AN INTERPRETIVE GUIDE TO THE

Canadian Forest Fire Behavior System

Canadian Forestry Service

AN INTERPRETIVE GUIDE TO THE

CANADIAN FOREST FIRE BEHAVIOR SYSTEM

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Forest Fire Behavior System

FIRE WEATHER INDEX

Rainfall
Relative Humidity
Wind Speed
Temperature

Rainfall
Relative Humidity
Temperature

Rainfall
Temperature

BLOCK 1 FINE FUEL MOISTURE CODE FFMC	*BLOCK 2* DUFF MOISTURE CODE DMC	*BLOCK 3* DROUGHT CODE DC

WIND SPEED →

BLOCK 4 INITIAL SPREAD INDEX ISI	*BLOCK 5* ADJUSTED DUFF MOISTURE CODE ADMC

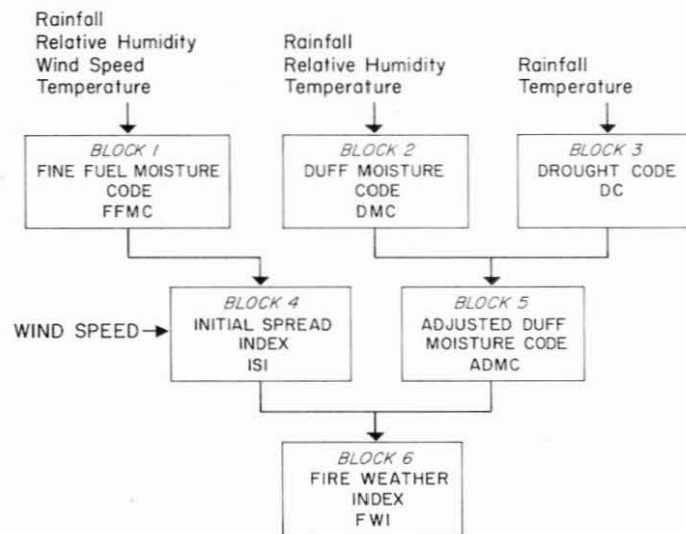*BLOCK 6*
FIRE WEATHER
INDEX
F WI

Fig. 1. Flow chart of Fire Weather Index.

Introduction

[Slide 1]

The Canadian Forestry Service is developing a new system of fire danger rating for use by Canadian fire management agencies. The new system is called the Canadian Forest Fire Behavior System (2, 10). This presentation will give user-oriented background on how the system is constructed and some suggestions on interpreting and applying the various fire behavior indices.

Structure of the System

[Slide 2]
        Fire behavior is principally controlled by the interactions
of three groups of variables. Past and present weather, fuel char-
acteristics, and local topography combine to produce the rates of spread
and energy release observed on any given fire. The Fire Behavior System
is composed of two families of indices. These indices take as many
variables into account as is practical for the various levels of usage
of a fire rating system.

        The Fire Weather Index (1) as the name implies, accounts
for the past and present weather effects on moisture content of stan-
dardized model fuels, and gives numbers related to fire occurrence
and fire behavior for a rating area. The Fire Weather Index, with its
component moisture codes, forms the first family of indices.

        The other family of fire behavior guides are called Burning
Indices. They introduce the effects of fuel and topography variables,
as well as weather, on the fire behavior to be expected in specific
fuel complexes, including both logging slash types and undisturbed
stands.

        By using this two-family approach in the Fire Behavior Rating
System, a fire manager can choose the combination of input variables
to calculate the indices best suited to his specific needs. No single
index number can provide the information required by every person en-
gaged in fire control decision making or involved in the use of pre-
scribed fire.

[Slide 3]
        This flow chart (Fig. 1) shows how the Fire Weather Index
is constructed. Daily weather observations are introduced so that
three different fuel moisture codes, or numbers related to the dryness
of various fuel components, can be calculated. These are Blocks 1, 2
and 3 of the Flow Chart. The higher the code numbers, the drier the
fuel. Block 4 gives a number related to a fire's initial spread rate
by combining wind speed with moisture content of the fine fuels.
Block 5 gives a number related to the proportion of fuel dry enough to
be available for combustion. Finally, Block 6, the Fire Weather Index
combines the initial spread rate number with the available fuel rating
to give a number related to potential fire intensity. We will look now
at these Fire Weather Index components or blocks in a little more detail.

[Slide 4]
First of all, to use the Forest Fire Behavior System, daily fire weather observations of temperature, relative humidity, wind velocity, and 24-hour precipitation must be taken throughout the fire season. These weather readings should be taken at noon, local standard time, at a properly maintained weather station which is representative of the forest areas to which you are going to relate the indices. Of course the indices can be no better than the weather observations used to calculate them, so weather reading must be accurate and representative.

[Slide 5]
The "standardized" or "model" fuel complex basic to the Fire Weather Index is a forest stand with a surface litter layer, an upland duff layer below that, and finally a deep, compact, duff or organic layer overlying the mineral soil. Blocks 1, 2 and 3 describe the relative dryness of these various fuel layers under all combinations of wetting and drying which occur at your weather station.

[Slide 6]
The three fuel classes described by Blocks 1, 2 and 3 take markedly different lengths of time to dry from saturation. Forest fuels dry out from saturation in similar ways, in that drying occurs rapidly at first, then more and more slowly as less and less moisture remains. We describe the drying rate of a fuel by the "timelag constant", which is the time it takes for the fuel to lose about 2/3 of its available moisture. This is the most convenient way of describing and comparing various forest fuels and we will define the time lags for each Block of the Fire Weather Index.

[Slide 7]
Block 1 is called the Fine Fuel Moisture Code (FFMC). It is a numerical rating of the moisture content of cured litter in a forest stand. FFMC can be used as an indicator of relative ease of ignition.

[Slide 8]
The fuel described by FFMC has a timelag of 2/3 of a day under average drying conditions. In other words, if the fine fuels were at 100% moisture content in the morning following a rain, after 2/3 of an average drying day, where the temperature reached 75° and the relative humidity drops to 25%, the fine fuels would have dried to about 40% moisture content. This surface litter layer described by the FFMC is about 1/2 inch deep and weighs 2 Tons per acre.

[Slide 9]

This layer of cured pine needles and fine twigs is the type of fuel represented by the Fine Fuel Moisture Code. They are the fuels which generally ignite first and contribute most to spread rate.

[Slide 10]

Block 2 is called the Duff Moisture Code (DMC). It numerically rates the moisture content of loosely compacted organic layers 2 inches to 4 inches deep.

[Slide 11]

The DMC represents fuels with a loading of 22 Tons per acre and a 12 day timelag, which means that 12 drying days after a saturating rain, these fuels would have lost 2/3 of their available moisture. If drying continued for another 12 days, a further 2/3 of the available moisture remaining would be given up, and so on until the duff layers would have lost 98% of their available moisture after 4 timelag periods.

[Slide 12]

This 2" deep organic layer under a lodgepole pine stand near Prince George is an example of the fuel type represented by the DMC.

[Slide 13]

Block 3 is the Drought Code (DC). This is a numerical rating of moisture content of deep compact organic layers. Since DC gives an indication of long term buildup through the fire season, it is a useful guide to long range preparedness requirements over large protection areas.

[Slide 14]

The deep slow-drying fuels represented by the Drought Code have a timelag of 52 days. Because tree rooting is present in these 1 to 2 foot deep organic layers, evapotranspiration is an important contributor to the moisture removing mechanisms in these fuels.

[Slide 15]

Drought Code can be thought of as accounting for the moisture present in deep layers like this one near Mission, B.C. and present in much of the Coast forest, interior wet belt, and northern interior spruce lowlands.

[Slide 16]

The first three Blocks of the Fire Weather Index, then convert past and present weather into numbers related to moisture content of various fuels.

Block 4 is the first indicator of potential fire behavior and is called the Initial Spread Index (ISI). The ISI combines wind speed with Fine Fuel Moisture Code (FFMC) to give a numerical rating of the relative rate of fire spread expected immediately after ignition in a standard fuel type, that is a fuel which can be described as to moisture content by the FFMC.

[Slide 17]

Block 5 is the Adjusted Duff Moisture Code (ADMC). This code is also referred to as a Buildup Index because it is a numerical rating of the total amount of fuel which should be available for combustion after any particular drying regime. This code is a weighted combination of the moisture conditions described by the Duff Moisture Code and by the Drought Code. Short-term preparedness activities can be geared to this index.

[Slide 18]

The 6th and final block is the Fire Weather Index (FWI). It combines the initial spread rate indicator (SI) with the available fuel indicator (ADMC) to give a numerical rating of potential fire intensity in a standard fuel type. Therefore FWI can be considered as giving a relative measure of expected fire behavior and daily fire control requirements which would guide daily preparedness dispatching decisions.

Calibrating the Fire Weather Index

[Slide 19]

This has been a brief description of what goes into and what comes out of the Fire Weather Index portion of the Fire Behavior System. The next step is to provide some interpretive guides as to what various Index numbers mean in terms of fire hazard levels in different areas and how well the Fire Weather Index and its components can be expected to predict fire occurrence and behavior. The FWI was calibrated for 20 first order weather observing stations throughout British Columbia (9).

[Slide 20]

All major climatic zones were included in the calibration test. Ten years of weather records for each station were used to calculate each day's FWI. Then all Forest Service reported fires within approximately a 60 mile radius of each station were correlated to each day's indices, for the period from May 1 to Sept. 30. Some results were as follows:
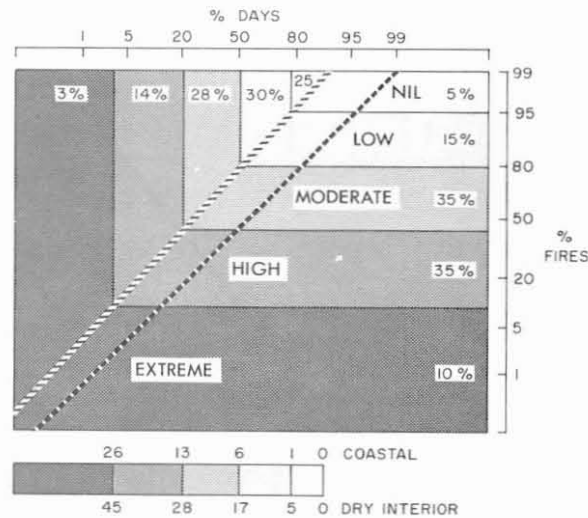
Fig. 2.   Percentage distribution of fire season days and fires by FWI class.

[Slide 21]
        FWI and ADMC descriptive rating classes could now be assigned
numbers in a rational way. If 3 per cent of the days in a normal fire
season which produce the highest Fire Weather Index numbers can logic-
ally be termed "Extreme", then any Fire Weather Index of 26 or greater
would rate as Extreme for the B.C. coast and "wet" central and northern
interior. Similarly, the "worst" 3 per cent of the days as far as Ad-
justed Duff Moisture Code is concerned exceeded 111 for these regions.
The interior dry belt portions of the Kamloops and Nelson Forest Districts
would require a higher base limit for Extreme FWI if the same 3 per cent
of fire season days are to be called Extreme. For these regions, any
FWI of 45 or greater should include the most hazardous 3% of days in a
normal fire season.
[Slide 22]
        Once a logical set of limits for descriptive classes of FWI
had been set, the occurrence of man-caused fires could be related to
these FWI classes (Fig. 2). For all regions of B.C., the 3 per cent of
the days with the highest FWI values have 10 per cent of the total number
of fires. Similarly, the 17% of the worst days, which would include the
High and Extreme days defined by FWI, would be expected account for 45%
of all man-caused fires for an average protection area. Obviously, then,
FWI can be used to predict relatively when your fires will occur, although
weather stations must be individually calibrated because of important
regional differences.

OCCURENCE OF MAN-CAUSED FIRES
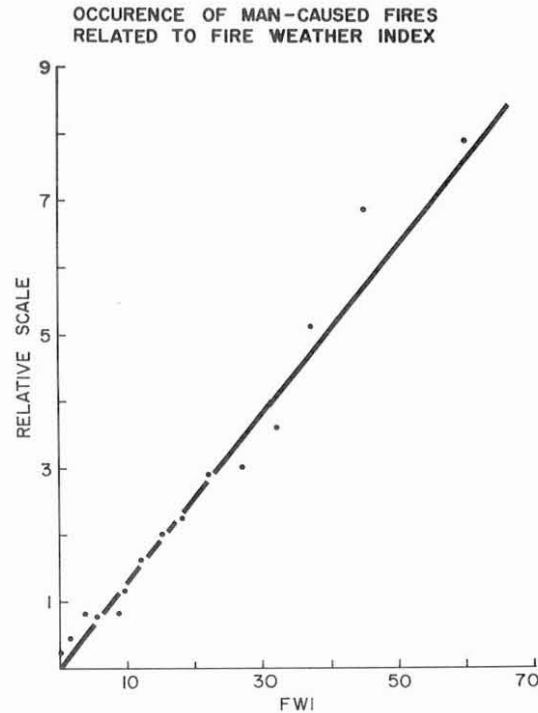**RELATED TO FIRE WEATHER INDEX**

Fig. 3. Relationship of fire occurrence to FWI.

[Slide 23]
[Slide 24]
        As this linear increase in fire occurrence with FWI shows,
you can expect about 5 times as many fires at FWI 35 as at FWI 10 for
an average rating area (Fig. 3).
[Slide 25]
        Fire load is determined by both number of fires and their
size. You would hope that Indices could help predict the highest fire
load periods as well as simply fire occurrence. What is the probability
of a fire becoming large?
[Slide 26]
        It was found that up to FWI 20, the relative size of an average
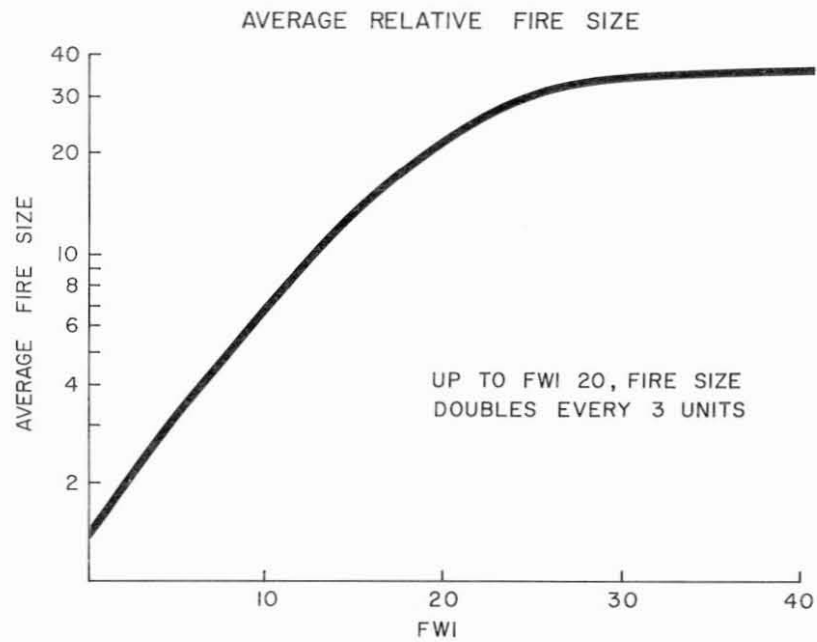fire doubled for each increase of 3 FWI units (Fig. 4).

AVERAGE RELATIVE FIRE SIZE

UP TO FWI 20, FIRE SIZE
DOUBLES EVERY 3 UNITS

Fig. 4. Relationship of fire size to FWI.

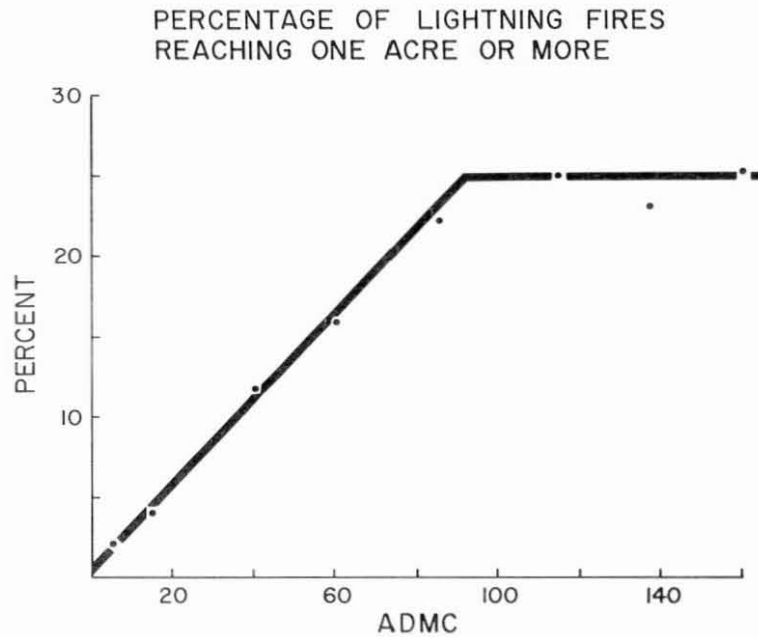PERCENTAGE OF LIGHTNING FIRES
REACHING ONE ACRE OR MORE

Fig. 5. Relationship of lightning fire growth to ADMC.

[Slide 27]

A significant increase in lightning fire size with increases in Adjusted Duff Moisture Code was also found.

[Slide 28]

The importance of gearing detection and initial attack capabilities to Fire Behavior Indices can be seen by the way the proportion of lightning fires which get larger than 1 acre steadily increases as ADMC rises to about 100 (Fig. 5). Of course there is much variation in this average relation from region to region since protection capability is highly variable.

[Slide 29]

Fire load, expressed as relative area burned on an administrative area from both man-caused and lightning fires, grows rapidly with increasing ADMC values (Fig. 6).

[Slide 30]

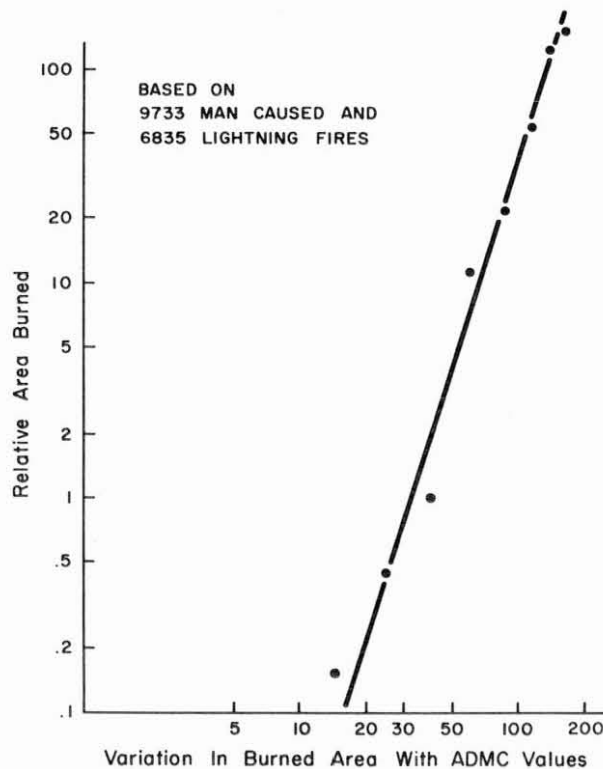In fact as ADMC doubles, your burned acreage can be expected to increase by 10 times.

Fig. 6. Relationship of burned area to ADMC.

[Slide 31]

British Columbia is so climatologically diverse that a distribution map of buildup levels to be expected in different regions should aid in the interpretation of what a given Adjusted Duff Moisture Code value means relative to normal for your station, and relative to another station in a different region. The map shows that 10 per cent of the fire season days in the Kamloops-Lytton region will have an ADMC greater than 200. At Tofino, on the other hand, your worst 10 per cent of the days in a fire season will only be 50 or greater ADMC.

[Slide 32]

A further calibration of one of the Fire Weather Index component codes was done to help coastal B.C. operators interpret a familiar fuel moisture indicator in terms of the new index. B.C. Forest Service Hazard Stick readings for 1600 hours were calibrated for Fine Fuel Moisture Code equivalents. For instance a FFMC of 90 should be approximately equivalent to a 1600 Stick reading of 7.0. This calibration is presented in Supplement BC-5 to the Forest Fire Behavior System.

[Slide 33]

Supplement BC-1, entitled "Guides to Initiate a Prescribed Burning Program", calibrates the Drought Code so that it can serve as a warning of excessively dry deep duff conditions in coastal, interior wet belt, and northern spruce forests when slash burning is being considered in the fall. Three classes of control difficulty and relative cost are described by Drought Code limits so that prescribed fire users can better judge whether they have had sufficient fall rain to overcome summer drought effects on the slow-drying fuels. The Drought Code has been found to be a good indicator of when organic layers in the green timber can be expected to be drier than in the slash, thereby presenting control difficulties in wet belt types (4).

Burning Indices

[Slide 34]

This has been a brief discussion of how the Fire Weather Index portion of the Fire Behavior Rating System was constructed, along with some information on the types of things that various index numbers represent.

The other main family of indices in the System are the Burning Indices. We will look now at what additional fire behavior information can be predicted with Burning Indices and what additional input information is required to use them.

[Slide 35]

Burning Indices are numerical ratings of the fire behavior which results from interactions of weather and topography on specific fuel complexes. These fuel complexes can be described by their characteristic fuel loading and distribution. Burning Indices are intended to be used as guides for both prescribed and wildfire management.

BURNING INDEX

Spruce - Balsam Slash

BLOCK 1	BLOCK 2	BLOCK 3
FFMC	DMC	DC

Wind Speed →
Slope →

BLOCK 4	BLOCK 5
RATE OF SPREAD	AVAILABLE ENERGY

← Fuel Loading
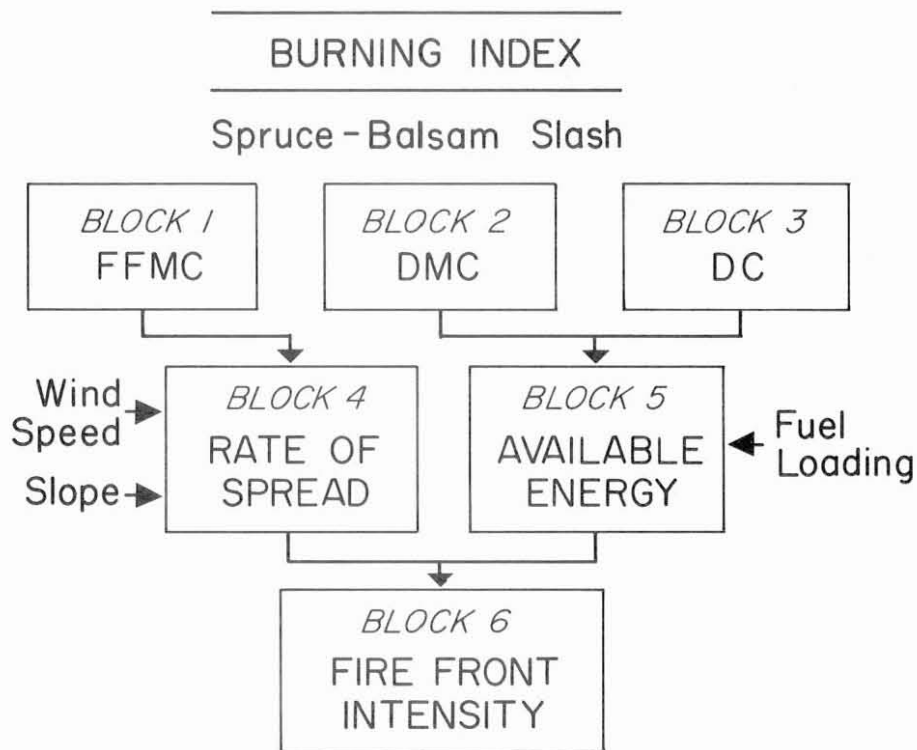
BLOCK 6
FIRE FRONT INTENSITY

Fig. 7. Flow chart of burning indices.

[Slide 36]

The same weather data are used in Burning Indices as for the Fire Weather Index. In fact, the same three moisture codes, Blocks 1, 2 and 3 of the FWI are also used as the first step in calculating a Burning Index (Fig. 7). As the diagram shows, these moisture codes are combined with such factors as wind speed, slope, and fuel loading to provide indices of spread rate and fire intensity for the fuel complex of interest.

[Slide 37]

     This chart illustrates how to calculate the Burning Indices for Spruce-Fir Logging Slash, which is Supplement BC-3 of the Fire Behavior System. There are two forms of this Index, General Burning Index and a Specific Burning Index. The General Burning Index indicates the spread rate and intensity for averaged conditions of slope and fuel loading for application over large areas of the fuel type. The Specific Burning Index, on the other hand, is intended to apply a specific area of the fuel complex, such as a particular logging side, where the user can be expected to know such additional information as fuel loading class, age of slash, slope, aspect, elevation and local wind. The specific B.I. provides measures of fire propagation intensity and available energy which can be interpreted in terms of each fire containment and fire impact on the site (6).

     Burning Indices have to account for as many of the significant fire-affecting fuel characteristics as possible. The following fuel complex properties are recognized directly or indirectly in the Burning Index system:

[Slide 38]

     Fuel Quantity, expressed as loading or weight per unit area, such as Tons per ac. or lb. per square foot.

[Slide 39]

     Fuel Size. Is the fuel complex mainly fines, mainly large logs, or well stratified into all sizes?

[Slide 40]

     Fuel Arrangement. Is the fuel complex porous and open or densely compacted?

[Slide 41]

     Fuel Distribution. Is the fuel complex continuous over the area or broken up by many skid trails or rock outcrops?

[Slide 42]

     Fuel Moisture Content. The moisture content of the various fuel components is indicated by the Fuel Moisture Codes of Fire Weather Index or by modifications of these.

     Predicting fire behavior and impact on a specific site obviously requires a different Burning Index for this west coast cedar-hemlock slash type [Slide 43] than for this north central interior spruce-balsam slash complex [Slide 44] and different again for this interior lodgepole pine stand [Slide 45].

Putting Fire Behavior System Numbers to Work

[Slide 46]
        Various indices of the Fire Behavior System can be used to
predict the following kinds of things:
        (i) Predicting fire behavior and impact
[Slide 47]
        <u>Ignition Potential</u>. Requires knowledge of risk on the area,
but FFMC can at least indicate when fuels will be receptive to ignition
from standard fire brands such as campfires or matches.
[Slide 48]<u>Rate of Spread</u> is indicated on a relative basis by the Initial
Spread Index of the FWI and is forecast in real units by the spread
component of the Burning Indices.
[Slide 49]
        <u>Available fuel</u>. Knowing the fraction of various fuels avail-
able for combustion enables the prediction of how much slash and duff
will probably be removed by a fire, and hence whether prescribed fire
objectives can be met or not. Available fuel is indicated relatively
by the Adjusted Duff Moisture Code of the FWI and in real units by the
Available Fuel components of the Burning Indices.
[Slide 50]
        <u>Fire Intensity</u>. This is the amount and rate of energy re-
leased by the fire, which determines such things as [Slide 51] <u>Resistance
to Control</u>, in other words, how close men and machines can work to the
fire, and [Slide 52] <u>Fire Impact on the Site</u>, which includes such in-
dicators as percentage of area with exposed mineral soil following the
burn. FWI indicates relative intensity while actual intensities are
forecast by the Burning Indices.
[Slide 53]
        Depending on individual fire protection and fire management
needs, the Fire Behavior Rating System can be used by people with fire
responsibilities in some of the following ways:
[Slide 54] (ii) Prevention
[Slide 55]
        As public information guides for Forest Service and Industry
to convey general fire hazard conditions in an area to the public.
[Slide 56]
        As guides to issuance and cancellation of industrial burning
permits.
[Slide 57]
        As guides to cancellation of public campfire permits.

[Slide 58]
      As Forest Service and Industrial guides to invoking woods travel
closures, industrial shutdown, and
[Slide 59]
      Industrial early operating shifts and
[Slide 60]
      requiring a watchman to be left on an active logging side
after operating hours.
[Slide 61] (iii) Detection
      Detection can be aided through better patrol flight scheduling
[Slide 62] if hazard indices for different districts in your protection area
are known.
[Slide 63] (iv) Preparedness planning
      Preparedness planning, including such things as manpower and
equipment standby requirements, can be better scheduled and located if
Fire Behavior Indices can enable you to predict probable fire occurrence
in your high risk areas [Slide 64]

      The Fire Behavior System should be considered as much a part
of the Fire Control and Use tools of the trade [Slide 65] as the air
tanker, weather forecast, drip torch, or prescribed fire plan.

      Manning and specific action guides for fire control [Slide 66]
could be based on Indices as predictors of potential fire behavior.
Such guides could include such variables as initial attack strength
[Slide 67] to be deployed by a dispatcher at different hazard levels.

      (v) Suppression tactics and strategy
[Slide 68]
      Suppression tactics and strategies could utilize Fire Behavior
Indices as guides to making decisions on such activities as utilizing
air tankers, [Slide 69] where and when to build a cat guard [Slide 70],
and where and when to temporarily take no suppression action.
[Slide 71] (vi) Use of prescribed fire
      There is no doubt that one of the highest pay off uses of Fire
Behavior Indices is for planning and conducting prescribed burns. This
is the fire management area in which the fire user knows most about the
environmental conditions under which fire is being applied to a site, he
knows the things he wants to accomplish with the burn, and he has the
ability to control the fire behavior on the particular site. The pred-
ictive ability provided the fire manager by the Fire Weather Index, Burning
Indices, and their accompanying guidelines should increase the probability
that a given prescribed burn's objectives are first of all reasonable and
secondly that they are met. Prescribed burning goals may be hazard red-
uction, silvicultural, or habitat improvement, or a combination of these.

Research is Continuing

A series of pictures follows which shows some of the fire research from the field which is utilized in the Fire Behavior System Indices. The work will continue in order to improve and expand the Fire Behavior System, and to provide more guidelines for its use in the future.

[Slide 72]

[Slide 73]

Controlled burning in standing timber is being used to collect fire behavior data for Burning Index development.

[Slide 74]

Work on Burning Indices and guidelines for use of prescribed fire in a number of logging slash types is progressing (3, 5, 7, 8).

[Slide 75]

Indices will interrelate fire behavior and fire accomplishment or impact in the defined fuel type under any weather history.

The Canadian Forest Fire Behavior System is imperfect and incomplete at this stage, but this should not discourage the user from becoming familiar with all the indices and guides which are now available. Continued improvement of the system will require not only continued research and testing, but a lot of feedback from field people making the day to day fire management decisions.

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