS. Daily calculations of system components are made from data recorded at more than one thousand weather stations across Canada. Some current uses of the danger rating system include:

- 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;
- escaped fire situation analysis; and
- prescribed fire planning and execution.

The CFFDRS is also being used increasingly by other wildland fire researchers and environmental scientists for applications ranging from fire suppression effectiveness and fire growth modeling to analyses of fire regimes and potential impacts of climate change. Although the CFFDRS was designed for Canadian use, several other countries have adopted system modules and/or its research philosophy as the basis for their own system of fire danger rating, most notably New Zealand, Fiji and the State of Alaska (U.S.). Evaluations of the System have also been undertaken recently in Croatia, China, Russia, Chile and the State of Michigan (U.S.).

Decision support systems

Fire management information systems exploit advances in computerized information handling, automatic remote collection and transmission of fire weather data, and automatic lightning detection and recording networks. The value of such technologies depends, in part, on the CFFDRS to integrate the information and provide fire managers with near-real-time fire occurrence and behaviour prediction capability.

Conceptually, the CFFDRS deals with the prediction of fire potential from point-source weather measurement (i.e., a single fire weather network station). The system deals primarily with day-to-day variations in the weather, but will accommodate variations through the day as well. The system does not account for spatial variation in weather elements between 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 the system's 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 it can be linked to a computer-based geographic information system which stores, updates and displays land base information in ways directly usable by the fire manager. Geographic information systems for fire management are in use in nearly all regions of Canada. For example, the Spatial Fire Management System (SFMS), is employed by a number of provincial fire management agencies.

Basic similarities and differences between the FBP System and BEHAVE

1. **Fire environment inputs:**

   Fuels – The FBP System contains 16 fuel types while BEHAVE has 13 fuel models. BEHAVE has the option to construct "Customized" fuel models or utilize the "two fuel model concept model" (see Rothermel 1983 Manual). See "Aids to Determining Fuel Models for Estimating Fire Behavior" by Anderson (1982) publication regarding US fuel models.

   Live fuel moisture - In the FBP System, conifer foliar moisture content is estimated from calendar date, location (lat/long) and elevation. In BEHAVE, understory live moisture content (herbaceous and woody) estimates based on phenology is required for certain fuel models.

Dead fuel moisture – The FWI System fuel moisture codes are dependent on the continuity of daily weather readings. In BEHAVE, dead fine fuel moisture content (1-hr TL) is calculated from current weather observations (e.g., Temperature and Relative Humidity) plus a number of other environmental variables. In Rothermel's (1983) manual "How to Predict the Spread and Intensity of Forest and Range Fires", a simple procedure is offered for calculating the 1-hr TL fuel moisture content (approximations: 10-hr TL = 1% + 1-hr TL and 100-hr TL =2% + 1-hr TL).

Strictly speaking, the three fuel moisture codes of the FWI System (FFMC, DMC, DC) are not comparable to the 1-hr, 10-hr and 100-hr TL fuel moisture contents even though they both imply light, medium and heavy fuel. However, the 1-hr/10-hr TLs and the FFMC moisture equivalent might be considered reasonably compatible. For example, Van Wagner (1975) obtained the following simple correlation coefficients (r) from one season's weather data (r = 1.0 if there is perfect agreement).

FFMC	vs. 1-hr	TL	r = 0.56
FFMC	vs. 10-hr	TL	r = 0.74
FFMC	vs. 100-hr	TL	r = 0.71
DMC	vs. 100-hr	TL	r = 0.24

Emphasis in the Canadian System is on the forest floor layer whereas in BEHAVE the emphasis is on herbaceous and wood vegetation and dead-down round wood fuels (twigs, branches). Furthermore, there are major differences in the manner in which wetting and drying processes are considered. For example, timelag in the Canadian system is measured in daily cycles and reflects the change from one afternoon to the next and is considered to vary with weather. In the US on the other hand, timelag is viewed as a property of the fuel, to be measured under constant conditions in the laboratory, and not changing with weather. Thus, the timelags of the Canadian fuel moisture codes and the American fuel moisture contents are not compatible (Van Wagner 1975).

Topography - Both systems consider the mechanical effects of percent slope on fire behavior. BEHAVE uses basic vectoring approach for cross-slope situations. BEHAVE also allows for the influences of slope exposure on 1-hr TL computation.

Weather – Wind values used in the FBP System reflect the International standard 10-m open wind as opposed to 20-ft (6.1-in) open wind standard used in the US. To utilize wind values obtained from a US weather station in the FBP System the windspeed must be converted using the following adjustment procedure: 20-ft (6.1-m) open wind x 1.15 = 10-m open wind and to utilize wind values obtained from a Canadian weather station in BEHAVE the windspeed must be converted using the following adjustment procedure: 10-m open wind x 0.85 = 20-ft (6.1-m) open wind. In BEHAVE, the 20-ft (6.1-m) open wind must be further reduced for vegetative cover and topographic position using wind ratios or adjustment factor in order to estimate the "mid-flame" wind speed (basically the "eye-level" wind).

2. **Fire behavior outputs:**

Both systems produce estimates of rate of fire spread and intensity as well as elliptical fire area and perimeter. However, the predictions from BEHAVE are strictly speaking only applicable to surface fires whereas the FBP System considers both surface and crown fires within a given fuel type.

BEHAVE also provides an estimate of flame length as well as several other outputs but does not provide any direct estimates of fuel consumption whereas the FBP System does.

BEHAVE does not make any allowances for the affects of acceleration on point source fire growth and behavior whereas the FBP System does.

3. **Technical basis:**

The FBP System is largely empirically derived from experimental fire observations and documented wildfire runs coupled with a liberal dose of simple logic. The BEHAVE system is based on laboratory fires and physical theory

Reference Cited:
Van Wagner, C.E. 1975. A comparison of the Canadian and American forest fire danger rating systems. Can. For. Serv. Inf. Rep. PS-X-59. (Now virtually obsolete due to significant changes to both the Canadian and U.S. fire danger rating/fire behavior prediction systems since the mid 70s).

Summary of comparisons[1]

Fire behavior descriptions

FIRE BEHAVIOR	NFDRS	FWI SYSTEM	BEHAVE	FBP SYSTEM	OTHER
Ignition	Ignition Component (IC)	Fine Fuel Moisture Code (FFMC)	Probability of Ignition, P(I)	Probability of Ignition, P(I)	---
Spread	Spread Component (SC)	Initial Spread Index (ISI)	Rate of Spread (ROS)	Rate of Spread (ROS)	---
Severity	Energy Release Component (ERC)	Buildup Index (BUI)	Total Heat/Area, (H/A)	Surface & Crown Fuel Consumption, (SFC & CFC)	---
Intensity	Burning Index (BI)	Fire Weather Index (FWI)	Fireline Intensity, (FLI)	Head Fire Intensity, (HFI)	---
Spotting	---	---	Spotting Distance	Spotting Distance Incorporated into Rate of Spread	---
Extreme Fire Behavior	Interpreted Hauling Chart	Interpreted Hauling Chart	Interpreted Hauling Chart	Interpreted Hauling Chart	Haines Index, Metafire,

Fuel complex descriptions

FUEL MODELS	NFDRS	FWI SYSTEM	BEHAVE	FBP SYSTEM
Number	20	1	13 + Custom	16 Fuel Types
Grass	4 Models	---	3 Models (1, 2, and 3)	1 Fuel Type – 2 Options (O1a & O1b)
Brush	6 Models	---	4 Models (4, 5, 6, and 7)	---
Timber/Litter	7 Models	1 Stylized Mature Pine Stand Fuel Type	3 Models (8, 9, and 10)	12 Fuel Types (C1-C7, M1-M4, D1)
Slash	3 Models	---	3 Models (11, 12, and 13)	3 Fuel Types (S1-S3)

Fuel moisture description

FUEL MOISTURE	NFDRS	FWI SYSTEM	BEHAVE	FBP SYSTEM	OTHER
Fine Fuel Moisture	1hr & 10hr Fuel Moisture	Fine Fuel Moisture Code (FFMC)	1hr & 10hr Fuel Moisture	Fine Fuel Moisture Code (FFMC)	---
Duff & Litter	100hr Fuel Moisture	Duff Moisture Code (DMC)	100hr Fuel Moisture	Buildup Index (BUI)	---
Drought	1000hr, KBDI	Drought Code (DC)	---	Buildup Index (BUI)	Palmer Drought Index
Seasonal Variation	Live Fuel Moistures, Fuel Models	---	Live Fuel Moistures, Dynamic Models	Fuel Models, Foliar Moisture Content	NDVI

[1] Adapted from information on the Michigan DNR Web site

Future of the Canadian Forest Fire Danger Rating System

Fire management agencies will continue to expand their application and training programs based upon advances in the CFFDRS. The responsibility for its continued development rests with the CFS, which maintains liaison with a variety of agencies to ensure research, development and application of the system continues in a timely and relevant manner. Further additions and improvements will require continued research, testing and feedback from the field.

Effective use of fire occurrence and fire behavior prediction systems requires improvements in fire weather forecasting, data collection and information handling capability. Computerized decision aids, which include advances in artificial intelligence and expert systems, will become prominent in fire management with outputs from the CFFDRS forming an integral part of any new knowledge-based system. This much is certain - Canada's national forest fire danger rating system will evolve in future years to reflect the needs of fire management agencies. The result will be demonstrable improvement in the effectiveness of forest fire management in Canada.

Training opportunities

Although CFFDRS can be utilized without formal training, experience has shown that training on the use of the system is highly desirable. Formal training on the Canadian Forest Fire Danger Rating System is included in the following two national courses sponsored by the Canadian Interagency Fire Centre:

Advanced Wildland Fire Behavior - S590
Wildland Fire Behavior Specialist - S591

Scheduled courses are advertised on the Internet at http://www.ciffc.ca

Other training is also available on interactive CDROM under the title – "Canadian Forest Fire Behavior Prediction (FBP) System Interactive Training and Reference".

To order:
UBC Press, University of British Columbia
6344 Memorial Road
Vancouver, British Columbia, Canada V6T 1Z2
Tel: 1 (604) 822-5959, Fax: 1800-668-0821

Further information on the CFFDRS is available on the Internet at:
http://www.nofc.forestry.ca/fire/index.html

Appendix:

Selected Bibliography of Recent Publications Related to the Fire Weather Index (FWI) and Fire Behavior *Prediction (FBP) Systems of the Canadian Forest Fire Danger Rating System* (CFFDRS)

CFFDRS General:

Alexander, M.E.; Stocks, B.J.; Lawson, B.D. 1996. The Canadian Forest Fire Danger Rating System. Initial Attack 1996(Spring): 6-9. [availability: NoFC; see also www.aeronautique.bombardier.com/htmen/c6q.htm; also available in French]

Merrill, D.F.; Alexander, M.E. (eds.). 1987. Glossary of forest fire management terms. Fourth ed. Natl. Res. Counc. Can., Can. Comm. For. Fire Manage., Ottawa, Ontario. Publ. NRCC No. 26516. 91p. [availability: CIFFC; also available in French; cost $CAN 10]

McAlpine, R.S.; Stocks, B.J.; Van Wagner, C.E.; Lawson, B.D.; Alexander, M.E.; Lynham. T.J. 1990. Forest fire behavior research in Canada. Pages A.02:1-12. in: Proc. International Forest Fire Research Conference. Univ. Coimbra, Coimbra, Portugal. [availability: NoFC]

Turner, J.A.; Lawson, B.D. 1978. Weather in the Canadian Forest Fire Danger Rating System: a user guide to national standards and practices. Can. For. Serv., Pac. For. Res. Cent., Victoria, British Columbia. Inf. Rep. BC-X-177 40p. [availability: PFC; also available in French]

Experimental Fire Studies:

Alexander, M.E.; Quintilio, D. 1990. Perspectives on experimental fires in Canadian forestry research. Mathl. Comput. Modelling 13(12): 17-26. [availability: NoFC]

Alexander, M.E.; Stocks, B.J.; Lawson, B.D. 1991. Fire behavior in black spruce-lichen woodland: the Porter Lake project. For. Can., North. For. Cent., Edmonton. Alberta. INF. Rep. NOR-X-310. 44p. [availability: NoFC]

Alexander, M.E.; Stocks, B.J.; Wotton, B.M.; Lanoville, R.A., 1998. An example of multi-faceted wildland fire research: the International Crown Fire Modelling Experiment pages 83-112 in: Proc. III International Forest Fire Research Conference/14th Conference on Fire and Forest Meteorology. Univ. Coimbra, Coimbra, Portugal. [availability: NoFC; see also http://www.nofc.forestry.ca/fire/fmn/nwt/]

Quintilio, D.; Alexander, M.E.; Ponto, R.L. 1991. Spring fires in a semimature trembling aspen stand in central Alberta, For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-323. 30 p. [availability: NoFC]

Stocks, B.J.: Hartley, G.R. 1995. Fire behavior in three jack pine fuel complexes. Can. For. Serv., Great Lakes For. Cent., Sault Ste. Marie, Ontario. Poster with text. [availability: GLFC]

Wildfire Case Studies:

Alexander, M.E. 1991. The 1985 Butte Fire in central Idaho: a Canadian perspective of the associated burning conditions. Pages 334-343 in: Proc. International Symposium on Fire and the Environment: Ecological and Cultural Perspectives. USDA For. Serv., Southeast. For. Exp. Stn., Asheville, North Carolina, Gen. Tech. Rep. SE-69. [availability: NoFC]

Alexander, M.E. 1992. The 1990 Stephan Bridge Road Fire: a Canadian perspective on the fire danger conditions. Wildfire News & Notes 6(1): 6. [availability: NoFC]

Alexander, M.E.; Pearce, H.G. 1992. Follow-up to the Spokane area firestorm '91 report: what were the Canadian fire danger indices? Wildfire News & Notes 6(4); 6-7. [availability NoFC]

Alexander, M.E.; Pearce, H.G. 1993. The Canadian fire danger ratings associated with the 1991 Oakland-Berkeley Hills Fire. Wildfire News & Notes 7(2): 1,5. [availability: NoFC]

Fogarty, L.G.; Jackson, A.F.; Lindsay, W.T. 1997. Fire behaviour, suppression and lessons from the Berwick Forest Fire of 26 February 1995. N.Z. For. Res. Instit., Rotorua and Natl. Rural Fire Authority, Wellington, New Zealand. FRI Bull. No. 197, For. Rural Fire Sci. Tech. Ser. Rep. No. 3. 40 p. [availability: NZFRI]

Pearce, H.G.; Morgan, R.F.; Alexander, M.E. 1994. Wildfire behaviour case study of the 1986 Awarua wetlands fire. N.Z. For. Res. Instit., Rotorua and Natl. Rural Fire Authority, Wellington, New Zealand. Fire Tech. Transfer Note No.5. 6p. [availability: NZFRI]

Rasmussen, J.H.; Fogarty, L.G. 1997. A case study of grassland fire behaviour and suppression: the Tikokino Fire of 31 January 1991. N.Z. For. Res. Instit., Rotorura and Natl. Rural Fire Authority, Wellington, New Zealand. FRI. Bull. No. 197, For. Rural Fire Sci. Tech. Ser. Rep. No. 2. 18p. + Appendix. [availability: NZFRI]

Ignition/Smouldering Potential:

Lawson, B.D.; Armitage, O.B.; Dalrymple, G.N. 1994a. Ignition potentials for simulated people-caused fires in British Columbia's lodgepole pine and white spruce-subalpine fir forests. Pages 493-505 in: Proc. 12th Conference on Fire and Forest Meteorology. Soc. Am. For., Bethesda, Maryland. SAF Publ. 94-02. [availability: PFC]

Lawson, B.D.; Armitage, O.B.; Dalrymple, G.N. 1994b. Ignition probabilities for lodgepole pine and spruce subalpine fir forests. Can. For. Serv., Pac. For. Cent., Victoria, British Columbia. FRDA poster with text. [availability: PFC]

Lawson, B.; Armitage, B.; Dalrymple, G. 1996. Wildfire Ignition probability predictor (WIPP). Can. For. Serv., Pac. For. Cent., Victoria, British Columbia. R&D Update. 2p. [availability: PFC]

Lawson, B.D.; Dalrymple, G.N. 1996. Probabilities of sustained ignition in lodgepole pine, interior Douglas-fir, and white spruce-subalpine fir forest types. Can. For. Serv., Pac. For. Cent. and B.C. Min. For., Res. Branch, Victoria, British Columbia. FRDA Suppl. 1 to FRDA Handb. 12. 17p. [availability: PFC]

Lawson, B.D.; Frandsen, W.H.; Hawkes, B.C.; Dalrymple, G.N. 1997. Probability of sustained smouldering ignition for some boreal forest duff types. Can. For. Serv., North. For. Cent., Edmonton, Alberta. For. Manage. Note 63. 11p. [availability: NoFC; also available in French]

FWI System:

Alexander, M.E.; De Groot, W.J. 1988.Fire behavior in jack pine stands as related to the Canadian Forest Fire Weather (FWI) System. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Poster with text. [availability: out-of-print but see www.nofc.forestry.ca/fire/cwfis/fwi(fwishow_e.html]

Canadian Forestry Service. 1984. Tables for the Canadian Forest Fire Weather Index System. Fourth ed. Can. For. Serv., Ottawa, Ontario. For. Tech. Rep. 25 . 48p. [availability: NoFC; also available in French]

Van Wagner, C.E.; Pickett, T.L. 1985. Equations and FORTRAN program for the Canadian Forest Fire Weather Index System. Can. For. Serv., Ottawa, Ontario. For. Tech. Rep. 33. 18p. [availability: NoFC; also available in French]

FBP System:

Alexander, M.E.; Maffey, M.E. 1992-93. Predicting fire behavior in Canada's aspen forests. Fire Manage. Notes 53-54(1): 10-13. [availability: NoFC]

Alexander, M.E.; Cole, F.V. 1995. Predicting and interpreting fire intensities in Alaskan black spruce forests using the Canadian system of fire danger rating. Pages 185-192 in: Proc. 1994 Society of American Foresters/Canadian Institute of Forestry Convention. Soc. Am. For., Bethesda, Maryland. SAF Publ. 95-02. [availability: NoFC]

Cole, F.V.; Alexander, M.E. 1995. Head fire intensity class graph for FBP System Fuel Type C-2 (Boreal Spruce). Ak. Dep. Nat. Resour., Div. For., Fairbanks, Alaska and Can. For. Serv., North. For. Cent., Edmonton, Alberta. Poster with text [availability: DOF]

De Groot, W.J. 1993. Examples of fuel types in the Canadian Forest Fire Behavior Prediction (FBP) System. For. Can., North. For. Cent., Edmonton, Alberta. Poster with text. [availability: NoFC; also available in French]

Hirsch, K.G. 1993. A brief overview of the Canadian Forest Fire Behavior Prediction (FBP) System. HotSheet [now Wildfire] 2(2&3): 37. [availability: NoFC]

Hirsch, K.G. 1996. Canadian Forest Fire Behavior Prediction (FBP) System: user's guide. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Spec. Rep. 7. 121 p. [availability: UBC; cost $CAN 14.95]

Hirsch, K.G. 1998. Canadian Forest Fire Behavior Prediction (FBP) System: interactive training and reference. Can. For. Serv., North. For. Cent and Alta. Environ. Prot, For. Prot. Div., Edmonton, Alberta. CD-ROM. [availability: UBC; cost $CAN 129.95]

Taylor, S.W.; Pike, R.G.; Alexander, M.E. 1997. Field guide to the Canadian Forest Fire Behavior Prediction (FBP) System. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Spec. Rep. 11. 60p. [English availability: UBC, cost $CAN 24.95; French availability: SOPFEU]

Fuel Moisture & Accessory Fuel Moisture System:

Lawson, B.D.; Armitage, O.B.; Hoskins, W.D. 1996, Diurnal variation in the Fine Fuel Moisture Code: tables and computer source code. Can. For. Serv., Pac. For. Cent. and B.C. Min. For., Res. Branch, Victoria. British Columbia. FRDA Rep. 245. [availability: PFC]

Lawson, B.D.; Dalrymple, G.N. 1996. Ground-truthing the Drought Code: field verification of overwinter recharge of forest floor moisture. Can. For. Serv., Pac. For. Cent. and B.C. Min. For., Res. Branch, Victoria, British Columbia. FRDA Rep. 268. 21p. [availability: PFC]

Lawson, B.D.; Dalrymple, G.N.; Hawkes, B.C. 1997. Predicting forest floor moisture contents from Duff Moisture Code values. Can. For. Serv., Pac. For. Cent, Victoria, British Columbia. Tech. Transfer Notes No.6. 6p. [availability: PFC; see also http://leaf.pfc.cfs.nrcan.gc.ca/publications/ftp/index.html]

Fire Occurrence Prediction:

Kourtz. P.; Todd, B. 1992. Predicting the daily occurrence of lightning-caused forest fires. For. Can., Petawawa Natl. For. Instit., Chalk River, Ontario. Inf. Rep. PI-X-1 12. 18p. [availability: NoFC]

Martell,D.J.; Bevilacqua, E.; Stocks, B.J. 1989. Modelling seasonal variation in daily people-caused forest fire occurrence. Can. J. For. Res. 19: 1555-1563. [availability: GLFC]

Todd, B.; Kourtz, P.H. 1991. Predicting the daily occurrence of people-caused forest fires. For. Can., Petawawa Instit., Chalk River, Ontario. Inf. Rep. PI-X-103. 16p. [availability: NoFC]

Vega-Garcia, C.; Woodard, P.M.; Titus, S.J.; Adamowicz, W.L.; Lee, B.S. 1995. A logit model for predicting the daily occurrence of human caused forest fires. Int. J. Wildland Fire 5: 101-111. [availability: NoFC]

Fire Management Applications:

Alexander, M.E.; Fogarty, L.G. 1997. A simple field guide for estimating the behaviour and suppression requirements of fires driven by wind coming from a constant direction, in open, fully cured grasslands at low fuel moisture. N.Z. For. Res. Instit., Rotorua and Natl. Rural Fire Authority, Wellington, New Zealand. Pocket card with text. [availability: NZFRI]

Alexander, M.E.; Lanoville, R.A. 1989. Predicting fire behavior in the black spruce-lichen woodland fuel type of western and northern Canada. For. Can., North. For. Cent, Edmonton, Alberta and Gov. Northwest Territ. Dep. Renewable Resour., Territ. For. Fire Cent, Fort Smith, Northwest Territories. Poster with text [availability: NoFC]

Fogarty, L.G.; Alexander, M.E. 1999. A field guide for predicting grassland fire potential: derivation and use. N.Z. For. Res.; Rotorua and Natl. Rural Fire Authority, Wellington, New Zealand. Fire Tech. Transfer Note No. 20. 8 [availability: NZFRI]

Hawkes, B.; Beck, J. 1997. A wildfire threat rating system. Can. For. Serv., Pac. For. Cent., Victoria, British Columbia. Tech. Transfer Note No.1. 6p. [availability: PFC; see also http://leaf.pfc.cfs.nrcan.gc.ca/publications/ftp/index.html]

Lanoville, R.A.; Mawdsley, W.M. 1990. Systematic assessment of daily fire preparedness planning. Pages 253-261 in: M.E. Alexander and G.F. Bisgrove (tech. coords.). The Art and Science of Fire Management. For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-309. [availability: NoFC]

Lee, B.S. 1995. The Canadian Wildland Fire Information System. Pages 639-646 in: Proc. Ninth Annual Symposium on Geographic Information Systems in Forestry, Environment and Natural Resources Management. GIS World, Inc., Fort Collins, Colorado. [availability: NoFC; see also http://nofc.cfs.nrcan.gc.ca/fire/cwfis]

Stocks, B.J.; Fosberg, M.A.; Lynham,T.J.; Mearns, L.; Wotton, B.M.; Yang, Q.; Jin, Y-Z; Lawrence, K.; Hartley, G.R.; Mason, J.A. ; McKenney, D.W. 1998. Climate change and forest fire potential in Russian and Canadian boreal forests. Climate Change 38:1-13. [availability: GLFC]

Taylor, S.W.; Armitage, O.B. 1996. SCORCH: a fire-induced tree-mortality prediction model for Canadian forests. Pages 137-138 in: Integrated Forest Vegetation Management Options and Applications. Can. For. Serv., Pac. For. Cent. and B.C. Min. For., Res. Branch, Victoria, British Columbia. FRDA Rep. 251. [availability: PFC]

Wiltshire, R.; Archibald, D.J.; Towill, W.D.; Bodnar, W. 1995. Interpreting fire danger in northwestern Ontario based upon site hazard and forest operations. Ont. Min. Nat. Resour., Northwest Reg. Sci. Tech., Thunder Bay. Ontario. Tech. Note TN-32 8p. [availability: OMNR]

Foreign Usage:

Alexander, M.E. 1994a. Proposed revision of fire danger class criteria for forest and rural areas in New Zealand. Natl. Rural Fire Authority, Wellington, New Zealand. NRFA Circ. 1994/2. 73p. [availability: NRFA]

Alexander, M.E. 1994b. New Zealand fire danger classes. Natl. Rural Fire Authority, Wellington and N.Z. For. Res. Instit., Rotorua, New Zealand. Poster with text. [availability: NRFA]

Fogarty, L.G. 1994. Fire problem, what fire problem? A review of "Fire danger ratings associated with New Zealand's major pine plantation wildfires" by H.G. Pearce and M.E. Alexander. N.Z. For. Res. Instit., Rotorua and Natl. Rural Fire Authority, Wellington, New Zealand. Fire Tech. Transfer Note No. 3. 2p. [availability: NZFRI]

Fogarty, L.G. 1996. A summary and status of the "Proposed Revision of Fire Danger Class Criteria for Forest and Rural Areas in New Zealand" by Martin E. Alexander, N.Z. For. Res. Instit., Rotorua and Natl. Rural Fire Authority, Wellington, New Zealand. Fire Tech. Transfer Note No. 7. 6p. [availability: NZFRI]

Fogarty, L.G.; Pearce, H.G.; Catchpole, W.R.; Alexander, M.E. 1998. Adoption vs. adaptation: lessons from applying the Canadian Forest Fire Danger Rating System in New Zealand. Pages 1011-1028 in: Proc. III International Forest Fire Research Conference/I4th Conference on Fire and Forest Meteorology. Univ. Coimbra, Coimbra, Portugal. [availability: NZFRI]

Pearce, H.G.; Alexander, M.E. 1994. Fire danger ratings associated with New Zealand's major pine plantation wildfires. Pages 534-543 in: Proc. 12th

Conference on Fire and Forest Meteorology. Soc. Am. For., Bethesda, Maryland. SAF Publ. 94-02. [availability: NZFRI]

Availability Sources:

NoFC: Northern Forestry Centre, Canadian Forest Service, 5320-122 Street, Edmonton, Alberta, Canada T6H 3S5.

PFC: Pacific Forestry Centre, Canadian Forest Service, 506 West Burnside Road, Victoria, British Columbia, Canada V8Z 1M5

GLFC: Great Lakes Forestry Centre, Canadian Forest Service, P.O. Box 490, Sault Ste. Marie, Ontario, Canada P6A 5M7.

CIFFC: Canadian Interagency Fire Centre, 210-301 Weston Street, Winnipeg, Manitoba, Canada R3E 3H4.

OMNR: Ontario Ministry of Natural Resources, Northwest Region Science & Technology, RR#1, 25th Side Road, Thunder Bay, Ontario, Canada P7C 4T9.

UBC: UBC Press, University of British Columbia, 6344 Memorial Road, Vancouver, British Columbia, Canada V6T 1Z2. [e-mail: orders@ubcpress.ubc.ca; see also http://ubcpress.ubc.ca]

DOF: Division of Forestry, Alaska Interagency Fire Center, P.O. Box 35005, Fairbanks, Alaska. USA 99703-0005.

NRFA: National Rural Fire Authority, P.O. Box 2133, Wellington, New Zealand.

NZFRI: New Zealand Forest Research Institute, Private Bag 3020, Rotorua, New Zealand.

SOPFEU, Aéroport international Jean-Lesage, 715-7e Rue, Ste-Foy (Quebec) G2E 5W1

Computer Software

Commercial software for both the FWI and FBP Systems is available REMSOFT Inc. of Fredericton, New Brunswick [see: http://www.remsoft.com]

The Canadian Forest Service Fire Research Network can provide upon request computer source code and Input/output examples for both the FWI and FBP Systems. Contact Mike Wotton, Physical Fire Research Scientist, Canadian Forest Service, Great Lakes Forestry Centre, P.O. Box 490, Sault Ste. Marie, Ontario, Canada P6A 5M7. E-mail: mwotton@nrcan.gc.ca

Please note that calculation of the Duff Moisture Code (DMC) and Drought Code (DC) (and in turn the Buildup Index and Fire Weather Index) components of the FWI System for latitudes below about 30 degrees N require a unique set of monthly values for the DMC effective day-length and DC day-length factor. Contact: Marty Alexander.

Training and Training Materials

A report and a 22-min video entitled "An Introduction to the Canadian Forest Fire Weather Index System" authored by S.W. Taylor and B.D. Lawson will soon be released by the Canadian Forest Service Fire Research Network. Contact: Steve Taylor Fire Research Officer, Canadian Forest Service, Pacific Forestry Centre, 506 West Burnside Road, Victoria, British Columbia, Canada V8Z 1M5. E-mail: staylor@nrcan.gc.ca

An interactive CD-ROM based training package on the FBP System is available through UBC Press. Contact K.G. Hirsch, Fire Research Officer, Canadian Forest Service, Northern Forestry Centre, 5320-122 Street, Edmonton, Alberta, Canada T6H 3S5. E-mail: khirsch@nrcan.gc.ca

Two nationally recognized fire behavior training courses offered under the auspices of the Canadian Interagency Forest Fire Centre (CIFFC) are available on a periodic basis (i.e., 6.5-day Advanced Wildland Fire Behavior Course and an 11-day Wildland Fire Behavior Specialist Course). Both of these courses involve extensive instruction on the CFFDRS, For information on upcoming course offerings contact the CIFFC Training Group Chair c/o CIFFC, 210-301 Weston Street, Winnipeg, Manitoba, Canada R3E 3H4. E-mail: ciffc@ciffc.ca [see: http://www.ciffc.ca]