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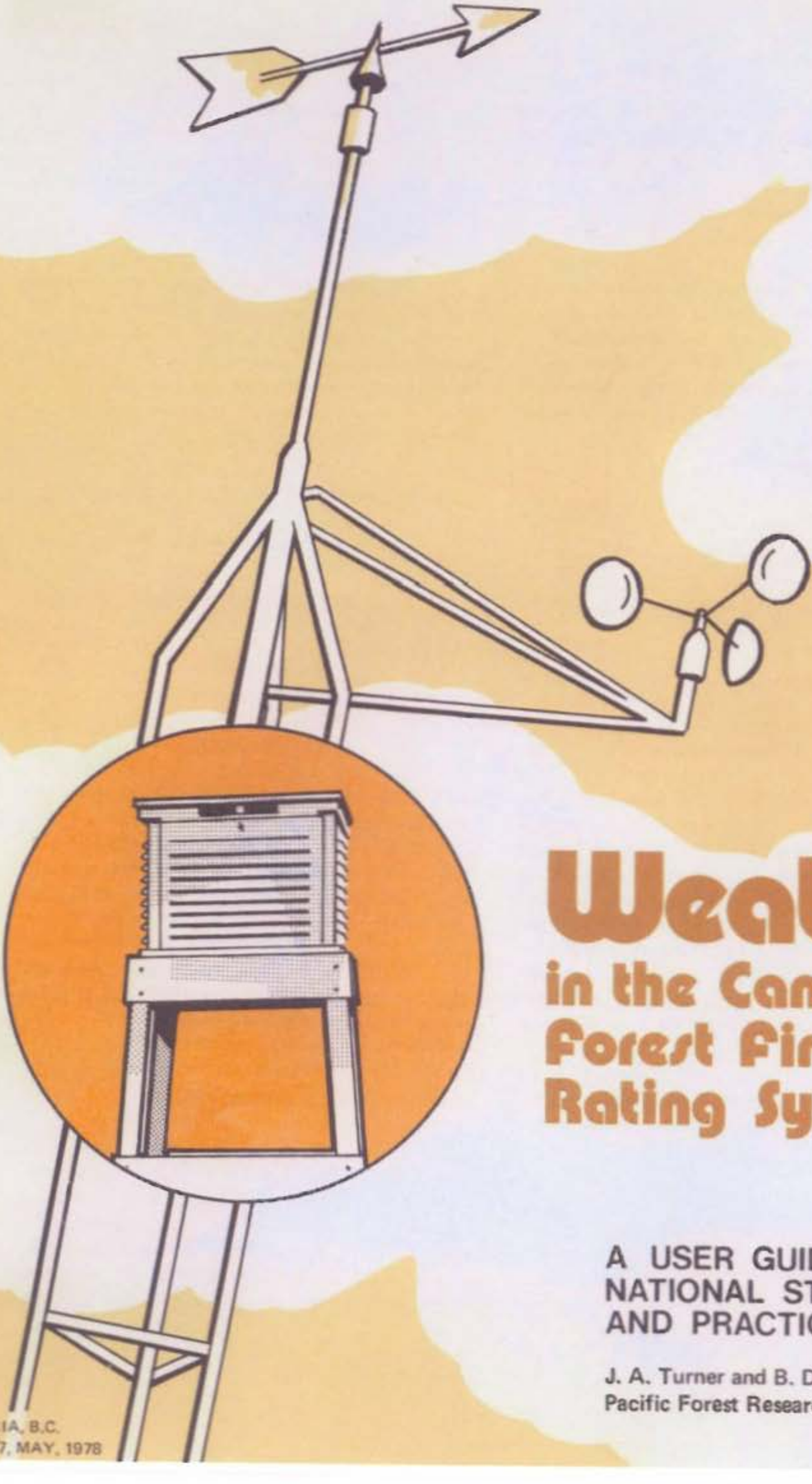

Weather in the Canadian Forest Fire Danger Rating System

A USER GUIDE TO NATIONAL STANDARDS AND PRACTICES

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ABSTRACT

Weather elements affecting the calculation of the Canadian Forest Fire Weather Index (FWI) are described. How to choose an adequate weather station site for fire danger rating observations, how to expose each weather instrument correctly, and the consequences of errors in weather data on the FWI are outlined. Weather instrument standards of accuracy and required precision in taking fire weather readings are described.

Adjustment procedures are provided to users for such things as anemometers exposed in clearings too small to give representative wind speeds for danger rating calculations, and for making corrections to spring Fire Weather Indices when overwinter precipitation has been insufficient to replenish forest fuel moisture.

RÉSUMÉ

Les auteurs décrivent les conditions météorologiques qui affectent le calcul de l'Indice Forêt-Météo canadien (IFM). Ils mettent en relief la façon de choisir l'emplacement d'un bureau météorologique qui servira à observer et évaluer les dangers d'incendie, la façon d'exposer correctement chaque instrument de météo, puis les conséquences d'erreurs dans les données météorologiques sur l'IFM. Ils décrivent les normes de précision des instruments et des lectures.

Des méthodes d'ajustement sont fournies aux utilisateurs d'anémomètres établis dans des clairières trop petites. On conseille comment faire les corrections aux Indices Forêt-Météo du printemps lorsque les précipitations hivernales ont été insuffisantes pour redonner au combustible forestier sa teneur normale en humidité.

The Authors

Jack Turner retired in 1974 from the Canadian Forestry Service, after 8 years as meteorologist with the fire research group of the Pacific Forest Research Centre in Victoria, B.C. During this time he was instrumental in developing, testing, calibrating and introducing the Fire Weather Index. Prior to 1967, he was fire weather specialist with the Protection Division of the B.C. Forest Service, having begun his career as a weather forecaster with the Atmospheric Environment Service (formerly the Met. Branch of Dept. of Transport).

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The Publication

This User Guide was funded jointly by the Canadian Forestry Service and the Atmospheric Environment Service of Environment Canada. It is intended for nation-wide use as a standard reference for all provincial and territorial agencies who utilize the Canadian Forest Fire Danger Rating System.

Copies are available from regional establishments of the Canadian Forestry Service and from the Forest Fire Research Institute in Ottawa.

Acknowledgments

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PREFACE

The Canadian Forest Fire Danger Rating System (FDRS) has been under development in its present form since 1968, and the system's first phase, the Canadian Forest Fire Weather Index (FWI), has been in operational use across Canada since 1971. Research continues on additional system components in several regions of the country by the Canadian Forestry Service. Regional needs for recognizing potential fire behavior differences among specific fuel complexes are being researched and hopefully will be satisfied by a system of Fire Behavior Indices. These indices, together with lightning and man-caused fire risk ratings and fire occurrence prediction schemes, will eventually form a comprehensive fire danger rating system. However, with the FWI being the only universally applied portion of the FDRS, we have aimed this publication at the FWI user's present needs for guidance with respect to the weather implications of the system.

This **User Guide to National Standards and Practices** updates the earlier Fire Danger Manual (Williams 1963) regarding standards of weather stations and observations. The **User Guide** will assist those responsible for establishing fire weather stations for danger rating networks and for administering fire prevention regulations or public information activities. To ensure standardization of Fire Weather Index calculations anywhere in Canada, the requirements of the basic weather observations described here must be met as completely as possible with respect to station location, instrument exposure, instrument accuracy and precision of measurement.

The **User Guide** is **not** designed as a weather instrument availability listing or a detailed instruction manual on taking weather observations with specific instruments or servicing and adjusting such instruments. Other references for such requirements are listed in the Bibliography.

This **User Guide** does provide the national standards of fire weather observations for FWI calculations as developed by the CFS fire danger group. These weather standards and the various suggested procedures for handling non-standard weather situations and weather observing practices contained in the Appendices should be of concern to all fire weather observers and persons responsible for weather network stations.

The Guide has been three-hole punched for ease of storage in a three-ring binder along with FWI Tables and other danger rating information which may be issued by regional fire management agencies or fire weather authorities.

B.D.L.

Chapter 1

Introduction

Weather is an essential ingredient of the Canadian Forest Fire Danger Rating System (FDRS). The Fire Weather Index (FWI) subsystem (Anon. 1978) is based on a specific set of weather observations taken daily, generally at noon local standard time (1200 h LST or 1300 h Daylight Saving Time), and at a location where readings are not seriously affected by unrepresentative features (e.g., rock outcrops, small bodies of water, parking lots, buildings, dusty roads).

Six components make up the Fire Weather Index: three primary ones called **moisture codes,** two intermediate indices, representing fire spread rate and amount of available fuel, and finally, the FWI itself, representing the intensity of a single fire in a standard fuel type. The three moisture codes represent three classes of forest fuels with different drying rates:

Fine Fuel Moisture Code (FFMC) is a numerical rating of moisture content of litter and other cured fine fuels in a forest stand.

Duff Moisture Code (DMC) represents moisture content of loosely compacted organic (duff) layers of moderate depth.

Drought Code (DC) represents moisture content of deep compact organic layers.

The two intermediate indices combine weather and/or fuel moisture influences on fire behavior. They are:

Initial Spread Index (ISI), a combination of wind speed and **FFMC,** representing fire spread rate without the influence of variable fuel quantity.

Buildup Index (BUI), a combination of **DMC** and **DC** that represents total amount of fuel available to the spreading fire.

The final index is the **Fire Weather Index (FWI),** a combination of **ISI** and **BUI** that represents the intensity of a spreading fire as energy output rate per unit length of fire front. Detailed descriptions of all **FWI** components are provided by Van Wagner (1974a).

One basic value of the Fire Weather Index is calculated per day, to represent fire danger conditions during the midafternoon peak period, assuming a normal diurnal pattern (Van Wagner 1974a). For a rainy day, calculation of the various codes has been standardized by first taking into account the effect of the rain, followed by the appropriate degree of drying.

The Fire Weather Index and its component code and index values, based on properly standardized weather observations, are effective predictors of daily fire potential. Such predictions are generally in line with on-the-spot assessments by experienced field personnel. On the basis of one index value per day, the system is not designed to indicate hour by hour changes, nor does the FWI account for fuel type variations from season to season or place to place. It does provide reference scales that permit fire danger comparisons with other days and other locations. The system also makes it possible to reconstruct past fire danger conditions whenever suitable historical weather records are available, and thus develop a 'fire climatology' for comparison with known fire history (Lawson 1977; Kiil et al. 1977; Stocks 1974).

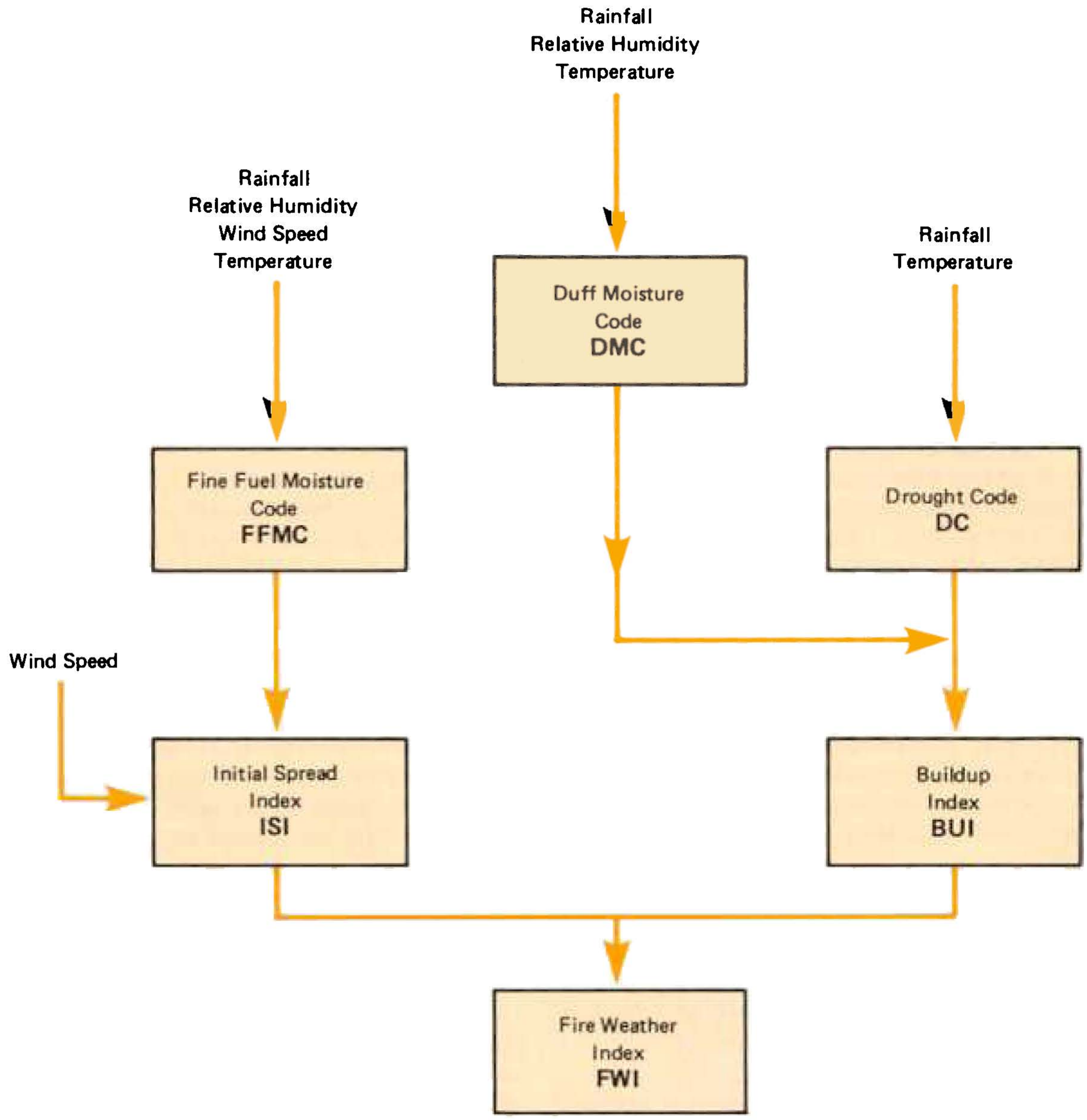


Fig. 1. Components of the Canadian Forest Fire Weather Index.

Chapter 2

Fire Weather Elements

The weather elements needed for Fire Weather Index calculations are those that influence (i) the ease with which fires can be started, (ii) the rate of spread and difficulty of control of fires which are burning, and (iii) the effects of fire on the environment.

The calendar date is introduced into calculations of DMC and DC to allow for variations in day-length throughout the season.

Other weather factors, such as lightning occurrence or wind direction, are not required for FWI calculations, but are generally included in any fire weather program because of their importance to management agencies and to forecasting personnel. There may also be local requirements for weather information at other than the **standard observation time.**

2.1 Precipitation

Precipitation, usually in the form of rain, is the only way the Fine Fuel Moisture Code (FFMC) can decrease below 73 (i.e., fine fuel moisture content of more than 28% as indicated by the standard conversion: Moisture Content = 101 - FFMC). It is also the only way the Duff Moisture Code (DMC) and the Drought Code (DC) can be reduced from the previous day's value.

The 24-hour rainfall total must reach certain amounts before it is considered to have any effect. These threshold values are different for each component code (Turner 1972; Van Wagner 1970, 1975), as indicated in **Table 1).**

Table 1

CODE	24-HOUR RAINFALL THRESHOLD mm
FFMC	0.6
DMC	1.5
DC	2.9

The effectiveness of any given rainfall in reducing each particular code value varies with the amount of the rainfall and the value of the code before the rain started. These variations in effectiveness are built into the system to reflect what is known about interception and rates of absorption. Precipitation is measured in the open but its effects are related to fuel moisture content within forest stands.

From time to time, during the fire season, precipitation may take place as hail or snow. In many cases this will have melted in the interval between

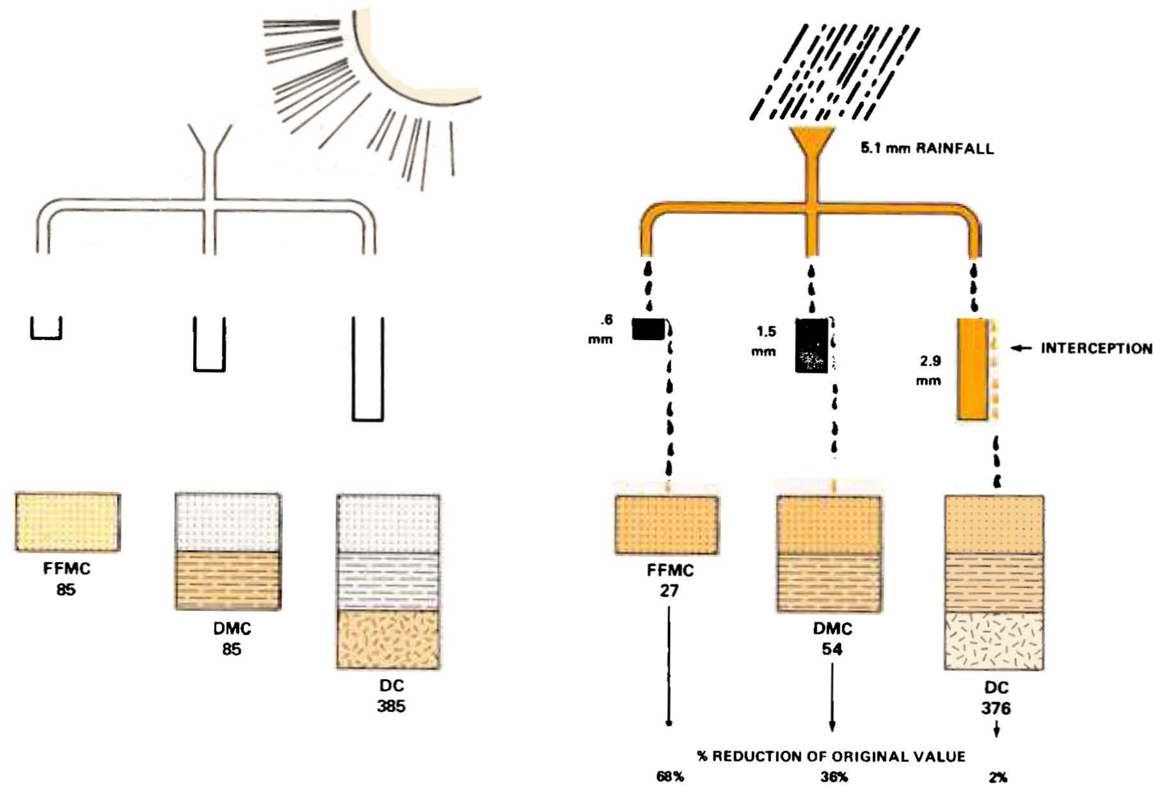


Fig. 2. Precipitation effects on the Fire Weather Index moisture codes.

observations, so the equivalent depth of water is entered in the tables as if it were rainfall.

As long as snow (or hail) remains on the ground at observation time, the calculation of the three moisture codes is carried on, using the water equivalent of snow that has fallen since the previous observation. However, the ISI and FWI are zero under these conditions and remain there until the snow or hail is melted.

Extended periods of fog or low cloud are reflected in the index calculations only by the associated high relative humidity and low temperature at observation time. The moisture codes may not fully represent the increase in moisture content of the actual fuel complex as long as the fog is present, but after one full drying period, the moisture codes will be indicating correctly. Where the fog is consistently present for part of the day, but **not at the standard observation time,** the "day-length" factor used in calculating the DMC and DC should be adjusted by using drying factors appropriate to September or October. Where fog is consistently present at observation time but clears within an hour or so, follow the procedure in 4.3, using observations taken after the fog has cleared.

2.2 Relative Humidity

In the early days of organized forest fire control activity, "fire weather" meant "relative humidity". Today, more than 50 years later, the "RH" is still used to give a quick assessment of the degree of fire danger. However, the mounting complexity of the problems requiring fire weather input demands a more sophisticated approach.

The Fire Weather Index makes use of two separate inputs of the noon relative humidity. For calculation of the FFMC, the Relative Humidity, along with Temperature and Wind Speed, controls the amount and direction of change from one day to the next, or in the period following rain.

The DMC, representing the moisture content of the intermediate duff fuel layer, also depends on daily values of Relative Humidity.

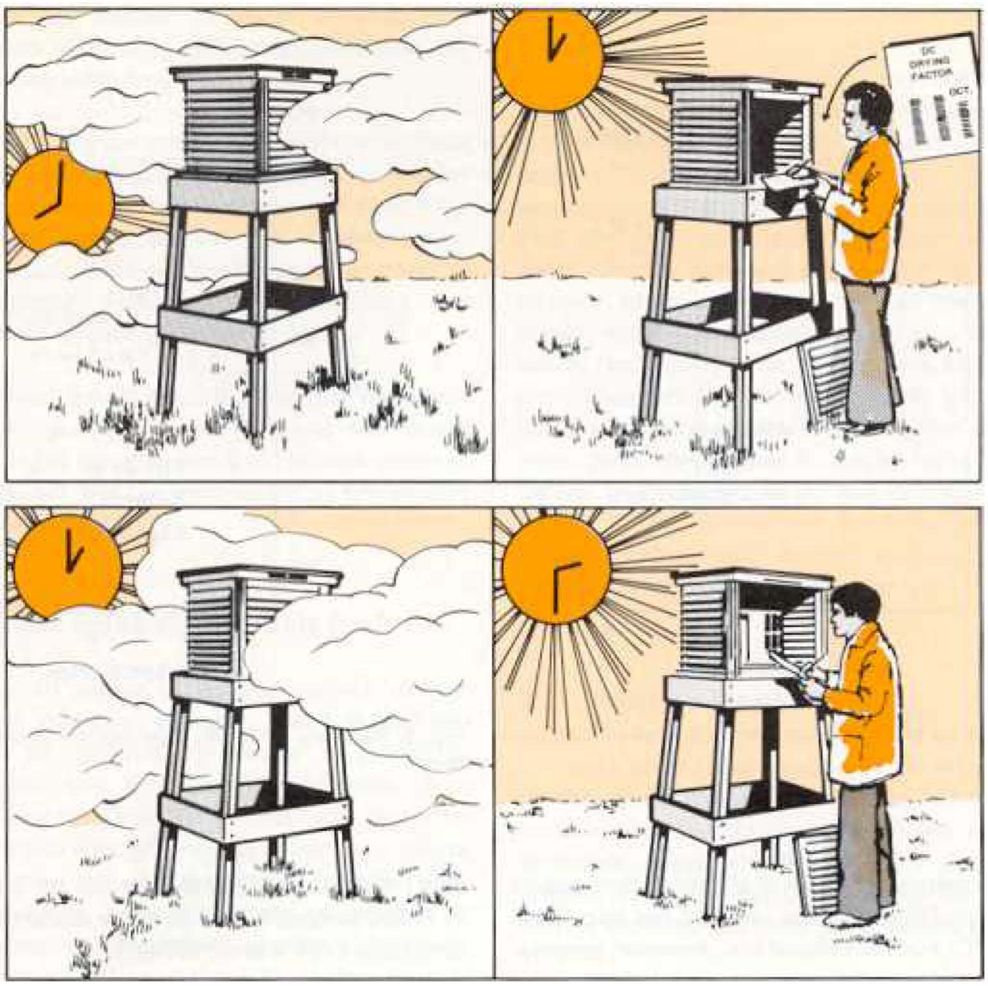


Fig. 3. Fog is best handled by varying the moisture code drying factors or time of observations.

Temperature and time of year (month) are required, along with Relative Humidity, for calculation of the daily DMC Drying Factor.

2.3 Temperature

The noon Temperature is used for the calculation of all three moisture codes.

In the FFMC calculations, Temperature, together with RH and Wind Speed, principally affects the rate at which the Code recovers after it has been reduced by rain. After the effects of rain have been erased, the Temperature and Relative Humidity determine an equilibrium value of the FFMC (not specifically calculated) which controls the day by day changes in the FFMC (Van Wagner 1974a).

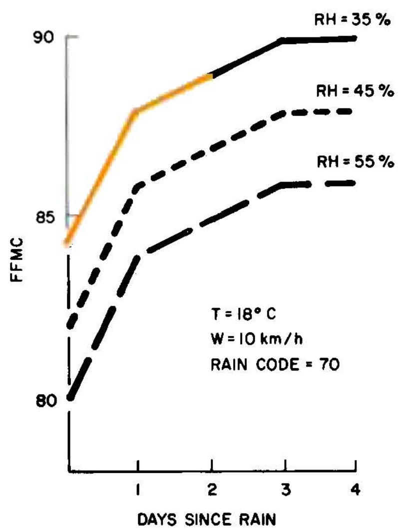


Fig. 4. Recovery of FFMC after rain for 3 levels of Relative Humidity.

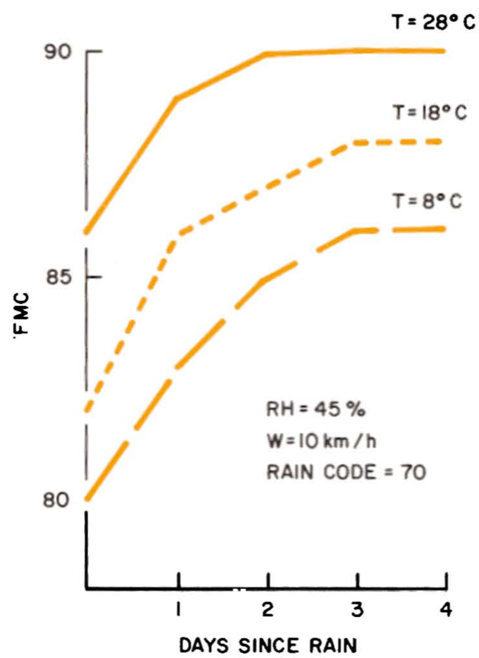


Fig. 5. Recovery of FFMC after rain for 3 levels of Temperature

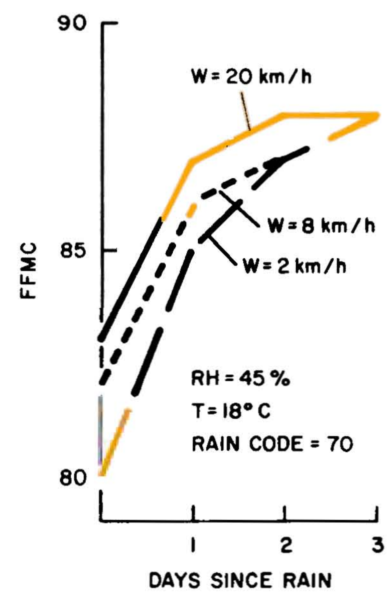


Fig. 6. Recovery of FFMC after rain for 3 levels of Wind Speed.

Temperature is one of the three components of the daily Drying Factor required for calculation of the DMC. For DC calculations, however, temperature is the only weather element used in determining the Drying Factor. Both DMC and DC Drying Factors are modified by a day-length factor depending on month of the year.

2.4 Wind Speed

This weather factor influences the Fire Weather Index in two ways.

A relatively weak effect is felt in the daily change in the FFMC, where Wind Speed chiefly affects the rate of recovery of the Code after rain (i.e., the rate of drying of the corresponding real fuel).

A much stronger influence has been built into the Initial Spread Index (ISI) to reflect the joint influence of Wind Speed and moisture content of fine surface fuels on fire spread. As a rule of thumb, the ISI doubles in value for every increase of 13 km/h in Wind Speed (for no change in the FFMC). (For comparison, with the wind held constant, the ISI requires an increase of 5 to 7 units in FFMC to double in value under moderate to severe conditions (Van Wagner 1974a)).

2.5 Supplementary or "Special Purpose" Weather Elements

The fire weather observation program is built around the needs of the Fire Weather Index subsystem, and is required to meet the standards demanded by the system.

Additional information, which is not part of the system, is often required for fire management purposes and to provide special information for the fire weather forecaster.

Standards for this supplementary information will be specified by the user agency to meet regional requirements. The following information may be useful:

(a) Observations of basic fire weather elements at times other than noon, including extremes of Relative Humidity and Temperature.

(b) Wind direction. Basically, this is of value to the fire weather forecaster to relate local wind patterns to broad-scale wind flow and topographic features.

(c) Lightning occurrence. The amount of detail varies from one user agency to another according to administrative need or local requirements of the fire weather office. Usually there is a minimum requirement to indicate whether or not lightning was observed on any particular day.

(d) Cloud information. Buildup and movement of lightning producing clouds and ceiling heights are often required for deployment of aircraft and the information of fire weather forecasters.

2.6 Weather Indirectly Affecting Fuels

Not all effects of weather operate through changes in moisture content. The fuel complex itself may be modified by specific or cumulative weather conditions, as in the case of green up of annual vegetation or killing of deciduous vegetation by frost. These changes may be seasonal in nature, but the timing may be modified by weather conditions over the preceding season. A number of these seasonal weather-related changes in fuel complexes are not built in to the FWI, so they must be handled in other ways.

One specific fuel modification not included in the Fire Weather Index System is the apparent drop in coniferous tree foliage moisture content in spring, prior to flushing of the new growth. This is not a weather-caused phenomenon so much as a physiological one which sees needle dry matter weights suddenly rise. The net result is a sharp drop in moisture content, often well below 100% of the needle dry weight, and an associated increase in probability of crown fire activity. The exact timing of this phenomenon appears to vary with latitude and elevation, but is a normal occurrence in April, May and June in most parts of Canada. A special index called the Crown Spread Index (CSI) was developed by Van Wagner (1974b) to account for spring conditions of foliage moisture and current weather (wind and FFMC) likely to result in crowning fires.

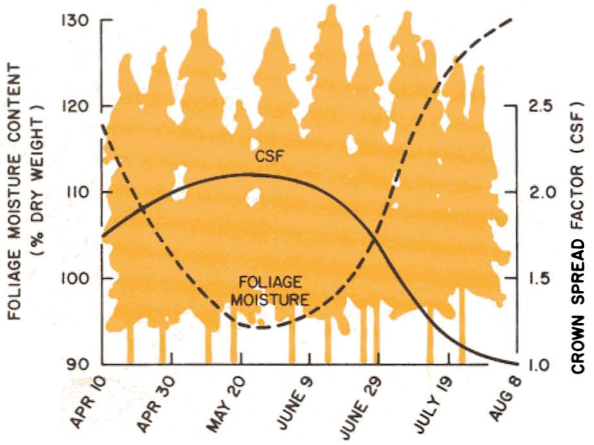


Fig. 7. Trend of reduced foliage moisture content in spring and resultant CROWN SPREAD FACTOR (CSF) determined for Petawawa, Ontario coniferous forests by Van Wagner. CROWN SPREAD INDEX (CSI) is obtained by multiplying CSF times the Initial Spread Index (ISI). Crown fires should be expected in pine stands when CROWN SPREAD INDEX exceeds 30.

2.7 Preseason Weather

In some regions and in some years, the degree of fire danger may be modified by abnormally dry conditions during the previous fall and winter. This carry-over effect is indicated by a change in the start-up value for the DC to allow for drier than normal duff and soil moisture conditions (**Appendix 1**).

2.8 Weather Not Directly Observable

There are a number of complex meteorological conditions, not readily recognized or easily measured, that significantly affect fire behavior. For example, temperature inversions which sometimes produce surprising variations of fire danger with small changes in elevation, strong instability resulting in unexpected fire activity, and chinook or foehn winds with their extreme drying potential are only part of the list (Schroeder and Buck 1970).

Brotak and Reifsnyder (1977) described frontal patterns, local wind profiles and temperature profiles occurring in the portion of the atmosphere from the earth's surface up to 5 500 m which are generally associated with extreme fire behavior. No provision can be made in the FWI system to account for these atmospheric situations, but the fire weather forecaster can sometimes recognize dangerous warning signs in the upper air balloon soundings taken daily at a number of stations across the country.

Chapter 3

Sensitivity of the Fire Weather Index

Users should have an idea of how sensitive the Fire Weather Index is to weather measurements and to our ability to measure accurately the weather elements. A change of about 20% in an **individual** FWI value is about as small a difference as can be associated with recognizable differences in fire behavior. In other words, the difference can be seen on the ground between fires at FWI 10 and FWI 12 or between fires at FWI 50 and 60, both being differences of 20%. However, the difference in rate of spread or intensity which would be seen between two fires occurring at FWI 10 and 11 or between two fires at FWI 50 and 55 would generally not be significant.

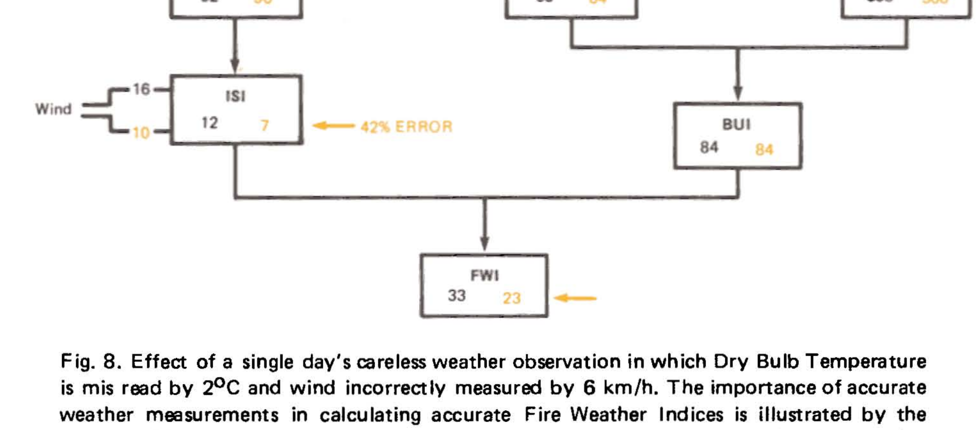


Fig. 8. Effect of a single day's careless weather observation in which Dry Bulb Temperature is mis read by 2°C and wind incorrectly measured by 6 km/h. The importance of accurate weather measurements in calculating accurate Fire Weather Indices is illustrated by the resulting 30% error in FWI. Even if just one of the errors had been made, the resulting FWI would still be 20% in error, a significant difference in terms of expected fire behavior.

At first sight, intervals of 20% might appear to be unduly large, but they are more precise than present assessments of the 'non-weather' components (e.g., fuels, topographic effects) of the total fire danger picture. For purposes of this User Guide, it will be sufficient to point out what changes in the fire weather elements are particularly effective in producing significant changes in the FWI. Such differences may be actual errors - or simply differences between two observations.

Changes of 20% in the FWI could be caused by a 35% change in the Initial Spread Index (ISI) or by a 45% change in the Buildup Index (BUI), or a combination of smaller changes in both. Changes of this magnitude in the ISI are consistent with changes of 2 units in the FFMC or changes of 6 km/h in the Wind Speed. The BUI is mainly sensitive to changes in the DMC; however, it requires at least a 45% change in the DMC to make this great a change in BUI.

The relative effect of rainfall (before drying) on the three moisture codes is shown in **Table 2.** In the case of the FFMC, the first day's drying reduces this effect by a significant amount, depending on Relative Humidity, Temperature and Wind Speed. The net result is that the first 5 to 10 mm are most effective in reducing the FFMC; the effect of any further rainfall above 10 mm tends to be masked by the subsequent drying stage.

In a more or less steady state, when sufficient drying has occurred to put the FFMC into the 80s or 90s, differences in the FFMC can be related to differences in temperature and relative humidity by the following rules of thumb: (1) a difference of 10% in RH corresponds to a difference of 2 in the FFMC; (2) a difference of 10°C also corresponds to a difference of 2 in the FFMC. As indicated, changes of these amounts in either of these weather elements, by these values, can lead to changes of 20% in the FWI.

TABLE 2

Relative Effects of 24-hour Rainfall on the Moisture Codes (Before Drying)

FFMC				DMC				DC			
	rainfall (mm)				rainfall (mm)				rainfall (mm)		
	5	10	20		5	10	20		5	10	20
Initial Code Value	% Reduction of FFMC			Initial Code Value	% Reduction of DMC			Initial Code Value	% Reduction of DC		
20	66	75	82	20	37	50	60	100	8	19	38
40	66	75	82	40	35	50	60	200	4	12	24
60	66	75	82	80	35	50	55	400	3	10	19
80	66	75	82	160	49	56	60	800	5	12	23
99	66	75	82	320	72	74	76	1000	6	14	26

Note: a 75% reduction means that a code value of 100 would be reduced by 75 units, giving a net value of 25.

Chapter 4

Observing Practices

Observing practices must be carefully specified and followed as closely as possible if effective management decisions are to be based on the results. These standards are essential for relatively permanent Fire Weather Stations which are part of a regional network, designed to be used for future calibration studies.

It may be necessary to relax the standards in some respects for short-term stations which may be set up from time to time to provide on-the-spot weather for specific purposes.

4.1 Time of Observations

The system is based on weather observations taken at a Standard Observation Time, which in almost every case is defined as **noon Local Standard Time** (1300 h Daylight Saving Time). Deviations may be specified at the regional level for stations close to time zone boundaries or at high latitudes.

Fig. 9. Keep observations within 15 minutes of Standard Observation Time.

The observation time must be late enough in the day to be indicative of conditions during the period of afternoon peak fire activity, but early enough to have indices and forecasts available for planning and operational purposes.

The earlier fire danger system used an observation time of local **apparent** noon (sun time) (Williams 1963). However, present day communications and data handling methods make it desirable to tie the observations in to the exact hour. This does not generally produce a significant loss of accuracy, provided the observations are taken within 15 minutes of the specified time (**Appendix 9**). On rare occasions, when it may be necessary to exceed these limits, the actual time of observation should be noted.

4.2 Precision Standards; Accuracy of Measurement

1. Temperature.

The normal precision (**Appendix 2**) required of dry bulb temperature observations for FWI calculations is the nearest half degree Celsius. The accuracy of the thermometers or other temperature sensors should be somewhat better than this; i.e., they should be accurate to $\pm 0.1^{o}C$.

Wet bulb temperatures will be measured to

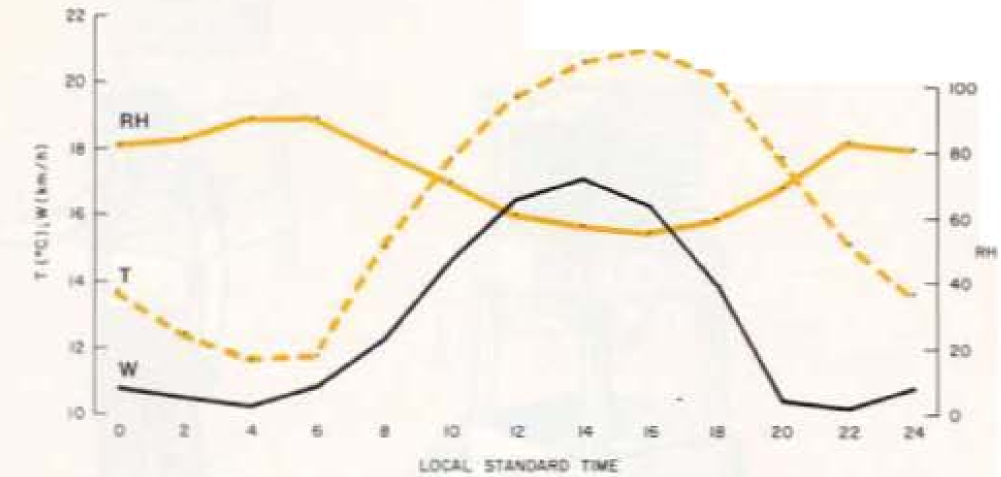


Fig. 10. Daily pattern of Temperature, Relative Humidity and Wind Speed for a typical station, Kapuskasing, Ont., July.

the same precision, on thermometers having comparable accuracy and response time to those of the dry bulb.

It is noted that a precision of ± ½°C for the wet and dry bulb leads to a precision of ± 1°C in the wet bulb depression so that calculated values of relative humidity from Table 10 in the standard FWI tables (Anon. 1978) are only significant to the nearest 5%.

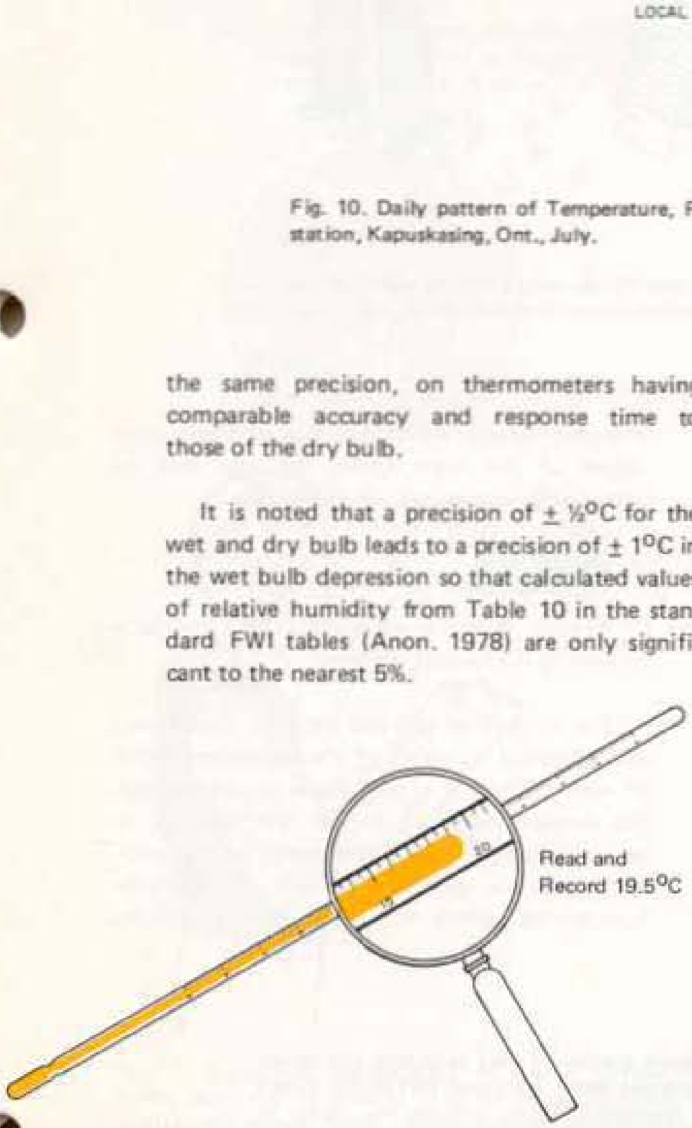


Fig. 11. Celsius thermometers should be accurate to ±0.1°C but are read to nearest ±0.5°C.

2. **Relative Humidity**

This will be calculated using Relative Humidity Tables 10, 10A, 10B or 10C (Anon. 1978) appropriate to the elevation of the station and recorded to the nearest whole percentage point. Table 10 is used for station elevations 305 m or less above sea level, Table 10A for stations between 306 and 760 m, Table 10B for stations between 761 and 1 370 m, and Table 10C above 1 371 m. (As indicated in the previous section, these tables can lead only to Relative Humidity values in steps of about 5%; nevertheless, it is convenient to retain the whole percentage value for subsequent entry in the FWI tables.)

The general accuracy of relative humidity values determined from ventilated wet and dry bulb temperatures will be well within fire weather requirements, provided the thermometers are accurate to the limits indicated in the previous section.

Readings of relative humidity from recording hygrographs are generally significant only to the nearest 5%, provided conditions are not

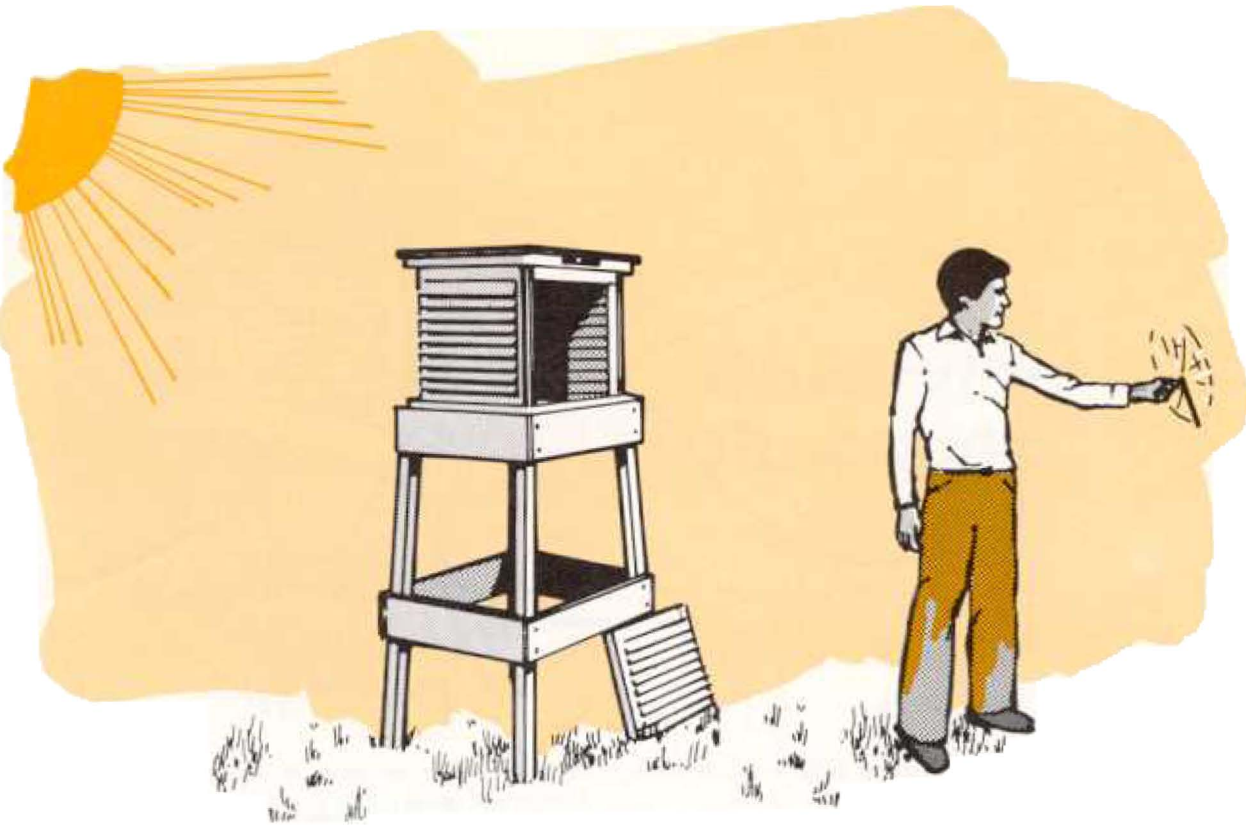


Fig. 12. Sling psychrometer must be twirled at least 20 sec. before reading Wet Bulb and then Dry Bulb temperatures; repeat to ensure correct values obtained. Shield from direct sun and rain when twirling and taking readings.

changing rapidly. As was the case with calculated values of RH from tables, readings may be recorded to the nearest whole per cent.

3. **Precipitation**

Rainfall is to be measured with a precision at least to the nearest 0.2 mm.

The amount of hail and snowfall is measured and recorded in terms of the equivalent depth of water. When it is reasonable to suppose that the amount collected in the rain gauge is an accurate sample, the actual depth of the melt-water will be used. For heavier snowfalls or hail storms, where the gauge has not caught

Fig. 13. Rain gauge graduate is read to at least the nearest 0.2 mm. The example shows the lowest part of the water's curved surface (meniscus) halfway between the marks, so this rain is recorded as 19.5 mm.

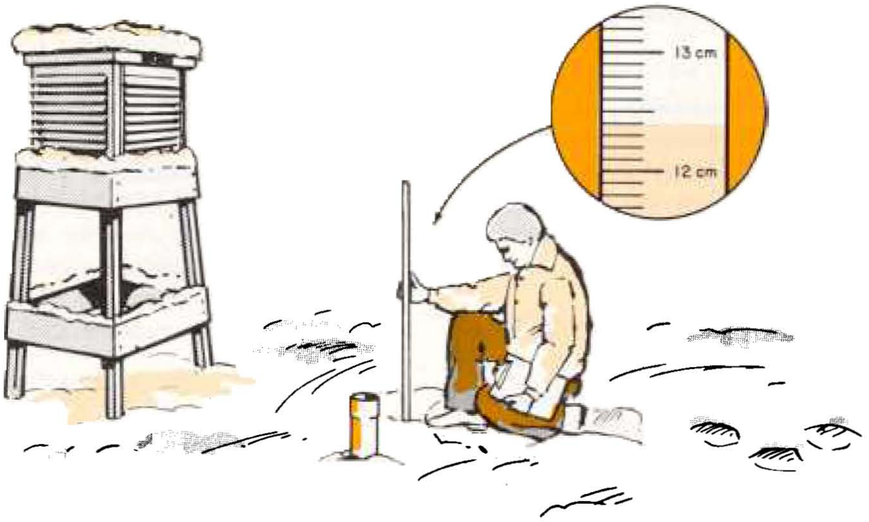
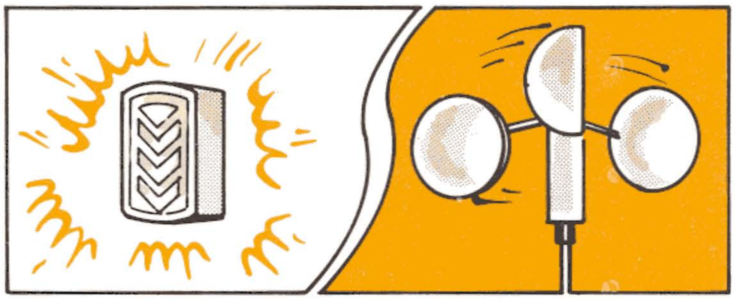


Fig. 14. Significant snowfalls should be measured at several places to nearest 0.2 cm, averaged, and recorded as the same number of mm of rain. In the example, read 12.4 cm of snow, record as 12.4 mm of rain.

a representative sample, an average value of the depth of snow or hail on the ground should be measured with a ruler to at least the nearest 0.2 cm. The water equivalent depth is then recorded as the same number of mm (i.e., 3.2 cm of snow is recorded as 3.2 mm of rain). This procedure assumes the water equivalent of snow is 10% of the snow depth. A note should be made in the REMARKS column of the monthly record when snow is recorded this way.

4. **Wind Speed**

Wind Speed should be averaged over at least a 10-minute period. Direct metric measurements should be made and recorded to the nearest whole km/h.



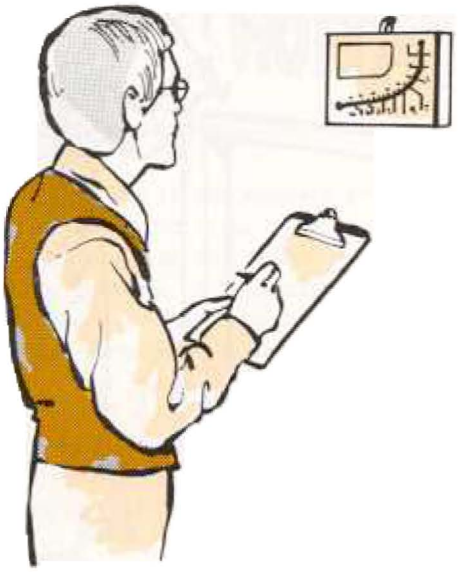


Fig. 15. Buzzer-type anemometers. At least 3 intervals of 2 min. each must be counted in 10 min period to obtain a satisfactory average wind. Meter-read-out anemometers. Meter must be watched for at least 5 intervals of 1 min. each in 10 min. period to obtain satisfactory average wind.

4.3 Sudden Weather Changes During Afternoon

Sudden weather changes occur frequently during the early afternoon in summer. Abrupt changes in wind speed, relative humidity, or occurrence of afternoon showers after the FWI has been calculated result in misleading information being used for the day unless the following procedure is used.

For local use (e.g., enforcing regulations, changing danger rating signs, etc.), up to 1600 h LST, it is acceptable to work up a **revised index** for the day to reflect more accurately the new weather regime. **A new set of weather observations should be taken and the FWI Tables re-entered.** For purposes of this interim calculation, the values calculated at noon will be ignored and new values of FFMC, DMC and DC will be calculated, using the **previous** day's values as the starting codes. Rainfall amounts used in the calculations should include any that may have fallen since noon. (Remember that this rainfall must be included in the 24-hour amount at the next regular observation).

For record purposes, the value at noon remains the basic observation for the day. It will normally provide the values from which the next day's codes are calculated.

There are occasional requirements for estimates of component code and index values at other times than noon, to allow for abnormal patterns of relative humidity, including abnormally low overnight values. Full directions for calculation of this type are in the appropriate CFS publication (Van Wagner 1972).

One basic assumption in the development of the FWI is that the component weather elements follow a more or less average diurnal pattern, at least from late morning through late afternoon. There are locations where the regular pattern is distinctly different from the average. Stations subject to strong sea breezes or valley winds, which pick up after noon, provide special problems. Valley bottom or coastal strips with morning fog, which persists until noon, are best handled with such additional observations as described above as long as they may

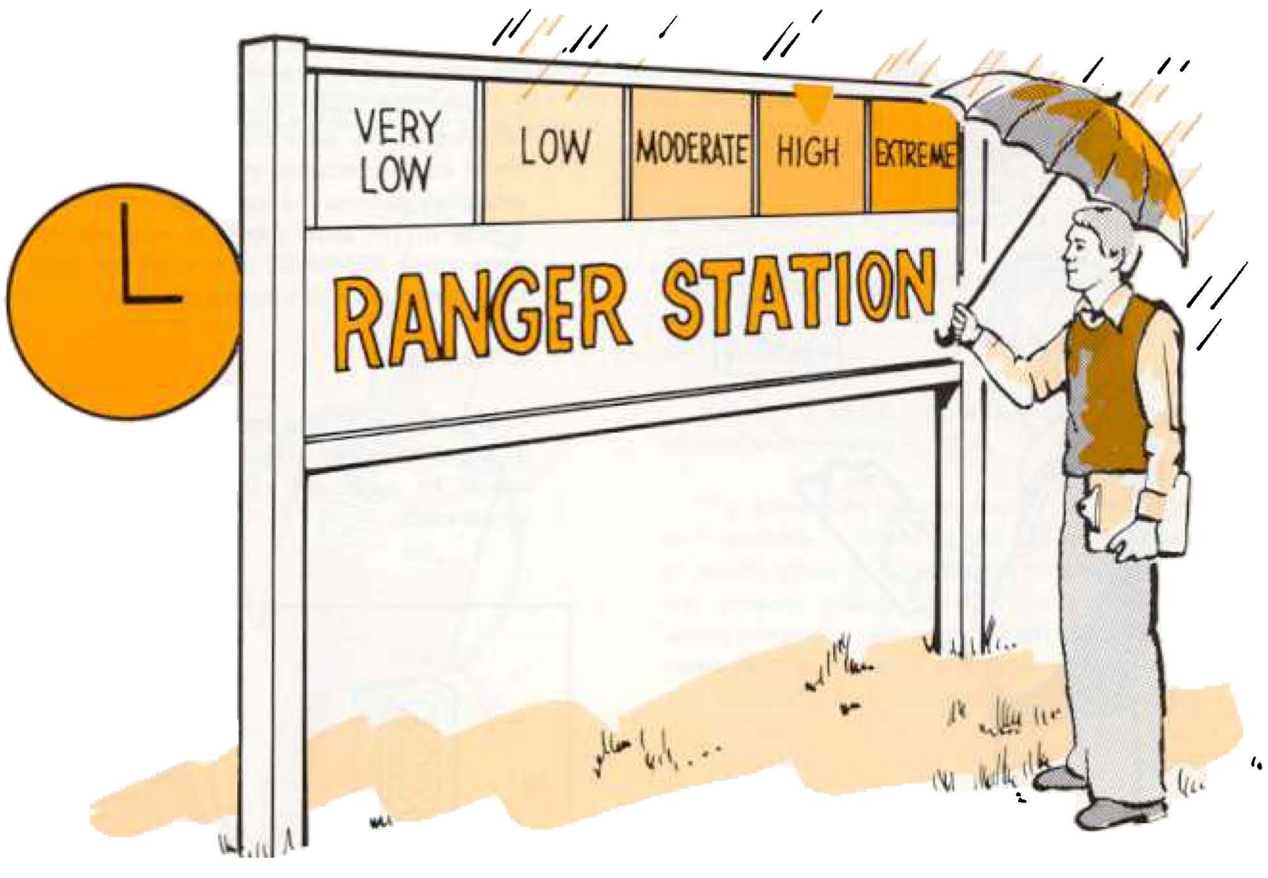


Fig. 16. Sudden afternoon changes in wind, RH or occurrence of showers requires new weather readings and index calculations.

be required.

It is possible to calculate FFMC for every hour around the clock if hourly weather readings are available. A computer program for these calculations is described by Van Wagner (1977). Its use is recommended to establish diurnal patterns of fire danger for unusual situations caused by latitude, elevation, coast or valley winds etc.

4.4 Recording Practices

Whenever possible, observations should be recorded directly on the permanent record form so that copying errors are reduced to a minimum. Failing this, entries should be made into a proper field notebook, which can be referred to in case of questionable values. Original observation records should always have the initials of the observer. If, for any reason, there is a deviation of more than 15 minutes from the regular observation time, this must be noted.

In addition, the weather information may need to be coded for transmission to the appropriate Fire Weather Forecasting Centre for data processing and use of the meteorologist. This will often include supplementary information according to regional needs. Details of coding and transmission of these messages are subject to regional requirements.

4.5 Missing Observations

The key to the accuracy of the FWI is continuity of records. Any break in the sequence of daily observations will lessen the accuracy of the system. However, it is possible, on occasion, that observations are missed because of equipment breakdown or some other reason. When this occurs, it is incorrect to ignore the missing day (or days) and start records again when observations are resumed, using the old starting codes. To keep the records going, an estimate of weather elements for the missing day or days is required.

Whether Index calculations are made by computer at a Fire Weather Forecasting Centre, or calculated locally from FWI Tables, the missing data must be replaced by average values or values extrapolated from a nearby station (**Appendix 3**).

4.6 Starting Procedures

Normally, the regional fire management agency or Fire Weather Forecasting Centre provides dates and starting values of the three moisture codes of the FWI each spring for primary network stations. If such direction is not available, the following procedures can be used to determine starting code values.

(a) Where snow cover is normal during the winter, begin calculations on the third day after the area (to which the Index is to apply) is essentially free of snow, using the following starting code values:

FFMC = 85
DMC = 6
DC = 15

(b) In regions where snow cover is not a significant feature, calculations should be started on the third **successive** day that noon temperatures of 12°C or higher have been recorded. On this day, use the following starting code values:

FFMC = 85
DMC = 2 x number of days since measurable precipitation
DC = 5 x number of days since measurable precipitation

There are often requirements for supplementary stations where it is not possible to get them in operation at the beginning of the season. In such cases, the regional Fire Weather Forecasting Centre should be contacted for an estimate of the starting code values to be used, particularly for the DMC and DC. (A wrong guess for the FFMC starting code will correct itself after about 3 days of record.) **Do not assume automatically that DMC and DC start at zero on the first day the observations start.**

Stations starting at the beginning of the fire season or later in the spring or summer may need their starting Drought Code values adjusted for over winter precipitation deficiency. These corrections are usually applied, when necessary, by the Regional Fire Weather Authority in consultation with the fire management agency, so these sources should be consulted in situations where a carry over of drying through the winter is suspected. A procedure for making Drought Code starting value adjustments is given in **Appendix 1.**

SUMMARY

Chapter 4. OBSERVING PRACTICES

4.1 Time of Observations

- 1200 h Noon Local Standard Time (1300 h Daylight Saving Time) is Standard Observation Time.
- If specified time is missed by more than 15 minutes, note actual time of observations in the monthly record.

4.2 Precision Standards; Accuracy of Measurement

1. Temperature
   - Both wet and dry bulb temperatures should be observed and recorded to the nearest half degree Celsius.

2. Relative Humidity
   - Enter table for correct station elevation with wet and dry bulb temperatures. RH is recorded to nearest whole per cent.

3. Precipitation
   - Measure and record rainfall to at least the nearest 0.2 mm.
   - For hail, measure or estimate water equivalent as rain.
   - For snow, measure water equivalent as rain, if possible; if not, measure snow depth to nearest 0.2 cm and record water equivalent as same number of mm.

4. Wind Speed
   - Measure at least a 10-minute average. Record to nearest 1 km/h.

4.3 Sudden Weather Changes During Afternoon

- Weather changes after Standard Observation Time such as:
  (i) rain showers,
  (ii) sharp increase in wind speed,
  (iii) clearing skies with sudden RH drop will cause FWI calculated at noon to be in error.

- Revised FWI calculation may be made as follows:
  (i) Take new set of weather readings.
  (ii) Use yesterday's moisture codes as starting values.
  (iii) Recalculate all codes and indices for the day. This is a valid procedure between 1200 and 1600 h only. Normally, the official record for the day consists of only the indices calculated for noon, not the revised calculations.

4.4 Recording Practices

- record weather observations directly into the permanent record to reduce errors.
- identify the observer and note if noon has been missed by more than 15 min.
- take care with computerized recording sheets, errors are easy to make.

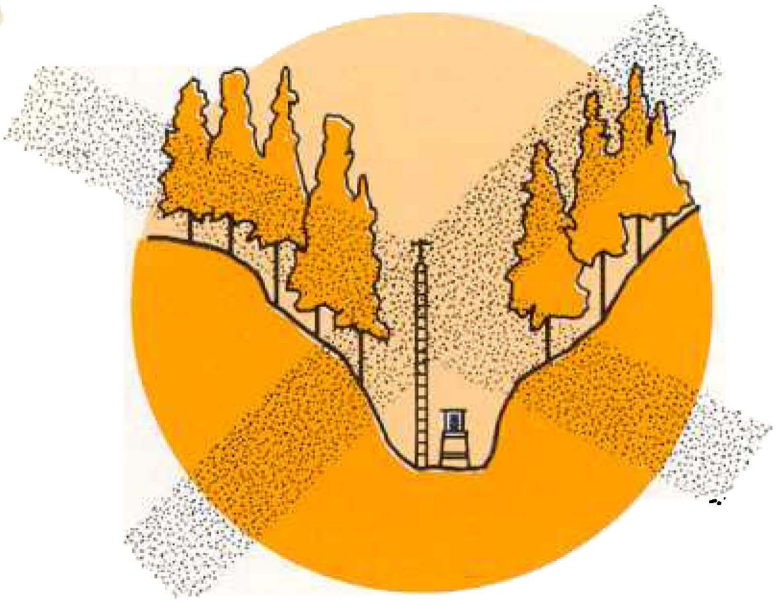
4.5 Missing Observations

- A continuous daily weather record is most important.
- If a day is missed, fill it in as follows:
  (i) Use recording instrument records if available; e.g., hygrothermograph.
  (ii) Use values from nearest similar station.
  (iii) Take average of day before and day after.
  (iv) Make rough estimate from knowledge of general weather pattern.

4.6 Starting Procedures

- Basic procedures are given in FWI Tables.
- Late starting stations require an estimate of starting codes from regional Fire Weather Forecasting Centre.
- Overwinter drought adjustments to Drought Code are detailed in **Appendix 1.**

Chapter 5



Weather Stations

5.1 Location Standards

In general, Fire Weather Station standards conform to those recommended by the World Meteorological Organization for agrometeorological observations in forest areas (WMO 1968).

The following standards are designed to give representative values of the various weather elements. It will not always be possible to meet all of them in practice, but any major deviation could result in reduced accuracy of the FWI.

Ideally, the Fire Weather station should be:

(i) located in a place which represents the general area of concern with respect to elevation, topography, vegetative cover, local weather patterns etc. Avoid sheltered valleys and exposed peaks and ridge tops. Level or nearly level ground is preferred. If slopes must be used, avoid north and

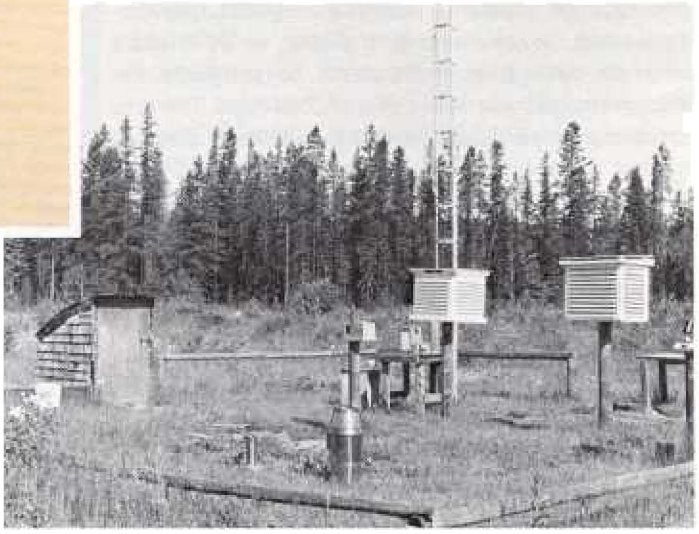


Fig. 17. Fire weather station in large clearing on open level ground. In addition to basic instruments, this station includes recording rain gauge, anemometer, solar radiation and dew recording devices. Both wire and open pole fencing were used. Vegetation has been cropped.

east facing slopes and avoid concave, i.e. dish-shaped land forms.

(ii) located at the centre of a forest clearing having a **diameter** no less than **10 times** the height of the surrounding timber;

(iii) no closer than 100 m to any major source of moisture (lake, stream, swamp, irrigated area);

(iv) no closer than 10 m, or in the case of buildings no closer than a distance equal to twice the height of the building, from large reflecting or radiating surfaces. These include metal or white painted buildings, black-topped or gravelled parking lots, rock outcrops, recently burned areas.

(v) no closer than a distance equal to 1.5 times the height of the obstruction from any large building, tree, or dense vegetation.

(vi) no closer than 5 m from any road.

(vii) at least 50 m away from excessively dusty areas. These can usually be avoided by looking for dust accumulation on nearby vegetation.

If the prevailing wind direction during fine weather is known for the area, locate the station on the **windward** side of any sources of moisture, reflection, radiation or dust.

It is good practice to arrange the instruments in a fenced enclosure approximately **7 m square.** The type of fencing is subject to regional specifications; but, in any event, it should be of suitable wire or open pole construction to safeguard the equipment and not more than 1.2 m high. The area inside the fence should be of mown grass or cropped natural vegetation. When located in a logged area, the enclosure should be cleared of logs and branches.

5.2 Instrument Exposure Standards

Wet and dry bulb thermometers must be adequately ventilated, preferably by a motor-driven fan pulling the air past the two thermometer bulbs. The two bulbs should be oriented so that the air will not pass over the dry bulb after being cooled at the wet bulb. Alternatively, wet and dry bulb readings may be taken with a good portable psychrometer with battery-operated fan, or with a sling psychrometer large enough to provide the necessary precision. Wicking for the wet bulb thermometer must be clean and should be replaced several times a season. Clean, mineral-free water or distilled water should be used to wet the wick.

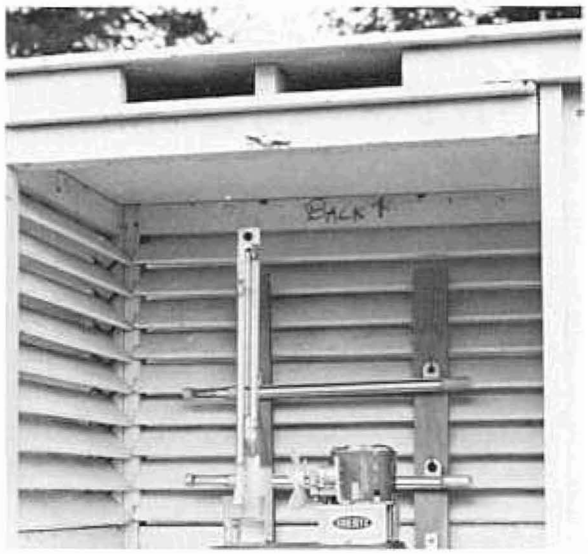


Fig. 18. Electric fan psychrometer with push-type fan, so wet bulb is on left, farthest from fan. Maximum and minimum thermometers at rear, mounted level or with bulbs slightly down.

These thermometers, together with maximum and minimum thermometers, when available, are to be housed in an acceptable white-painted, wooden Stevenson-type screen, with **double louvered** sides and **double** roof. The screen should be solidly mounted, with the floor **115 cm** above ground level, the door opening to the north. The shelter should be mounted on a rigid but open framework of posts or 2x4s not on a solid base, such as a stump.

Additional recorders, such as hygrothermographs, should be in a separate screen from the thermometers.

Precipitation measurements may be made, using any suitable gauge, provided the collecting area is rigid enough to be reasonably constant, and the depth to the funnel is adequate to prevent splashing. The gauge must be rigidly mounted, with the top surface of the collecting funnel carefully leveled. The older style MSC copper gauge is mounted with

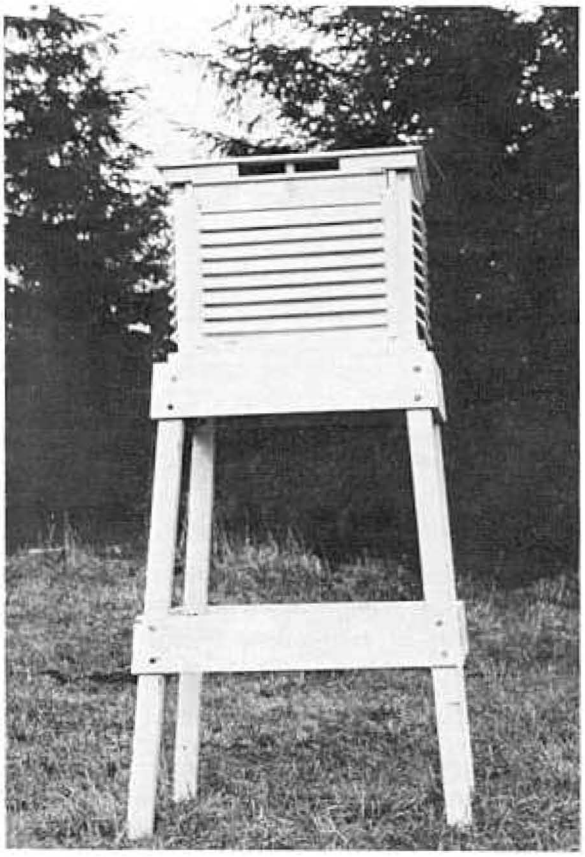


Fig. 19. Stevenson screen on open framework stand, floor at 115 cm above ground. Painted white, door faces north.

Fig. 20. Hygrothermograph mounted in separate screen. Note this is preferred type of screen with double-louvered sides and double roof.

the surface 30 cm above ground level, whereas the newer Atmospheric Environment Service (AES) metric gauge is mounted at 50 cm. Being mounted lower could result in errors from splashing; being mounted much higher could result in the amount of rain collected being reduced by turbulence, unless the gauge is equipped with a properly designed wind shield, as at some AES stations.

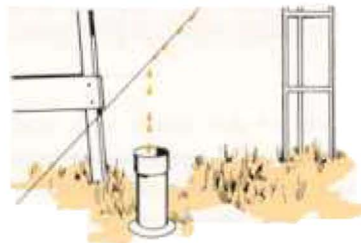


Fig. 21. Rain gauge exposure on weather station is important. This gauge is not mounted on a rigid base, is too close to instrument shelter and catches guy wire drips.

The gauge should be located so that no obstructions are closer to it than twice the height of the obstruction. (This is not always possible with anemometer masts, but watch out for weather screens, or fences and guy wires that could drip into the gauge.)

Wind speed measurements are usually made at the same site as the other weather elements. With remote measuring or recording equipment, it is sometimes more convenient to place the anemometer as much as 500 m away, if this is required to give a more representative value.

To meet World Meteorological Organization (WMO) standards on which the FWI system was based, the anemometer should be mounted on a substantial, well-guyed mast, with provision for climbing with safety or lowering the anemometer head for servicing. Provision for lightning protection is highly recommended (Fischer and Hardy 1976).

Wind speed increases rapidly in the layers just above the ground and it is strongly influenced by nearby obstructions. The **standard height** for an anemometer over open level ground is **10 m**; this height is just barely acceptable in a clearing if the nearest timber edge is more than **five times** the average height of the timber away from the mast.

Clearings of this size are not easy to find where they are needed, thus an alternative solution

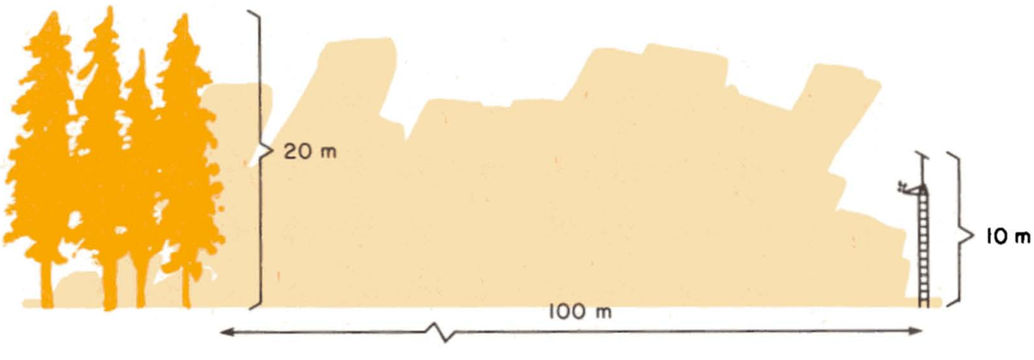


Fig. 22. Standard anemometer height is 10 m if clearing is large enough so that nearest timber edge is at least a distance 5 times the height of the trees away from the mast.

is usually required. The best solution is a taller mast. If no clearings were available, the correct height would be 10 m above the mean treetop level. Most of the time smaller clearings are available, so that the corresponding anemometer height is somewhere between the "open ground" value of 10 m and the "closed canopy" requirement of tree height plus 10 m. As average distance from anemometer to trees approaches five times the height of the trees, the mast height can be decreased to the standard 10 m level. **Appendix 4** gives the mast heights to be used with smaller clearings; for example, if the mast is located 30 m from the nearest timber edge, and the average tree height is 20 m, the anemometer height is 23.4 m. If it could be located 50 m away from the same edge, the mast height could be reduced to 16.5 m.

The heights given in **Appendix 4** are heights above **effective** ground level. If the clearing is relatively free from irregularities, this coincides with the actual ground surface. If, however, there are **frequent** large irregularities throughout the clearing, such as hummocks, clumps of brush or slash piles, the **effective** ground level is raised from the actual ground level by an amount equal to ¾ of the average height of the irregularities. For example, if the clearing were dotted with brush averaging 2 m high, the effective ground surface should be elevated by 1.5 m, i.e., the tower height as determined by **Appendix 4** should be increased by 1.5 m. See Appendix 5.

5.3 Instrumentation Accuracy Standards

It is not intended to deal with maintenance of specific meteorological instruments used for fire weather observations. Details are already covered in a number of publications (Fischer and Hardy 1976; Anon. 1969; Anon. 1974; Anon. 1977a and b).

Specifications for fire weather instruments are too detailed for a user's manual of this type. However, guidance is available from AES offices. Evaluation of new types of equipment is one of the services available from AES as a "cost recoverable" service, and should be arranged through the District Meteorologist.

Thermometers, particularly when used for determining relative humidity, should have an accuracy of $\pm 0.1^{\circ}C$. Fans for ventilating wet and dry bulb thermometers should be capable of delivering air with a velocity of at least 3 m/s.

Thermographs used for auxiliary measurement should be capable of an accuracy of $\pm 0.5^{\circ}C$ and have a time constant of the order of several minutes or less.

Hygrographs should be accurate to less than ± 5% under steady conditions. The hairs should be arranged or spaced to have a short response time at normal operating temperatures. The instrument should not have any significant temperature coefficient or, if it does have one, the correction factor should be known and applied to the readings.

Instrument screens should be large enough to house properly the equipment they are designed to shelter. Auxiliary equipment not requiring this kind of screen (e.g., wind recorders) is more properly housed in a separate box. It is particularly important that the screens be kept painted and in good repair.

While it is possible to specify short response times for thermometers, these are normally overridden by the response time of the instrument shelter. Typical values are of the order of 10 minutes for shelters in forest clearings, and such response times are adequate for fire weather purposes (MacHattie 1965).

Rain gauges are subject to few limitations. The area of the collecting surface should be well defined (i.e., have a rigid, sharp edge), and between 60 and 300 square centimeters. There is little to choose between the dipstick or graduated collecting vessel. The funnel design should minimize splashing.

The three cup anemometer, with its ruggedness and reliability, is well suited to fire danger measurements. It is a simple matter to count the number of meters of wind (or fractions of a mile on non-metric instruments) that pass the cups in the basic 10-minute period.

5.4 Fire Weather Station Networks

How large an area can reliably be represented by any given FWI value from a single station? There is no hard and fast answer to this question, although the result of studies made on the former Fire Danger System still generally apply over eastern and central Canada; namely, within a radius of about 40 km, the index values can be expected to be highly reliable; at distances greater than 160 km, weather conditions are usually so different as to make the index generally unreliable (Williams 1963).

In British Columbia, Alberta's East Slopes, and the Yukon, where weather patterns tend to vary from one valley to another or from one elevation zone to the next, the area accurately represented by a given station can best be determined by local knowledge of the terrain and climate. Nevertheless, a 10-year study of index values and fire statistics in British Columbia indicated that index values did give useful information about fire activity for fires occurring as far as 100 km away (Lawson 1972).

There is no simple rule for choosing locations for fire weather stations. Until suitable automatic fire weather stations are available, weather stations will be located where people can attend them daily and on time. However, each station should be located where it can best represent the area it is intended to cover, whether that area be some tens of thousands of square kilometers for a regional network or a few square kilometers covering a particular operating area.

In some areas there may be problems in choosing a representative station. Locations with regular strong diurnal winds (lake or sea breeze, valley winds) or coastal fog strips may not be representative of the general area, but may be important enough to require sampling.

Distance alone may not be the factor that determines the reliability of a particular station. Differences in elevation can be far more significant in limiting the area represented by any given station in mountainous terrain. Thus it is often particularly difficult to relate information from valley bottom stations to nearby ridge top conditions only a few kilometers away.

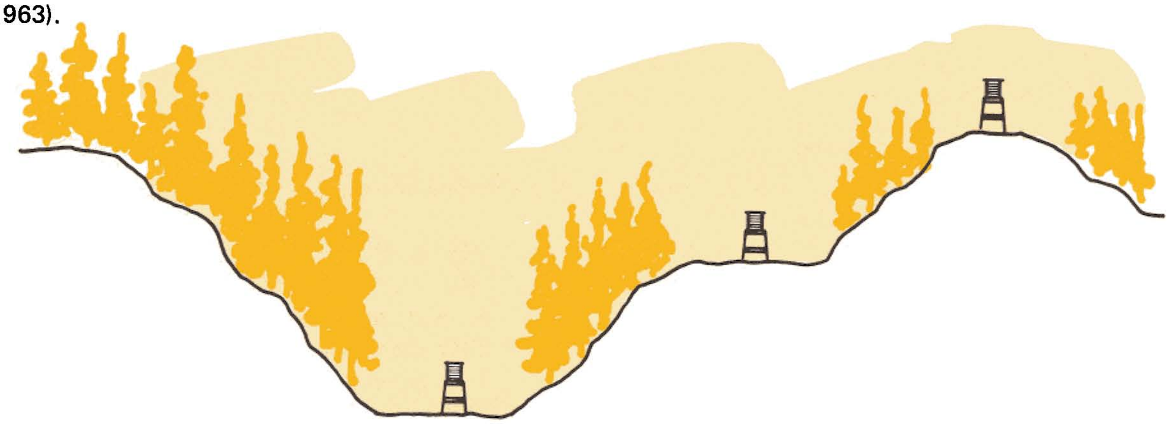


Fig. 23. Networks of fire weather stations must take into account such problems as ridge top and valley bottom locations being easier to service but not as representative of important fire danger conditions as mid-slope bench locations.

5.5 Supplementary Fire Weather Stations

In addition to the regular Fire Danger network stations, which should have a real expectation of permanence, there is frequently a need for special purpose supplementary fire weather stations.

Some of these differ from the network stations only in their permanence; i.e., they may be in existence only during some specific activity.[1] Others may be as simple as an auxiliary rain gauge, perhaps read at infrequent intervals in order that qualitative adjustments may be made to moisture code values from a nearby network station. Still others may simply be a suitable location where relative humidity is obtained with a portable psychrometer, and wind speed is estimated or measured with a hand-held wind gauge. As a rule, wind speeds measured with an "eye-level" wind gauge should be increased by slightly more than 50% to make them consistent with speeds measured at 10 m; i.e., a reading of 6 km/h at eye level indicates 9 km/h at 10 m (**Appendix 6**). Non-instrumental estimates of wind speed, using such guides as the Beaufort Scale (**Appendix 8**), are generally for the 10 m level.

Fig. 24. Supplementary fire weather station set up in advance of prescribed burn to record weekly rainfall. Hygrothermograph in shelter. Wind measured with eye-level gauge, adding 50% to adjust to 10 m height.

SUMMARY

Chapter 5. WEATHER STATIONS

5.1 Location Standards

- Fire weather station should be:
(i) located where it represents the general elevation, topography, vegetation and local weather patterns of the general area of concern. Avoid sheltered valleys and exposed peaks and ridge tops. Level or nearly level ground is preferred. Avoid north and east exposures (aspects) and concave or dish-shaped topography.
(ii) located at **center of forest clearing with diameter at least 10 times the height** of surrounding timber;
(iii) at least 100 m from any water source;
(iv) at least 10 m or twice the height of the object away from reflecting and radiating surfaces such as parking lots or white buildings;
(v) at least a distance equal to 1.5 times the height of the object away from any large building, tree or dense vegetation;
(vi) at least 5 m from any road;
(vii) at least 50 m from any source of dust;
(viii) located to windward of any of the above features;
(ix) fenced with open pole or wire fencing no higher than 1.2 m.

5.2 Instrument Exposure Standards

1. Wet and dry bulb thermometers must be ventilated. If electric fan is used, make sure wet bulb is farthest from fan if fan **blows** the air. It is preferable to have fan **pull** the air, with wet bulb thermometer

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[1] See 4.6 for late start-up procedures.

mounted closest to the fan.

2. These thermometers, together with maximum and minimum thermometers if used, must be mounted in a Stevenson-type screen. The screen should be:
   (i) wooden, double louvered sides, double roof;
   (ii) painted white;
   (iii) rigidly mounted on wooden framework with floor 115 cm above ground and door facing north.

3. Recording instruments, such as hygrothermographs, should be in a separate screen from thermometers.

4. Precipitation gauges must be:
   (i) rigidly mounted at correct height for specific gauge;
   (ii) level;
   (iii) no closer to any obstruction than twice the height of the object.

5. Wind should be measured with an anemometer exposed as follows:
   (i) **10 m above open level ground,** if nearest timber edge is at least **five times** the height of the timber away from the anemometer mast.
   (ii) 10 m above average treetop level in a forest stand, if no clearing is available.
   (iii) if smaller clearings than specified in (i) are used, anemometer masts should be raised above the 10 m standard. Guidelines are given in **Appendix 4.**
   (iv) if anemometer site is not on open level ground, irregularities like brush, slash, hummocks should be corrected for by raising mast height. Guidelines are given in **Appendix 5.**

5.3 Instrumentation Accuracy Standards

Consult the appropriate agency manual for details of particular instruments, including observing and maintenance practices. Several manuals are listed in **Bibliography** section.

1. Thermometers should have accuracy of $\pm 0.1^{\circ}C$.

2. Ventilating fans for wet and dry bulb thermometers should move air with velocity at least 3 m/s.

3. Thermographs should have accuracy of $\pm 0.5^{\circ}C$ and have a time constant no more than several minutes.

4. Hygrographs should be accurate to at least $\pm 5\%$ RH under steady conditions where the relative humidity is not changing rapidly.

5. Rain gauges are not subject to many accuracy limitations, so long as the required measurement precision (Section 4.2.3) can be achieved. Gauge collecting surfaces must be rigid, free of dents and can vary in size from 60 to 300 cm^2. To ensure accurate readings, the correct graduated cylinder or dip stick for the particular instrument must be used. An instrument of large enough capacity to match the heaviest rainfall expected at a given location should be selected. Gauges should not be mounted higher than 50 cm above ground without a proper windscreen or turbulence will affect accuracy.

6. Anemometers of the three-cup type with mechanical counters can provide suitably accurate 10-minute wind speed averages for fire danger indices. Accuracy depends on proper maintenance of cups (round, free of dents or holes, turning freely on shaft), counters and power supply.

Chapter 6

Fire Weather Forecasts and Fire Danger Forecasting

The Federal Department of the Environment Policy on Meteorological Services for Forest Fire Control sets out the responsibilities of the AES and CFS in provision of fire weather forecasts, fire danger forecasts and other weather-related services to the various fire control agencies. Briefly, this policy gives AES the responsibility of providing current and forecast fire weather and Fire Weather Indices in accordance with the needs of fire control agencies. The CFS role is that of research and development of improved Indices, research on fire behavior relationships with weather factors, and cooperation with AES in preparation of training aids and manuals. Both AES and CFS share the responsibility of improving meteorological services for fire control in Canada.

Weather forecast services provided to fire control agencies are produced at several levels.

The Canadian Meteorological Center of the Atmospheric Environment Service at Montreal is concerned with the motions and development of major global weather patterns. By using sophisticated computer technology, they are able to produce weather outlooks for several days ahead. These outlooks are lacking in detail, both in time and space, but they can be used as planning guides.

Forecasters at the AES regional Weather Centers located in Vancouver, Edmonton, Winnipeg, Toronto, Montreal, Halifax and Gander are able to put a magnifying glass on their particular area and fill in missing details by maintaining a continuous watch on the behavior of the global and medium-sized systems with their associated weather. In this way, they can be much more specific as to times and to occurrence of local features not controlled by the large-scale systems.

The Fire Weather Forecasts are provided by specialized units, usually, but not always, part of the Weather Center. The actual organization varies from region to region, and is flexible enough to serve the specific needs of the user agencies.

6.1 Fire Weather Forecasts

One of the most satisfactory ways of providing a specialized fire weather forecast service is to have meteorological personnel operating as an integral part of the fire control organization. In this way, it is possible to put the necessary emphasis on those weather factors significant to the user agency (duration of dry spells, local wind systems, lightning activity). The direct, one-to-one contact between meteorologist and fire control officer ensures that the former is kept informed of changing weather requirements as they develop, and the fire control officer is able to request specific details and get some feel for the expected reliability of forecast information.

It is not possible to measure more than a very small sample of weather. The Atmospheric Environment Service of Environment Canada, in cooperation with other national weather services, operates a synoptic network of weather stations that is adequate to sample on a global or continental scale. These stations are, of necessity, located in well-exposed sites and are usually representative of non-forested areas.

Specialized fire weather station networks are required in the provision of fire weather forecasts, as well as being of current value to fire management personnel. These stations are necessary to fill in the gaps between synoptic stations and to enable the fire weather forecaster to provide the amount of detail and precision that is required in spot forecasts for specific locations, that can be interpreted in terms of fire behavior.

6.2 Fire Danger Forecasting

Routine calculation of the FWI, with its component codes and Indices, is normally performed daily for the regional fire weather network using a computer program (Van Wagner and Pickett 1975). An estimate of potential fire severity for the current afternoon period is the result. Because the FWI was designed to be entirely a function of weather, forecast values of the Index can be produced readily from forecast values of the necessary weather elements.

One of the problems that must be recognized in making and using such forecasts is the inherent difficulty in forecasting two of the fire weather elements to which the Index is most sensitive; namely, the amount of rainfall and the wind speed. This is offset somewhat by the fact that the need for precise Index forecasts is reduced with the occurrence of any appreciable rainfall.

Forecasts of numerical values are traditionally given as a single figure, sometimes rounded off to the nearest 5 or 10 units. This has usually been a matter of economy in transmission. This seems to imply categorically that the value forecast is expected to occur, while all other values are not expected. In actual fact, the value shown is usually the most probable value, while there may be a number of other values with an expectation only slightly less than the one indicated.

There are two ways of improving this situation. The first, used by the FORET METEO service for Quebec (Pouliot 1974), increases the expectation of success by forecasting broad ranges of numerical values and entering these in abbreviated tables to provide more realistic forecasts by **index classes.** A logical extension of the first method requires that the forecaster assign probabilities of occurrence to each range of values for each forecast element. This is true 'probability' forecasting, and is not designed to make the product look good, but simply to indicate the uncertainties of the given weather situation. (The current practice of giving the per cent chance of rain is a minimal kind of probability forecasting with only two classes: - 'rain' and 'no rain'.)

There are two basic approaches to fire danger forecasting in current use. These are 'area averaging' and 'point forecasting', an example of the former being described for the Atlantic provinces by Paul (1970) and the latter described by Nikleva (1975) for B.C.

In regions where the scale of significant fire weather patterns is large enough to be represented by several observing stations over an area, the weather observations from such a group of stations are subjectively averaged together before today's fire danger indices are calculated. The forecast fire danger indices for tomorrow uses today's **area** fire danger calculation together with tomorrow's **area** forecast weather observations so that the numbers issued by the forecaster represent an **average** index for an **area.** This technique tends to minimize some of the difficulties associated with rainfall and wind speed variability from station to station.

The 'point forecasting' approach is used in mountainous regions, such as British Columbia, where topography forces the fire weather pattern into a fine-scale mosaic. A number of areas or weather zones with fixed boundaries are selected and one or more reference weather observing stations are chosen to represent at least some part of each zone. Indices are then calculated for the observed and forecast weather for these specific station locations. This approach recognizes that there will be locations within each zone where index values are markedly different from those at the **selected station.** These differences, however, can be allowed for, at least in a qualitative way, on the basis of recognizable features of the landscape.

The forecast weather element values, used for forecasts of the FWI, are for noon local standard time and, therefore, require adjustment for the maximum temperature and associated relative humidity. At the same time, the forecast wind speed must be reduced somewhat more than for non-forested areas to make it comparable with values measured in generally forested areas. Simard (1971) has suggested a technique for calibrating wind speeds at forest stations against more exposed airport stations. **Appendix 7** gives an estimate of the adjustment factors that might be expected on the basis of broad classes of surface roughness that can be assigned in advance.

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APPENDIX 1

OVERWINTER ADJUSTMENT TO DROUGHT CODE STARTING VALUE

Fire weather stations are normally operated only during the fire season, which in most regions of Canada includes part of April, May through September, and part of October. Generally, there is sufficient precipitation over the winter months to saturate forest fuels so that the moisture codes of the Fire Weather Index can safely be started up from zero early each spring. However, in some regions in some years, winter precipitation may be insufficient to saturate the deep, heavy duff fuels. In these circumstances, Drought Code can be adjusted upward in the spring when daily calculations begin after snowmelt is complete.

To ensure consistency of fire danger records, it is recommended that **Regional Fire Weather Authorities** be consulted each spring for individual fire weather station Drought Code starting values. These meteorological people have winter precipitation amounts for the entire region at their finger tips and are best equipped to make the calculations of over winter deficits and spring adjustments to Drought Code as required by the fire weather network stations. Persons responsible for operating fire weather stations which are not part of a provincial or regional network would be advised to contact the Regional Fire Weather Authority for starting code values to ensure that non-network stations received the same treatment as network stations.

The following procedure can be used to determine spring Drought Code starting values. Although the DC starting values would normally be provided by the Regional Fire Weather Authority, the procedure is given here for the user's information.

The following two values must be obtained from the appropriate sources of records for Fire Weather Index data and year-round weather data:

1 **The DC value reached on the last day of index calculations the previous autumn.** Ideally this date should be November 1 or date of continuous snow cover or ground freeze-up, whichever comes first. Call this **DC_F**.

2. **Precipitation amount, total in mm water equivalent for period between date of last calculation in autumn to date of spring start up of calculations.** Over winter precipitation is measured by the network of synoptic and climatological stations operated by the Atmospheric Environment Service. Some regions have high elevation snowpack data available from hydrological surveys and other sources to supplement the AES network of lower elevation stations. Call this precipitation amount **P**.

In addition, two fractional values must be selected by the user or regional fire weather authority to permit entry into the equation or the graph of starting DC values below. These two values are:

1 **Carry over fraction of last fall's moisture.** Three values are recommended, the choice to be based on the following considerations. Use **1.00** if daily calculations of DC were made right up to the time of continuous snow cover, ground freeze-up, or November 1, whichever comes first. Use **0.75** if daily calculations of DC were stopped before any of the above conditions were

achieved or if the area is subject to occasional winter "Chinook" conditions which leave the ground temporarily bare and subject to moisture depletion. Use **0.50** as a lower limit of fall moisture carry over, to be applied in areas and seasons where the forested areas have been subject to long periods of fall or winter conditions favoring soil moisture depletion. Call this fraction **a.**

2. **Effectiveness of winter precipitation in recharging depleted soil moisture reserves in the spring.** The fraction of total winter precipitation which is actually available to percolate into the forest fuel and soil layers the next spring depends on a number of complex factors. Some of these are depth and type of ground frost; interception, evaporation, and water content of snowpack; spring thaw temperature regimes which affect amount of runoff that occurs before melting of ground frost, and occurrence of "Chinook"-type warm dry winds which can remove large amounts of snow by evaporation before any of the moisture has a chance to enter the forest fuels.

In the absence of any accurate workable system to make detailed calculations of all these factors involved in an over-winter forest fuel moisture budget, three values for precipitation effectiveness are suggested for the user to select from to best suit his type of winter regime. These are as follow:

Use **0.50** precipitation effectiveness in Chinook-prone areas and in areas subject to early and deep ground frost. Well-drained sites favoring rapid percolation e.g. sandy soils, and topography favoring rapid runoff prior to melting of ground frost should use **0.50** as well.

Use **0.75** for areas where deep ground frost does not occur until late into the fall if it occurs at all. Moderately drained sites where a major portion of the melting snowpack would infiltrate the duff and soil layers regardless of how early or late spring thaw occurs should use 0.75.

Use **0.90**, which is probably an upper limit of possible precipitation effectiveness, for poorly drained, boggy sites with deep organic layers.

Call this fraction **b**. One particular combination of **a** and **b** may be chosen to apply to all the stations in a region, primarily for convenience.

These four factors are entered into the following general equation to determine each station's DC starting value:

$$SMI_S = a(SMI_F) + b(3.94P) \qquad \text{Equation A1-1}$$

where SMI_S = Spring starting DC, (DC_S) expressed in units of Stored Moisture Index (SMI)

a = carryover fraction of fall moisture (1.00, 0.75 or 0.50).

SMI_F = Fall value of DC (DC_F) for Nov. 1 or freeze-up, expressed in units of Stored Moisture Index.

b = precipitation effectiveness fraction (0.50, 0.75 or 0.90).

P = overwinter precipitation in mm water equivalent from Nov. 1 or freeze-up to spring start up date.

Conversions from DC to Stored Moisture Index (SMI) units and vice versa are made as follow:

$$SMI = 800 \exp(-DC/400) \qquad \text{Equation A1-2}$$

$$DC = 400 \ln(800/SMI) \qquad \text{Equation A1-3}$$

The following graph can be used to estimate spring DC starting values rather than solving the above equations, if preferred. In order to enter the graph, first calculate the values $(DC_F)^*$ and P^* as follows:

$(DC_F)^* = DC_F + A$ .... Equation A1 - 4

where $A = 0$ if $a = 1.00$
$A = 115$ if $a = 0.75$
$A = 277$ if $a = 0.50$

$P^* = bP$ .... Equation A1 - 5

Now the graph can be entered by locating the appropriate value of $(DC_F)^*$ on the horizontal axis, running up vertically until the appropriate curve of P^* is intersected (interpolation between the curves will be necessary), then running horizontally over to the vertical axis where the spring Drought Code starting value, DC_S, is read off.

Example

Station XYZ ended FWI calculations on October 10, 1977 with a DC of 500. Precipitation (water equivalent) between October 11, 1977 and April 15, 1978 totalled 120 mm. Freeze up was not general in the region until November 30, so to allow for soil moisture depletion during October and November, the carry over fraction of last fall's moisture, fraction **a** is chosen as 0.75. Precipitation effectiveness, fraction **b**, is chosen as 0.75 as well.

$DC_F = 500$
$P = 120$
$a = 0.75$
$b = 0.75$

METHOD 1. Solving the equations for spring starting DC value:

$SMI_F = 800 \exp(-DC_F/400)$ .... Eqn. A1 - 2
$= 800 \exp(-500/400)$
$= 800\ (0.29)$
$SMI_F = 232$

$SMI_s = a(SMI_F) + b(3.94\ P)$ .... Eqn. A1 - 1
$= 0.75(232) + 0.75(473)$
$= 174 + 355$

$SMI_s = 529$

$DC_s = 400 \ln(800/SMI_s)$ .... Eqn. A1 - 3
$= 400 \ln(800/529)$
$= 400\ (0.415)$
DC_s = **166 = Spring Starting DC for Apr. 15.**

METHOD 2. Entering the graph for spring starting DC value:

First calculate the values of $(DC_F)^*$ and P^* from Equations A1 - 4 and A1 - 5.

$(DC_F)^* = DC_F + A$ . ..... Eqn. A1 - 4
$= 500 + 115$
$(DC_F)^* = 615$

$P^* = bP$ .... Eqn. A1 - 5
$= 0.75(120)$
$P^* = 90$

Find $(DC_F)^* = 615$ on X-axis. More vertically to the line of P^* midway between $P^* = 80$ and $P^* = 100$ to locate $P^* = 90$. Move horizontally, finding the DC_s value of 166 on the Y-axis.

Summary of Procedure using Graph (Fig. 25)

1. Obtain last fall's final Drought Code calculation (DC_F).
2. Obtain amount of overwinter precipitation, mm water equivalent (**P**).
3. Regional fire weather authority chooses carry over fraction of last fall's stored moisture (**a**) and effectiveness fraction of winter precipitation (**b**).
4. Obtain $(DC_F)^*$ from Equation A1 - 4.
5. Obtain P^* from Equation A1 - 5.
6. Obtain spring starting Drought Code (DC_s) from graph (Fig. 25).

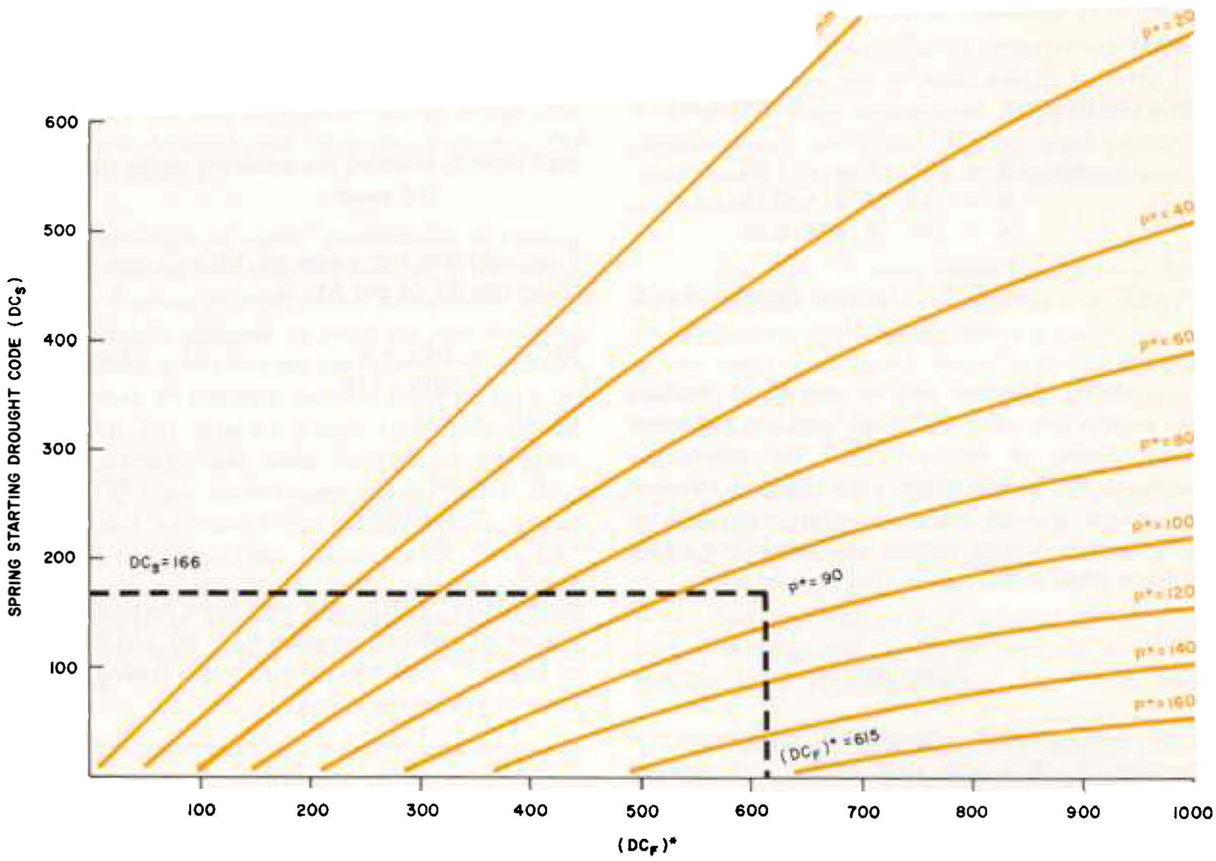


Fig. 25. Overwinter adjustment to Drought Code starting value.

APPENDIX 2

ACCURACY, PRECISION AND SENSITIVITY

These three terms are all used from time to time in connection with fire weather measurements and danger rating scales. A few words of explanation may help to clear up any confusion in their use.

Accuracy has to do with the instrument or technique of measurement. When an instrument is referred to as having an accuracy of ±5 units, this generally means that a series of measurements made with it of some constant property were mostly (usually 95% of the time) within 5 units of the correct value.

Precision is concerned with the size of unit, or the number of decimal places used in making and recording a given measurement. To say that a given length is 6 m implies that the measurement was somewhere between 5½ and 6½ meters. The same length expressed as 600 cm implies a precision of one cm; i.e., that the measurement fell between 599½ and 600½ cm. Occasionally precision may be expressed as a fraction (½°C) or as a round number (5%).

In general, if it is desired to take full advantage of the accuracy of a particular measuring system, the precision is to the next whole unit below the range of accuracy of the equipment. For example, Relative Humidity is normally measured and recorded to the nearest whole per cent, even though the accuracy of the equipment may be ±5%.

Sensitivity has to do with the amount of change in a measurement or a derived index that is produced by a given change in the property to be measured, or in one of the component factors. It is a relative property. As an example, some types of hygrograph are more sensitive to changes in Relative Humidity at lower values than they are near saturation.

APPENDIX 3

FIRE WEATHER INDEX CALCULATIONS MISSING OBSERVATIONS

Instructions for the Fire Weather Index System specify that daily weather observations be taken at noon Local Standard Time (1 PM Daylight Saving Time) throughout the fire season.

There will be some days when observations are missed. **Since gaps in the record mean a loss of accuracy of the Index, these gaps should be as few as possible.** The following procedures outline a consistent method of making use of available information to minimize errors caused by missing observations.

PROCEDURES

1) Measure total rainfall on the day following the day (or period) of missed observations, and do your best to assign reasonable portions of that total to each day on which observations were missed (including the day of measurement).

Check the hygrothermograph chart to help estimate the timing of rainfall. (This is primarily useful in determining whether or not all rain fell on one day).

2) Estimate the noon (1 PM daylight time) relative humidity and temperature from the hygrothermograph. Regular time-check marks on the chart can be a great help, particularly toward the end of the chart if the clockwork is slightly off.

3) Assume the wind to be in the 4-13 km/h class for use in the FFMC tables - unless you have good reason to suspect that it should be in one of the other classes.

4) After making the necessary estimates of rainfall, relative humidity, temperature and wind speed, proceed to calculate the codes and indices for each missing day as you would if the observations had been taken in the regular way.

All such days should be indicated on the original record sheet, preferably by a star (*) and a footnote.

NOTES

1) A common error is to treat days with missing data as if they didn't exist, using the values on the last day before the gaps as the starting point for calculations on the next day of observation. **This always results in misleadingly low values of DMC and DC.** Separate calculations must always be made for each missing day, based on the best possible estimate for each required weather factor.

2) If the above procedures are not feasible, owing to lack of hygrothermograph or instrument breakdown, try to get missing observations from the nearest station or, even better, average the values from several stations.

3) Estimated values of wind and of distribution of rain are usually adequate for the bookkeeping required to keep track of the moisture codes. **However, the values of the FWI and ISI calculated on those days may be subject to large errors and should be treated with caution.**

APPENDIX 4

ANEMOMETER HEIGHT FOR SMALL CLEARINGS

Average distance from timber edge in m. (d) \ Average stand height in m. (h)	5	10	15	20	25	30	35	40	45	50
5	14.2	MAST HEIGHT = TREE HEIGHT PLUS 10 METERS								
10	12.4	18.4	23.8							
15	11.0	16.7	22.6	28.1	33.2	38.7	43.8	48.9		
20	10.3	14.9	20.9	26.7	32.2	37.7	42.9	48.2	53.3	58.5
25		13.2	19.9	25.1	30.9	36.7	42.1	47.4	52.6	57.8
50			12.1	16.5	22.2	28.2	34.1	40.2	45.8	51.8
100	MAST HEIGHT = 10 METERS				11.4	14.1	18.4	23.0	28.6	34.4
150							11.3	13.2	16.2	19.8
200									11.4	12.8

This table gives the required height of the anemometer, in meters, based on the average distance from the timber edge (d) in meters, and the average stand height (h) in meters.

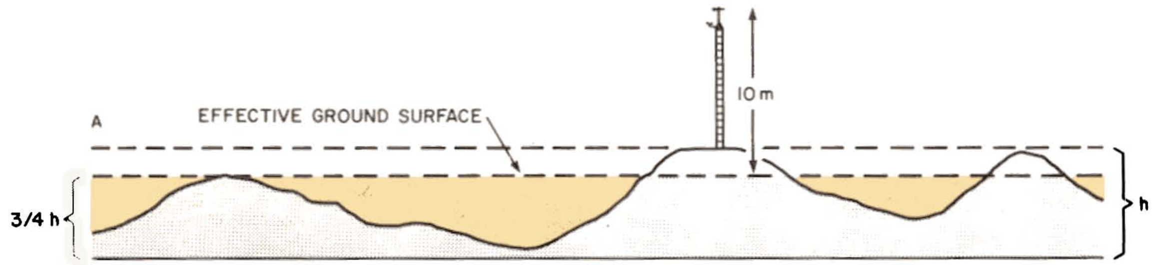
Where the clearing is rough or dotted with brush, the heights from **Appendix 4** are measured from the effective ground level, as determined in **Appendix 5.**

Example: If mast is located 30 m from the edge of a 20 m tall stand of trees, the required anemometer height above open level ground is **23.4 m.** (Find h = 20 and d = 30. Interpolate between 25.1 (d = 25) and 16.5 (d = 50). 5/25 x (25.1 – 16.5 =) 8.6 = 1.7. So 25.1 – 1.7 = 23.4). If anemometer could be located 50 m away from same stand edge, mast height could be reduced to (intersection of h = 20 and d = 50) **16.5 m.**

APPENDIX 5

ADJUSTED ANEMOMETER HEIGHT FOR UNEVEN GROUND OR BRUSH

1. If the clearing is partially covered with brush or if the ground is generally uneven, the wind speed at observation height behaves as if the ground surface were more or less flat and raised about ¾ of the average height of the brush or hummocks. We call this the **effective ground surface.**
2. Anemometer height should be measured from this level, as indicated in the illustration below. (Only rough estimates are required.)



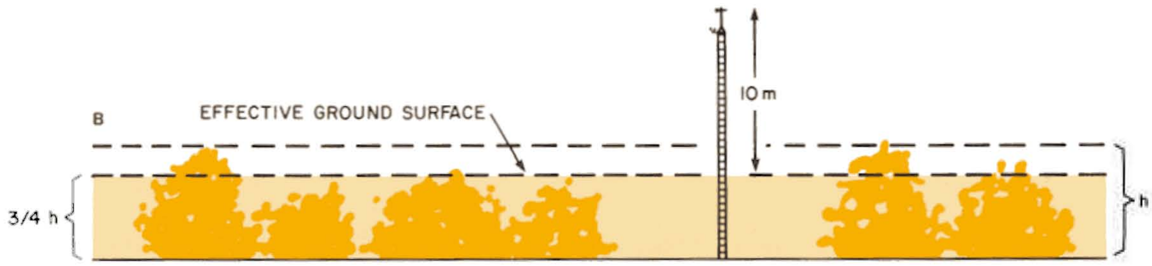


Fig. 26. Example A. Anemometer mounted in a clearing in rough terrain. Sensor should be 10 m above a representative high spot, determined by taking 3/4 of the difference in height between ridges and valleys.
Example B. Anemometer mounted in a clearing covered with clumps of brush 2 m high. Mast should be 10 m + (3/4 x 2m) = 11.5 m.

APPENDIX 6

WIND SPEED ADJUSTMENT FOR MAST HEIGHTS OTHER THAN 10 m.

For temporary or other auxiliary stations, it may not be practical to mount the anemometer on a 10 m mast.

Provided that the exposure is adequate (i.e., the clearing is large enough), the following adjustment can be applied to the measured wind speed to give a **good estimate** of the wind at 10 m.

For Wind Speed Measured at a Height Between:	Add:
2 and 2.9 m	48 %
3 and 3.9 m	35 %
4 and 4.9 m	25 %
5 and 6.9 m	15 %
7 and 8.9 m	7 %
9 and 11.9 m	no correction

Example: A wind speed of 12 km/h is measured at the top of a 6 m mast. The 'standard' wind speed at 10 m is estimated by adding 15% of the measured speed to give:

12 + (15% of 12) = 12 + 1.8 = 14

So the estimate of the 10 m speed is 14 km/h.

NOTE: the above correction cannot be used with any confidence in a small clearing.

APPENDIX 7

EFFECT OF SURROUNDING TERRAIN ON WIND SPEEDS MEASURED AT 10 m.

The standard wind observation for Fire Weather Index calculations is taken at 10 m above open level ground. Adjustments for wind measurements taken in clearings too small to be considered "open" are given in terms of raising the mast height (**Appendix 4**). Additional mast height adjustments are given to allow for roughness of the weather station clearing itself (**Appendix 5**). Adjustments are also given for the case where clearing size is adequate, but where the observations must be taken at lower than standard heights (**Appendix 6**). It is also of interest to the fire weather observer how the standard wind he measures is affected by the nature of the surrounding country, particularly the roughness of the ground or vegetation surfaces.

Surface roughness affects wind velocities, turbulence and gustiness to a height of 600 m or so above mean ground level, depending on atmospheric stability. We call the wind at the top of this friction layer the "gradient" or "free air" wind.

A typical comparison of how surface roughness reduces the wind speeds we measure near the earth's surface would be to compare observations from our 10 m mast located in open grassy fields to observations taken in an area where our opening is surrounded by a 15 m tall pine forest. We would expect our anemometer in open fields to give us wind speeds of about 60% of the gradient wind speed. We would measure only about 36% of the gradient wind speed if our standard opening was surrounded by pine stands. Cities or urban areas, in general, cause an even further reduction in wind speeds. Our standard anemometer would give us only about 23% of the gradient wind speed if located in an opening surrounded by houses and commercial buildings because of the scale of roughness of these objects.

What this relationship means to our standard 10 m wind speeds measured in our standard forest clearing is that if our weather station clearing is surrounded by a 15 m tall pine stand, we would be measuring a wind speed only about 60% of what it would be if measured 10 m above large grassy fields, assuming the same pressure gradient. An anemometer located in an opening in an urban setting would measure only about 40% of the wind speed measured over open fields.

Example

Gradient Wind at 600 m	64 km/h
Wind at 10 m above extensive open grassland (.60 x 64=)	38 km/h
Wind at 10 m in opening surrounded by 15 m pine stand (.36 x 64 or .60 x 38=)	23 km/h
Wind at 10 m in opening surrounded by city buildings (.23 x 64 or .40 x 38=)	15 km/h

While these percentage wind speed reductions, owing to surface roughness, are subject to wide variations, they can be regarded as typical values. Many airport locations give wind speeds similar to the theoretical open field comparison with openings surrounded by pine stands as given here. A generally acceptable rule of thumb for Fire Weather Index purposes is to **multiply winds measured at airports by 60%** to reduce them to comparable forestry opening winds.

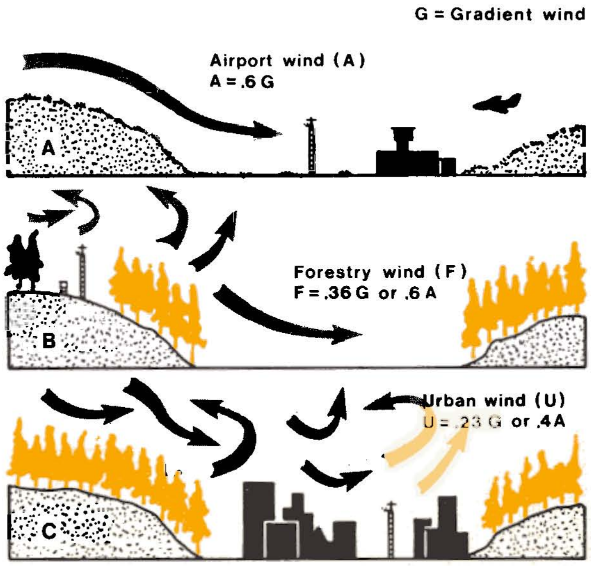


Fig. 27. Reduction of surface wind speeds depends on roughness of surrounding terrain. Figure A illustrates an airport wind in relatively smooth open grassland, B is a typical forestry wind where surrounding timber slows the wind and creates turbulence, and C shows wind measured in a city opening even further reduced by surface roughness.

APPENDIX 8

BEAUFORT SCALE FOR ESTIMATION OF WIND SPEEDS

When suitable instruments are lacking or when the instruments are not in operating condition, wind speeds can be estimated with reasonable accuracy by observing common effects of the wind, according to the following guide:

Beaufort Scale of Winds

Speed Range km/h	Descriptive Term	Observed Wind Effects
less than 2	Calm	Smoke rises vertically.
2-5	Light Air	Direction of wind shown by smoke drift but not wind vanes.
6-11	Light Breeze	Wind felt on face; leaves rustle; vanes moved by wind.
12-19	Gentle Breeze	Leaves and small twigs in constant motion; wind extends light flag.
20-29	Moderate Breeze	Raises dust and loose paper; small branches are moved.
	Fresh Breeze	Small trees in leaf begin to sway; crested wavelets on inland waters.
	Strong Breeze	Large branches in motion; whistling in telephone wires; umbrellas used with difficulty.
	Near Gale	Whole trees in motion; inconvenience felt walking against wind.
62-74	Gale	Breaks twigs off trees; generally impedes progress.
	Strong Gale	Slight structural damage occurs; e.g., shingles, T.V. antennae blow off roofs.
88-101	Storm	Seldom experienced inland; trees uprooted,considerable structural damage.
102-116	Violent Storm	Very rarely experienced; widespread damage.
more than 116	Hurricane	

APPENDIX 9

AVERAGE RATES OF CHANGE OF TEMPERATURE, RELATIVE HUMIDITY AND WIND SPEED AT NOON (LST).

STATION	TEMPERATURE (°C/h)	RELATIVE HUMIDITY (%/h)	WIND SPEED (km/h/h)
Bagotville, Que.	.70	2.8	.61
Chatham, N.B.	.74	3.5	.69
Kapuskasing, Ont.	.75	2.8	.50
Gander, Nfld.	.55	2.6	.66
Ft. McMurray, Alta	.89	4.2	.60
Port Hardy, B.C.	.52	2.2	.58
Prince George, B.C.	.77	3.0	.47
The Pas, Man.	.64	3.2	.42
Whitehorse, Y.T.	.66	2.4	.26
Average		3.0	.53

As long as weather observations are taken within 15 min of noon (Local Standard Time) at most stations, temperature, relative humidity and wind speed will not be in error enough to reduce accuracy of the FWI calculations. The above table shows that around noon at typical Canadian stations temperature is increasing on the average less than 1°C per hour, RH is dropping less than 4% per hour, and wind speed is increasing around a half km/h per hour. This table was calculated for all days May through October, including cloudy, rainy days as well as clear days. Somewhat larger changes in temperature, relative humidity and wind speed should be expected for clear days, perhaps 60 per cent greater than the hourly rates of change shown in the table. Any particular day could greatly exceed the average rate of change shown in the table for any of the weather elements.

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