Prescribed burn documentation and fire danger ratings: A case study

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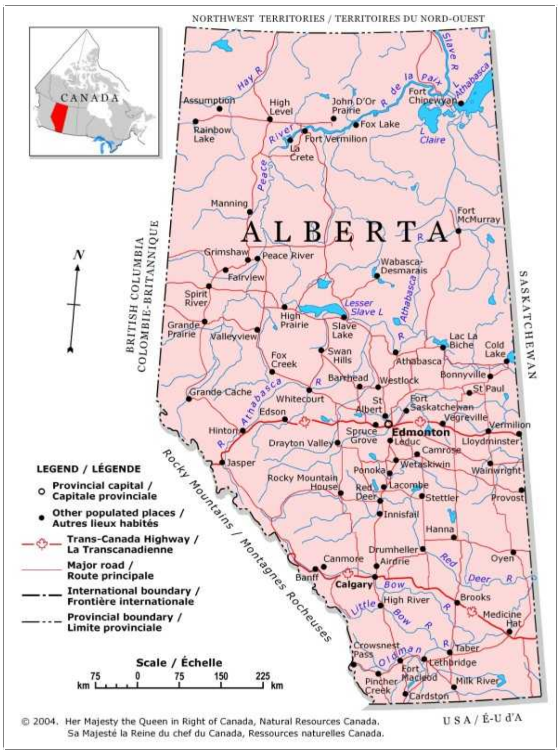
Abstract: The six standard relative numerical ratings of the Canadian Forest Fire Weather Index (FWI) System associated with a prescribed fire previously reported on in the literature (Woodard, P.M., Bentz, J.A., Van Nest, T., 1983. Producing a prescribed crown fire in a subalpine forest with an aerial drip torch. Fire Manage. Notes 44(4), 24-28.) have been recomputed based on all the available weather data, in addition to being updated in terms of the current edition of the FWI System. This case study approach has been taken in order to illustrate the importance that fire danger rating information should play in the formal prescribed burn documentation process. A key feature in this particular retrospective analysis was the manner in which the previous day's fuel moisture codes, which are required as starting values for FWI System calculations, were estimated (in the absence of pre-burn fire weather monitoring) for the actual site using the observations from nearby fire weather network stations. This information was combined with the on-site fire weather observations on the day the prescribed fire took place in order to quantify the burning conditions in terms of past and present weather influences that prevailed just prior to and/or during the ignition phase of the prescribed burning operation according to the three fuel moisture codes and three fire behavior indexes comprising the FWI System.

Keywords: Alberta, burning prescription, Canada, Canadian Forest Fire Danger Rating System, Canadian Forest Fire Weather Index System, fire management, fire weather, fire weather monitoring, prescribed burning, prescribed fire.

1. Introduction

Woodard *et al.* (1983) described a prescribed fire in a 18-ha open-grown, subalpine white spruce (*Picea glauca* (Moench Voss)) stand (~ 300 years old) conducted for bighorn sheep habitat improvement purposes near the Ram Mountain Lookout in the former Rocky-Clearwater Forest of west-central Alberta, Canada on May 30, 1983. Ram Mountain is located approximately 60 km directly west of the city of Rocky Mountain House (Figure 1). Bentz (1981) documented the preburn vegetation conditions at the site and Michalsky (1987) reported on some immediate post-fire effects. In terms of documenting the attendant environmental conditions, the on-site weather observations just prior to ignition were given as well as codes and indices of the Canadian Forest Fire Weather Index (FWI) System (Van Wagner, 1987) from the two closest fire weather stations (Baldy and Baseline Lookouts) based on the standard daily fire weather observations were presented by Woodard *et al.* (1983). The purpose of this paper is to offer an alternative method of computing and expressing the fire danger ratings associated with the 1983 Ram Mountain prescribed fire which may have wider applicability with respect to prescribed burn documentation in the future. It is not intended as a direct criticism of the approach taken in the original paper by Woodard *et al.* (1983).



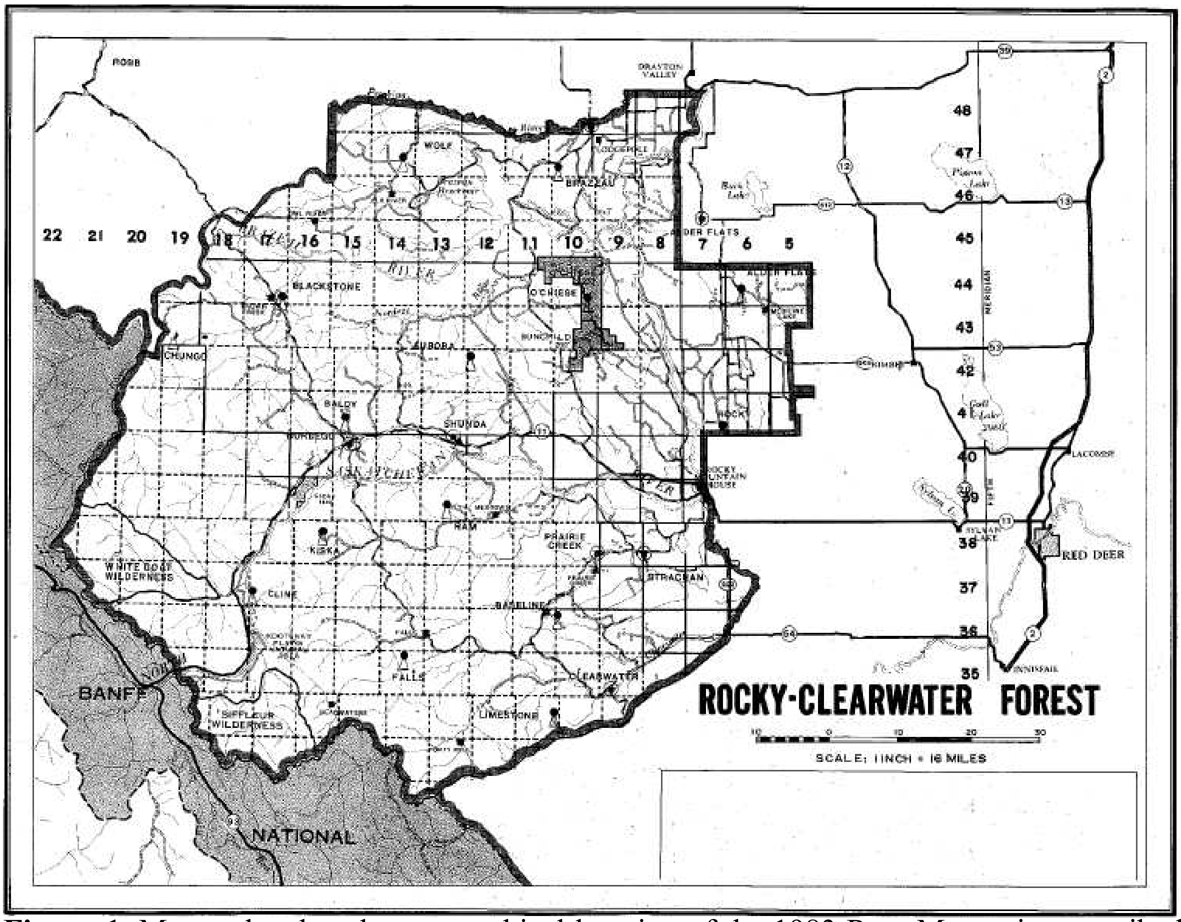


Figure 1. Maps related to the geographical location of the 1983 Ram Mountain prescribed fire in Alberta, Canada and nearby fire weather stations at Baldy and Baseline Lookouts.

2. General Background Information

Structurally, the FWI System consists of six standard components that provide relative numerical ratings of wildland fire potential (Figure 2). The first three components are fuel moisture codes that follow daily changes in the moisture contents of three classes of forest fuel with different drying rates, namely fine surface litter, loosely compacted duff, and deep, compact organic matter. For each code, there is both a wetting and drying phase. The three moisture codes are liken to bookkeeping systems in that they add moisture after rain and subtract some for each day's drying. Code values are arranged so that higher values represent lower moisture contents and hence greater fuel flammability. The final three components, which are based on the moisture codes plus wind speed, are fire behavior indexes representing rate of spread, amount of available fuel, and fire intensity. Their values increase as fire weather severity worsens. The FWI System is dependent on weather only and does not consider differences in ignition risk, fuel types or topography. Thus, it provides a uniform method of rating fire danger across Canada.

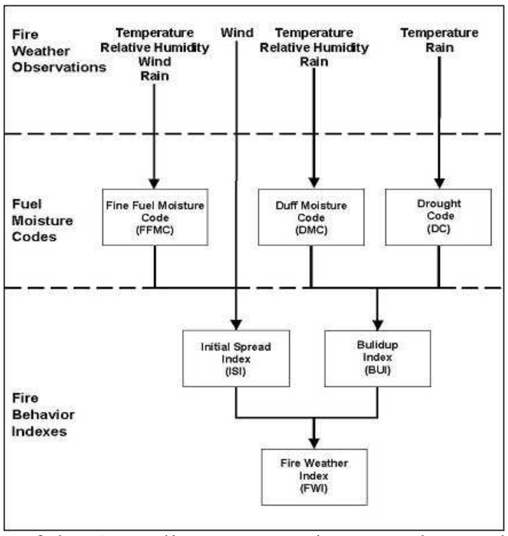


Figure 2. Structure diagram of the Canadian Forest Fire Weather Index System.

Calculation of the components of the FWI System is based on consecutive daily observations of temperature, relative humidity, wind speed, and 24-hour rainfall (if any), measured at a suitable weather station (Turner and Lawson, 1978). Wind is measured in the open at the international standard height of 10 m above level ground. The daily observations are taken at noon local standard time or 1300 hours daylight savings time. Component values can be calculated from a set of tables (Canadian Forestry Service, 1984) or from a computer program (Van Wagner and Pickett, 1985). Weather observations and fire danger computations should begin on the third day following snow-free cover in the spring in regions normally covered by snow during the winter, otherwise in regions where snow cover is not a significant feature, calculations should begin on the third successive day that noon local standard time temperatures of 12°C or higher are recorded. In either case, standard fuel moisture code starting values -- i.e., Fine Fuel Moisture Code (FFMC) 85, Duff Moisture Code (DMC) 6, and Drought Code (DC) 15 -- are generally sufficient (Turner and Lawson, 1978; Canadian Forestry Service, 1984) unless there's been a lack of overwinter precipitation (Alexander, 1983; Lawson and Dalrymple, 1996) and/or a fire weather station begins operation much later in the spring or even early summer.

Ideally, for a prescribed fire, weather should be monitored from a temporary station immediately "off-site" from the time of the recommended start-up date in the spring until the day the burning takes place. The relatively recent development of moderately priced automatic recording weather stations and single instruments (Finklin and Fischer, 1990; Malcolm, 1993; McBeath, 1994) such as the "quick deploy" fire weather station (Alexander 2004) produced by Forest Technology Systems Ltd. of Victoria, BC (http://www.ftsinc.com/), has greatly facilitated this process. In actual practice however, on-site fire weather monitoring prior to the burning operation is not always practical because of logistics, cost considerations, equipment availability, etc. (Lawson, 1982); alternatively, fuel moisture codes can be estimated from sampled fuel moisture contents (Lawson and Dalrymple, 1996; Lawson *et al.*, 1997).

The recommended minimum period of daily on-site preburn monitoring of fire weather conditions has generally been taken to be three weeks (McRae *et al.*, 1979; Trowbridge *et al.*, 1987). This period of time generally permits the fuel moisture codes to reflect local fuel moisture levels adequately. If more than three weeks have passed since snow-free cover, the fuel moisture codes from the nearest or most representative station to the prescribed burn area or an average of surrounding stations should be used for the starting values (Turner and Lawson, 1978). A poor estimate for the FFMC starting value will correct itself after about three or four days time (Turner and Lawson, 1978); note that the drying influence of wind on the FFMC is really only effective within a few days after a rain (Turner and Lawson, 1978, p.10). For the DMC and DC, substantial rains are required to for self-correction to occur due to their timelag characteristics (Van Wagner, 1987). For further inferences on the FWI System, one should consult the CD-ROM based training course available on the system (St. John and Alexander 2004).

3. Methods

The daily 1300 hours Mountain Daylight Time (MDT) fire weather observations recorded at Baldy and Baseline Lookouts (LO) prior to the prescribed burning operation (Table 1) were obtained from the Forest Protection Division of Alberta Environmental Protection's Land and Forest Service (now Alberta Sustainable Resource Development). Baldy LO is located 27 km northwest of the burn site at an elevation of 2025 m above mean sea level (MSL) whereas Baseline LO is located 35 km southeast of Ram Mountain at 1890 m MSL (Figure 1). Computer calculation (Van Wagner and Pickett, 1985) of the FWI System components was then undertaken (Table 2).

The burn site was situated on a southwest facing exposure or aspect just below the Ram Mountain LO and exhibited an average slope steepness of 42%. Ignition was completed, beginning at the top (1950 m MSL) and gradually progressing down slope to the bottom of the burning unit (1740 m MSL), with a helitorch or flying drip torch using strip head fires spaced about 75 to 125 m apart (Figure 3). The on-site weather data collected on the day of the burn was taken at an elevation of 1910 m MSL immediately adjacent to the unit.

The suggested procedures to be employed in this case, since on-site weather was not taken until the day the prescribed fire actually took place, are as follows:

Step 1: Compute an estimate of the on-site FWI System fuel moisture codes for the day prior to the prescribed fire by averaging the Baldy LO and Baseline LO 1300 hours MDT values for May 29.

Table 1. Standard daily fire weather observations recorded at 1300 hours MDT for Baldy and Baseline Lookouts prior to the Ram Mountain prescribed fire in west-central Alberta on May 30, 1983. Baldy and Baseline lookouts reported snow-free cover on May 20 and 22, respectively.

Calendar date (1983)		Baldy Lookout					Baseline Lookout				
		Dry-bulb temperature	Relative humidity	10-m open speed		24-hr rain	Dry-bulb temperature	Relative humidity	10-m open speed		24-hr rain
		(ºC)	(%)	Direction (From)	Speed (km/h)	(mm)	(ºC)	(%)	Direction (From)	Speed (km/h)	(mm)
May	23	8.5	52	E	5	Trace	-	-	-	-	-
	24	11.5	35	SW	12	0.0	-	-	-	-	-
	25	13.5	23	SE	36	0.0	16.5	20	W	35	0.0
	26	6.5	53	E	6	0.0	12.5	49	N	12	0.0
	27	11.5	43	SE	7	0.0	13.5	41	NE	8	0.0
	28	17.0	34	SE	8	0.0	17.5	25	SW	12	0.0
	29	17.5	35	SE	14	0.0	20.0	33	NE	15	0.0
	30	14.5	33	SE	18	0.0	14.0	35	E	18	0.0

Table 2. Standard daily fire danger ratings [a] calculated from the 1300 hours MDT fire weather observations at Baldy and Baseline Lookouts prior to the Ram Mountain prescribed fire in west-central Alberta on May 30, 1983.

Calendar Date (1983)		Baldy Lookout						Baseline Lookout					
		FFMC	DMC	DC	ISI	BUI	FWI	FFMC	DMC	DC	ISI	BUI	FWI
May	23	85.1	7	19	2.8	7	2	-	-	-	-	-	-
	24	87.6	9	23	5.6	9	6	-	-	-	-	-	-
	25	90.9	12	28	30.0	12	25	91.7	10	20	31.8	10	24
	26	88.3	13	32	4.5	13	6	89.1	12	25	6.9	11	8
	27	88.3	15	36	4.8	15	7	89.2	14	30	5.7	14	7
	28	89.5	18	42	5.9	18	9	91.3	17	35	9.4	17	12
	29	89.7	21	47	8.3	21	13	91.3	21	41	11.0	21	15
	30	89.7	24	52	10.2	24	16	90.8	24	46	12.0	24	17

[a] The six components comprising the Canadian Forest Fire Weather Index System are defined below (from Canadian Forestry Service 1984):
Fine Fuel Moisture Code (FFMC) - 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.
Duff Moisture Code (DMC) - A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-sized woody material.
Drought Code (DC) - A numerical rating of the 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.
Initial Spread Index (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.
Buildup Index (BUI) - A numerical rating of the total amount of fuel available for combustion; it combines DMC and DC.
Fire Weather Index (FWI) - A numerical rating of fire intensity; it combines ISI and BUI. It is suitable as a general index of the fire danger throughout the forested areas of Canada.

Figure 3. Scenes of the Ram Mountain prescribed fire during the ignition phase and subsequent stages of development illustrating the high-intensity, crown fire type of behavior associated in part with the junction zones created by the merging flame fronts. Photos courtesy of Hinton Training Centre, Forest Protection Division, Alberta Sustainable Resource Development, Hinton, AB.

Step 2: Use the values determined in ***Step 1*** and the on-site 1300 hours MDT fire weather observations on May 30 (i.e., dry-bulb temperature -16.8°C, relative humidity - 33%, 10-m open wind speed -15 km/h, and 24-h rain - 0.0 mm) to calculate the three fuel moisture codes and Buildup Index (BUI) on the day of the prescribed fire.
Step 3: Use the FFMC determined in ***Step 2*** and the average 10-m open wind speed for the main burning period (the 10-m open wind speed averaged 15 km/h between 1700 and 1800 hours MDT) to calculate the Initial Spread Index (ISI).
Step 4: Use the BUI determined in ***Step 2*** and the ISI determined in ***Step 3*** to calculate the FWI component itself.

It's worth noting that there was no need to adjust the FFMC for time of day (Lawson *et al.*, 1996) prior to ***Step 3*** since the burning operation, which was completed between 1729 and 1815 hours MDT, coincided with the normal peak in daily fire danger (i.e., generally in mid to late afternoon when air temperature is at a maximum and relative humidity is at a minimum). Furthermore, there appeared no reason to adjust the FFMC for slope steepness and aspect on the basis of existing guidelines and our current "state-of-knowledge" (*see,* for example, Taylor *et al.*, 1997, p. 57).

4. Results and Discussion

The FWI System component values for the 1983 Ram Mountain prescribed fire based on the procedures described above are presented in Table 3 following the format of Newstead and Alexander (1983). All computations were performed with the use of a computer program employing the current version of the FWI System (Canadian Forestry Service, 1984; Van Wagner and Pickett, 1985; Van Wagner, 1987) which was released in 1984, whereas the values cited by Woodard *et al.* (1983) were based on the tabular version of the previous (third) edition of the system; note that the captions for Tables 2 and 3 in the article by Woodard *et al.* (1983) were inadvertently reversed.

Table 3. Fire weather observations and fire danger ratings associated with the Ram Mountain prescribed burn in west-central Alberta on May 30, 1983.

Fire weather and fire danger parameters	Proposed burning prescription[a]	Actual conditions experienced
Dry-bulb temperature (°C)	≥ 18	16.7
Relative humidity (%)	25-45	33
Wind direction & speed (km/h)[b]	SW 18	S 15
Number of days since >0.6 mm rain	-	~9[c]
Fine Fuel Moisture Code (FFMC)	≥ 85.9	90.0
Duff Moisture Code (DMC)	30	24
Drought Code (DC)	30	53
Initial Spread Index (ISI)	≥ 10	9.2
Buildup Index (BUI)	-	24
Fire Weather Index (FWI)	15-25	15

[a]After Woodard *et al.* (1983).

[b]As measured at a height of 10 m in the open on level terrain. On-site winds were actually measured at 3.0 m but were adjusted, taking into account the slope steepness, to the standard measure using the factor recommended by Turner and Lawson (1978, p. 37).

[c]Baldy LO recorded 0.8 mm of rain on May 21.

In spite of the lack of on-site antecedent weather data, which ultimately would have been preferred, there are two reasons for supporting the view that the FWI System component values presented in Table 3 are actually representative of the on-site conditions. For one, a very short rainless period following snow-free cover in the spring preceded the burning. Secondly, the elevational differences between the burn site and the two lookout weather stations, which can affect temperature and relative humidity readings (Hayes, 1941), were, for practical purposes, inconsequential. However, guidelines are currently available for this eventuality (Cramer, 1961; Nikieva, 1975; Furman, 1979).

It's worth emphasizing that the averaging of the two closest fire weather stations may not always be the best approach. Depending on topography, landform characteristics, drainage features, elevational differences, etc., it may be better to use a single station and ignore a second one that could even be closer to the site but perhaps less representative. A spatial interpolation approach (Flannigan and Wotton, 1989; Lee and Anderson, 1989) could possibly have some value in this regard, depending on the kind of assumptions made especially with respect to rainfall patterns as opposed to air temperature and relative humidity which are more easily handled by physical or statistical modelling with a moderately high degree of confidence, even in complex mountainous terrain (Balick, 1978; Hungerford *et al.*, 1989). Thus, fire managers could be provided with "spot" FWI System fuel moisture code starting values derived from a computerized fire management information system (Lee *et al.*, 2002). However, reliance upon such convenience should not be at the expense of avoiding preburn fire weather data collection or minimizing the length of record prior to the burning operation.

It's difficult to specify exact standards for fire weather monitoring (e.g., when is a temporary station required in lieu of using an existing permanent station given the location of the prescribed fire site?). Often local knowledge of fire climate and weather patterns (Finklin, 1983) can be valuable in determining what should be considered as reasonably appropriate (e.g., the existence of "rain shadows" or "dry spots"). For example, in situations where there's little elevational difference between the prescribed fire site and a permanent fire weather station, and the intervening topography is flat or very gently undulating then one could rightly assume that the daily temperature, relative humidity and wind speed data recorded at the permanent installation prior to the day of burning was also applicable to the site. Of the four weather elements required for the calculation of the FWI System's components, rain generally tends to be the most variable, at least spatially, even on level terrain (Webb, 1968; Turner and Lawson, 1978). For this reason it's felt that as a bare minimum, rain should be recorded on-site prior to the burn taking place unless a permanent fire weather station is located a very short distance away; a very simple rain gauge might suffice (e.g., Wrage *et al.*, 1994). The need to meet this minimum requirement will, to some extent, depend on whether the prescribed burn site possesses a substantial organic layer or not; normally it shouldn't be necessary to monitor preburn rainfall amounts for more than a few days if only fine fuels are present (e.g., cured annual grasses). On the burning day, temperature, relative humidity, and the 10-m open wind speed or its equivalent[1] should be measured at least every hour and if possible more frequently (e.g., every 10 minutes or half hour, especially wind speed). If automatic recording equipment is available, the hourly weather 24 hours in advance of the burning should be documented as well; this would also permit a more exact way of calculating the FWI System components

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[1] For example, wind speed measured at "eye level" in a large clearing, which exhibits a diameter that is at least 10 times the average height of the surrounding forest, would be adjusted upwards to approximate a 10-m open wind speed using an appropriate factor (e.g., Chrosciewicz, 1975; Turner and Lawson, 1978).

especially with respect to the FFMC and ISI (Forestry Canada Fire Danger Group, 1992; Taylor *et al.*, 1997) as well as the FWI component itself.

The other elements included in the burning prescription given in Table 3 involved the time of year (spring) and time of day for ignition (1300-1800 hours MDT). With respect to the former parameter, it's worth noting that based on the geographical location (52.37°N latitude, 115.8°W longitude) and elevation (1740-1950 m MSL) of the site and the julian date (151) on which the prescribed fire took place, that the estimate of the foliar moisture content (FMC) provided by the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group, 1992) was 91-95%. Woodward and Van Nest (1990) have speculated that the FMC could be an important element of the burning prescription for future prescribed fires designed to create mountain sheep habitat. According to the FBP System, the minimum FMC (85%) at the Ram Mountain site would occur around June 18-22.

5. Implications for Fire and Ecosystem Managers

Although fire danger rating systems were developed primarily for use in wildfire protection programs, they do in fact serve a multiple role in fire management (Brown and Davis, 1973; Alexander and Maffey, 1992-93). Prescribed fire monitoring and evaluation involves a host of variables (NWCG Prescribed Fire and Fire Effects Working Team, 1982). However, for a given fuel type/topographic situation, any variations in fire behavior and impact or short-term fire effects are wholly a reflection of past and current weather conditions. Thus, whenever prescribed fires are conducted, proper fire weather records should be kept and the relevant fire danger ratings documented in some manner (e.g., Newstead and Alexander, 1983; Hawkes, 1985; McRae, 1986, 1997), including any assumptions that have been made about fuel moisture code starting values and fire weather observations. This will enable the burning conditions to be duplicated and/or understood by others (Alexander, 1982, 1984; Hawkes and Lawson, 1983; Johnson and Miyanishi, 1995). Daily fire weather observations preceding the burn day should also be adequately archived (Alexander 1982, 1984; Alexander and Sando 1989) along with any measurements made immediately prior to and during the burning operation.

On-site or immediately off-site meteorological observations are needed for spot fire weather forecasts (Cuoco, 1992-93) and for assessing holdover potential or sub-surface fire persistence (Melton, 1996) in addition to judging whether the burning prescription has been met or not. In fact, conducting a prescribed burn without having undertaken any fire weather observations should be regarded as "prescribed fire situation #14 that shouts watch out!" (Alexander and Thomas, 2006).

The Canadian system of forest fire danger rating (Alexander *et al.*, 1996; Taylor and Alexander, 2006) is dependent on the continuity of a daily fire weather observation record (i.e., today's fuel moisture codes and fire behavior indices depend in part on the previous day's values). Therefore, it's imperative that the means of determining the starting values and monitoring weather conditions at a prescribed fire site be as rigorous as practically possible -- this becomes especially important as Canadian fire and resource management agencies begin to more fully integrate the use of planned-ignition prescribed fire as a substitute for natural fire in ecosystem management practices (Canadian Council of Forest Ministers, 2005). Only in this way can the quoted fire danger ratings be considered as truly representative for the area being treated with prescribed fire.

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