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INTRODUCTION

The BEHAVE fire behavior prediction and fuel modeling system is a set of interactive, "user-friendly" computer programs. It is a flexible system that can be adapted to a variety of specific wildland fire management needs. BEHAVE is ideally suited to real-time predictions of the behavior of wildfires or unplanned ignition prescribed fires. It can be used in fire behavior training and initial attack dispatch of fire crews. With proper care, it can be used in prescribed fire planning. BEHAVE is of limited use for predicting fire effects and it will not satisfy the broad area planning needs met by the National Fire-Danger Rating System.

BEHAVE draws together state-of-the-art fire behavior prediction technology into one easy-to-use package. Many of the mathematical prediction models in BEHAVE have been available for application in other forms. For example, the TI-59 handheld calculator with a fire behavior CROM (Custom Read Only Memory) (Burgan 1979a) has been widely used as a method of calculating fire behavior in the field. BEHAVE does the calculations that the TI-59 does, and more. BEHAVE will likely replace the TI-59 for office work, although there will be a continued need for a portable field tool. Other methods of obtaining the fire behavior predictions that are in BEHAVE include, for example, the tables in the S-390 Intermediate Fire Behavior Course (National Wildfire Coordinating Group 1981), nomograms (Albini 1976a; Rothermel 1983), calculator programs (Albini and Chase 1980; Chase 1981), and computer programs (Albini 1976b). BEHAVE also offers options that are not available elsewhere, the most significant being that of allowing the user to design custom fuel models. Use of BEHAVE for fuel modeling is described by Burgan and Rothermel (1984). This paper covers use of BEHAVE for operational fire behavior prediction.

The author of this handbook assumes that the reader has had experience with fire behavior prediction. The major prediction techniques are covered in Richard C. Rothermel's (1983) "How to Predict the Spread and Intensity of Forest and Range Fires." The material in that publication is based on the Interagency S-590, Fire Behavior Officer Course, and is directed toward field use. The same basic procedures, however, are used for other applications.

The bulk of this handbook describes the basis of the predictions and specific application of BEHAVE. A relatively small section describes operation of the computer program. "User-friendly" design eliminates the need for detailed instruction.

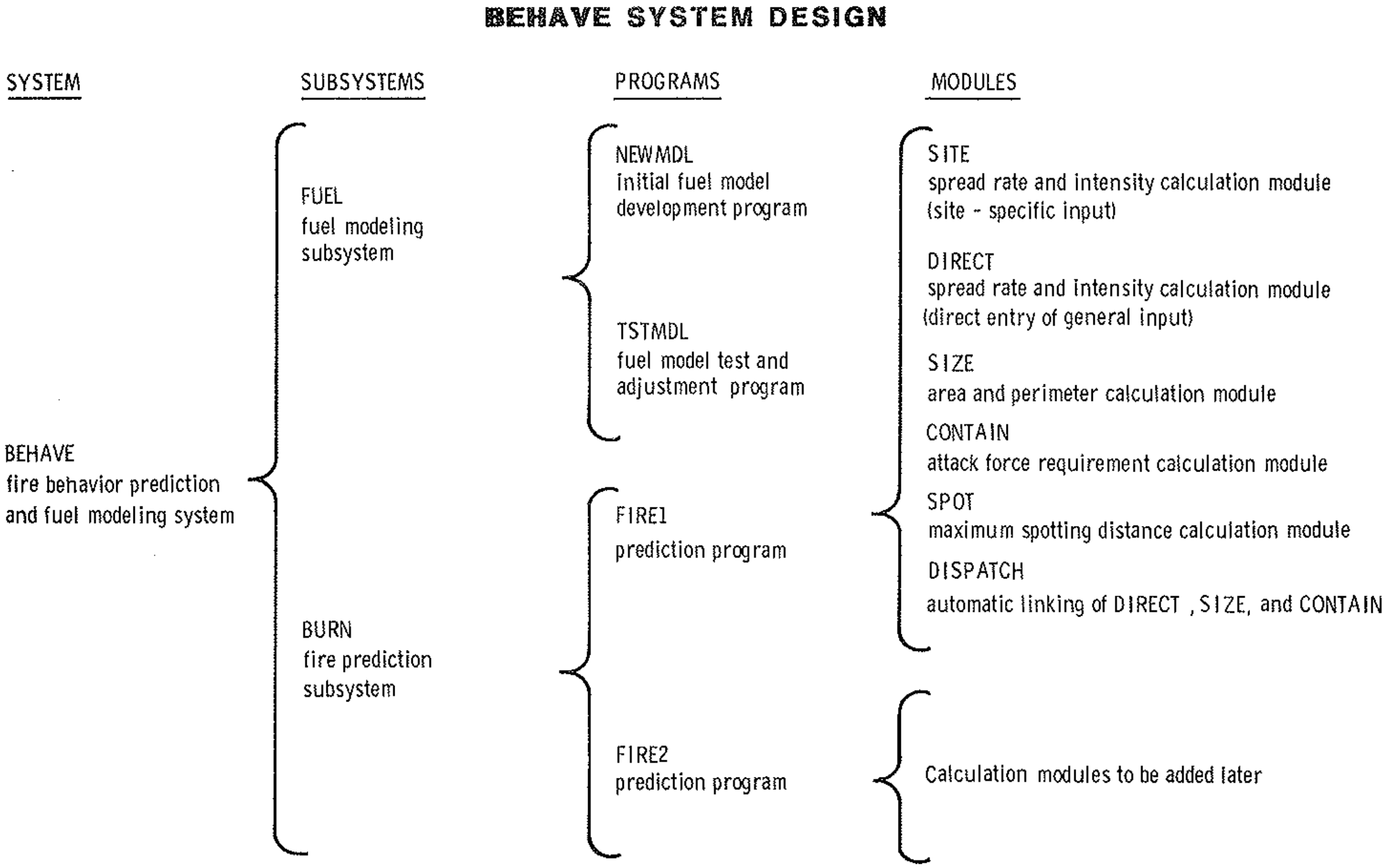


Figure 1.—Subsystems, programs, and modules of the BEHAVE system.

THE BEHAVE SYSTEM

The BEHAVE system (fig. 1) is made up of two subsystems: the fuel modeling subsystem, FUEL, and the fire behavior prediction subsystem, BURN. The FUEL subsystem of BEHAVE is described in a separate publication (Burgan and Rothermel 1984). This manual describes the BURN subsystem: operation of the computer program, the mathematical models that drive the predictions, and application of the predictions.

FUEL offers a systematic method of building fuel models to cover specific situations. The FUEL subsystem of BEHAVE consists of two programs—NEWMDL ("new model") and TSTMDL ("test model"). NEWMDL is used to initially set the values for the fuel model parameters; then TSTMDL is used to examine the fire behavior predictions using the fuel model and a variety of environmental conditions. The values of the fuel model parameters can be adjusted if necessary.

The BURN subsystem of BEHAVE is used for predicting fire behavior. BURN currently consists of one program, FIRE1. Another program, FIRE2, will be added to the BEHAVE system at a later date. The program is divided into modules (fig. 1). The major modules of the FIRE1 program are SITE, DIRECT, SIZE, CONTAIN, and SPOT. SITE and DIRECT are for predicting spread rate and intensity. SIZE calculates the area and perimeter of a fire that started from a point source and has a roughly elliptical shape. CONTAIN calculates the final fire size based upon user-specified control force capabilities, initial fire size, and environmental conditions. Conversely, CONTAIN can also

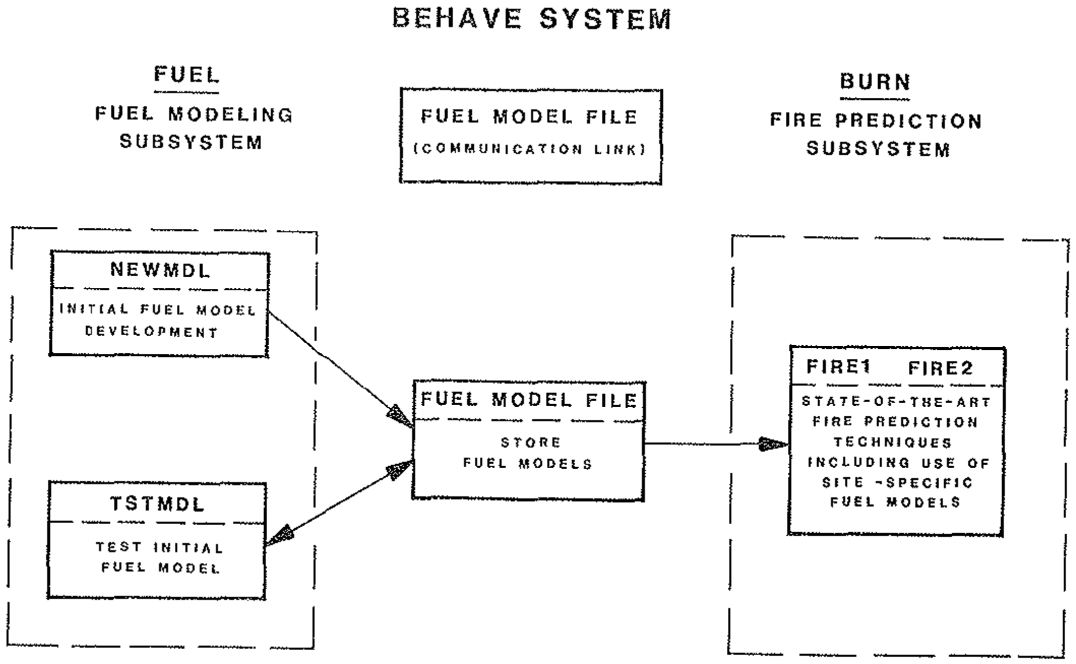


Figure 2.—The fuel model file is the communication link between the two BEHAVE subsystems, FUEL and BURN.

estimate the control forces required to contain the fire at a specified size. SPOT gives the maximum spotting distance from a torching tree or a burning pile of debris. The modules can be run independently or they can be linked, with the output from one being carried as input to the next. As new fire behavior prediction models become available, they will be added to the BEHAVE system.

The link between the FUEL and BURN subsystems consists of files of the custom fuel models that users design and save through FUEL (fig. 2). These fuel models can then be used by BURN through access to the files. Once the file name is specified, fuel models are referenced by number, as are the standard 13 NFFL fuel models. Appendix C is devoted to the subject of fuel model files. Understanding the fuel model file concept is basic to proper use of the BEHAVE system.

BURN and FUEL are separated as subsystems because of their mode of use. BURN can be used totally independent of FUEL if only the 13 standard NFFL fuel models (Anderson 1982) are used. FUEL is used to expand the basic set of 13 NFFL fuel models. Site-specific fuel models are developed for a given area of concern, a National Forest for example. This may be done by the fuel specialist on the Forest. BURN will be run in an operational mode, possibly utilizing the fuel models developed earlier. A wider range of people will use BURN. A dispatcher, for example, would not be likely to build fuel models. Therefore, it is not necessary to learn to use FUEL before reading this publication and learning to use the BURN subsystem of BEHAVE.

OPERATING INSTRUCTIONS

FIRE1 is a "user-friendly" program. It asks you questions. If you respond incorrectly, it will tell you so then ask the question again. You should not be able to "crash" the program. Some of the questions require a yes or no response, some ask for an input value, and others request keywords.

An example of a user's session with FIRE1 is given in appendix A. If you are just learning about BEHAVE, I recommend that you read appendix A now so you can see how the system works. Examples of everything described in this section on operating instructions are included in the appendix. Hands-on practice, however, is the best way to learn to run the FIRE1 program.

Keywords

The keywords give FIRE1 its flexibility. A list of the keywords and a brief description of each is given in exhibit 1.

Mode keywords	
WORDY	prints extra messages and explanations throughout the run (default)
TERSE	skips extra messages and explanations
PAUSE	limits output to at most 24 lines at a time for a terminal with screen display
NOPAUSE	prints output without pause for a terminal with hard copy output
Rescue keywords	
KEY	prints the keywords that are allowed at the current point, along with a brief description of each
HELP	tells you where you are in the program and what you can do next
Module keywords	
DIRECT	accepts direct input of the basic input values to calculate spread rate and intensity
SITE	accepts site-specific input to calculate spread rate and intensity
SIZE	calculates area, perimeter, length-to-width ratio, and forward spread distance
CONTAIN	calculates line construction capabilities needed or final fire size
SPOT	calculates maximum spotting distance
DISPATCH	automatically links DIRECT, SIZE, and CONTAIN
Operation keywords	
INPUT	asks for all input of the current module
LIST	lists current input values
CHANGE	changes individual input values by line number
RUN	does calculations and prints results
Other Keywords	
QUIT	gets back to the previous level in the keyword hierarchy or terminates the run
CUSTOM	specifies a custom fuel model file to be used or lists what is in a file

Exhibit 1.—FIRE1 keyword summary.

The "mode" keywords are WORDY, TERSE, PAUSE, and NOPAUSE. They are used to set a mode to be applied until you change it. These keywords can be entered any time a keyword is requested.

WORDY - Prints additional explanation and messages throughout the run. You will definitely want to use the WORDY mode while you are learning to use the program. And there is nothing wrong with always using the WORDY mode. The default mode is WORDY.

TERSE - Cancels the WORDY mode. You may want to use the TERSE mode when you become so proficient that you can anticipate what will be printed next. This mode is especially useful when you are using a hard-copy terminal and want to speed things up.

PAUSE - Causes output to be limited to at most 24 lines at a time. There is no reason to use this mode when you are using a hard-copy terminal. When a prompt symbol is printed without a question, the program is pausing until you indicate that you are through viewing the output. Press the return key to indicate that you are ready to continue. The PAUSE mode is also set when you answer "YES" to the question at the beginning of a run: "ARE YOU USING A TERMINAL WITH A SCREEN ? Y-N".

NOPAUSE - Cancels the PAUSE mode. The NOPAUSE mode can also be set at the beginning of a run by answering "NO" to the question "ARE YOU USING A TERMINAL WITH A SCREEN ? Y-N".

The "rescue" keywords are HELP and KEY. They can be entered any time a keyword is requested. The response should rescue you if you get mixed up.

KEY - Lists the keywords that can be entered at this point. A brief description is given for each.

HELP - Tells you where you are in the program and what you can do next.

The "module" keywords are DIRECT, SITE, SIZE, CONTAIN, SPOT, and DISPATCH. They are used to get you into a specific fire behavior prediction module. Appendix B includes input/output forms for each module and descriptions of input variables.

DIRECT - Calculates rate of spread, flame length, fireline intensity, heat per unit area, reaction intensity, effective windspeed, and in some cases direction of maximum spread. You can calculate fire spread in the direction of maximum spread when the wind is blowing cross-slope, or in any other specified direction of spread. The basic input values (fuel model, fuel moisture, midflame windspeed, and percent slope) are entered directly.

SITE - Calculates the same values as does DIRECT. However, SITE is designed to help the user estimate fine fuel moisture, wind, and slope. Very site-specific information (temperature, days since precipitation, canopy cover information, etc.) is input to SITE. A major feature of SITE is the capability to estimate moisture of fine, dead fuel.

SIZE - Calculates area and perimeter for a point-source fire that retains a roughly elliptical shape. SIZE can be used independently or be linked with DIRECT or SITE; that is, output from DIRECT or SITE will be used as input to SIZE.

CONTAIN - Calculates attack requirements. Burned area can be predicted, given forward rate of spread, initial area, fire shape length-to-width ratio, and control line construction rate. CONTAIN can also calculate line construction rate needed to hold the burned area to a fixed value, given the other variables listed. CONTAIN can be used either independently or linked with SIZE and either DIRECT or SITE.

SPOT - Calculates maximum spotting distance from a burning pile of debris or from torching trees, given a description of the terrain, forest cover, and windspeed.

DISPATCH - This module is an example of the type of fire behavior prediction that could be made from input values that might be available to a dispatcher. This keyword essentially causes an automatic link between DIRECT, SIZE, and CONTAIN.

The "operation" keywords are INPUT, LIST, CHANGE, and RUN. They are used to enter the input and obtain the output. They do exactly what you would expect them to do. After you type one of these keywords, you will be asked direct questions.

INPUT - All of the input values for the module are asked for.

LIST - The currently stored input values are listed.

CHANGE - You can change individual input values by indicating the line number on the worksheet.

RUN - Calculations are done and results are printed.

Other keywords are CUSTOM and QUIT.

CUSTOM - This keyword must be used, usually at the beginning of a run, if you are going to use custom fuel models. It allows you to specify the name of the file to be attached to this run and to see what is in the file. You can list the numbers and names of the fuel models in the file or the parameters for a specific fuel model. The custom fuel model file is created by the FUEL subsystem (NEWMDL and TSTMDL programs) and can be read but not altered by the BURN subsystem (FIRE1 program).

QUIT - Indicates that you are finished working with the module that you have been in. QUIT takes you back one level in the hierarchy of keywords as described in the next section. If you type QUIT when you are at the first level, the program run will ask if you **really** want to quit; a positive response will terminate the run. When you terminate the run, the input values that you entered are lost.

Hierarchy of Keywords

The hierarchy of FIRE1 keywords is shown in exhibit 2. Some of the keywords can be entered any time a keyword is requested. These are WORDY, TERSE, PAUSE, NOPAUSE, HELP, KEY, and QUIT. Others can be entered only in the appropriate place. When you are in the WORDY mode, the valid keywords are listed after every keyword request. You can also type KEY to see the list of valid keywords with a brief description of each.

The program will lead you through the logic of the keyword hierarchy. You enter a keyword to specify which module you want to be in. Use the keywords INPUT, LIST, CHANGE, and RUN to enter the input and obtain the output. When you are through with a module, you either type QUIT to return to the previous level in the hierarchy or you type the keyword to link the next module.

SIZE and CONTAIN can be used as independent modules, where you are required to type in every input value. Or they can be linked to other modules, where some of the input values are calculated. When SIZE is linked to DIRECT, it is similar to the setup on the TI-59 CROM (Burgan 1979a). Conversely, the containment program for the TI-59 (Albini and Chase 1980) is like the CONTAIN module of FIRE1 used independently. Allowing any module to be used either independently or linked to other modules when possible gives FIRE1 maximum flexibility.

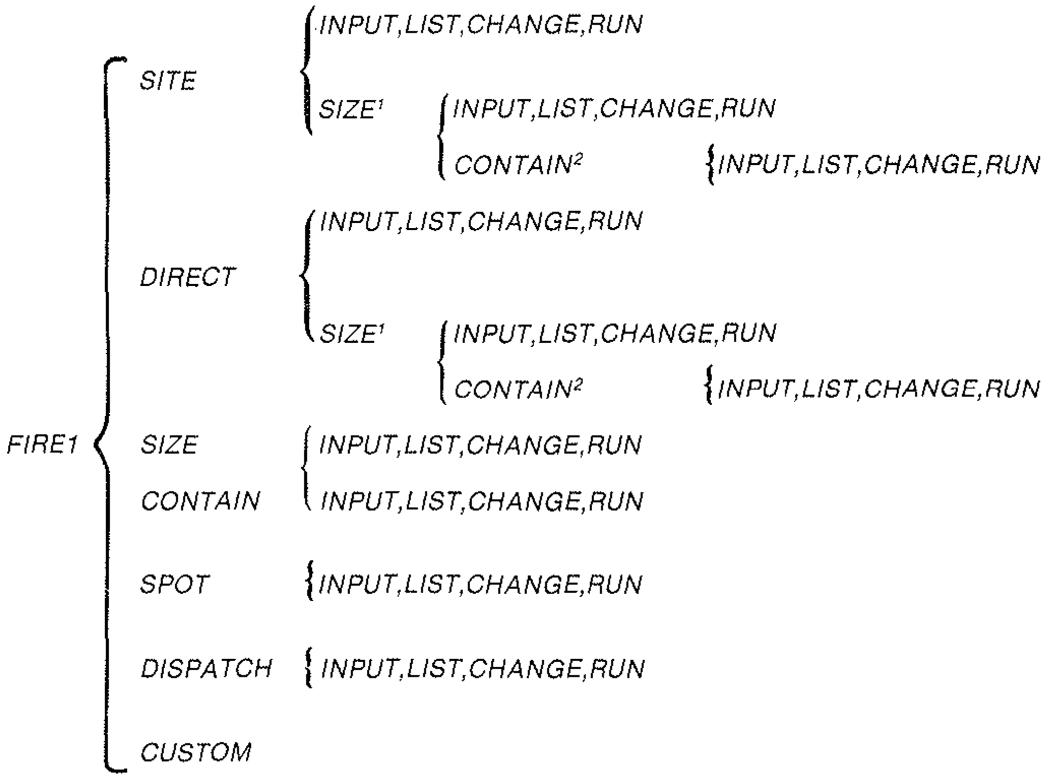


Exhibit 2.—FIRE1 keyword hierarchy. TERSE, WORDY, PAUSE, NOPAUSE, HELP, KEY, and QUIT can be entered any time a keyword is requested.

[1] SIZE is a legal keyword here only after a successful RUN.
[2] CONTAIN is a legal keyword here only after a successful RUN.

After you use keywords to indicate what you want to do, FIRE1 will ask you questions. The required response may be a value, range of values, or a code. If you enter an improper value, you will get a message, your input will be echoed, and the question will be repeated. You will stay in this loop until the computer is satisfied with your answer.

The following are general guidelines for the FIRE1 program. Page numbers refer to examples in appendix A.

—Valid answers are always listed after the question mark (p.64).

—Input must be entered without imbedded blanks (p.65).

—Integers can be entered with or without a decimal point (p.65).

—If a fractional value makes sense, it can be entered to no more accuracy than tenths (one decimal point) (p.64).

—A range of values is specified by entering the starting value, the ending value, and the step size, separated by commas. Up to 7 values are allowed for some input variables. After you specify the range that you want, the individual values will be printed for your verification. You will have the chance to repeat your input (p.66).

—If a range of values is entered for only one input variable, a list of output values will be printed (p.67). If a range is entered for two input variables, a table of output values will be printed. You will be requested to specify the table variable that you want (p.68). If a range is entered for more than two input variables, you will be warned of an error (p.83).

—If you are in the WORDY mode and the input is a code, definitions are printed under the question (p.74). In the TERSE mode code definitions are not printed (p.75). If you do not remember the code, you can refer to the listings in appendix B.

Appendix B lists the input values for each module, the valid answers, whether a range is allowed, and whether an integer is required. Code definition are also given. This appendix is for reference. The program will guide you through your choices without the list.

THE BASIS OF THE CALCULATIONS

The FIRE1 program is easy to run. It is possible to quickly generate a lot of fire behavior predictions. It may be tempting to ignore what the computer doe between the time RUN is typed and the time results are printed. The timelag will hardly be noticeable, but what happens is important. The computer should not be thought of as a "black box." To be used effectively, the basic assumptions, limitations, and proper application of the models must be understood. This, however, does not mean that it is necessary to study the equations themselves. The mathematical models that are programmed into FIRE1 are generally documented in scientific publications if you are interested in further study References are included in this paper with the description of each model. A summary of the equations used in BEHAVE is given by Andrews and Morris (in preparation).

The predictions that come from FIRE1 are based on mathematical models that include simplifying assumptions. You must judge the applicability of the results according to how closely the real situation conforms to the idealized model. This section is included to help you make such judgment. A later section is devoted to application.

Rate of Spread and Intensity (SITE and DIRECT)

The SITE and DIRECT modules of the FIRE1 program allow you to predict rate of spread, heat per unit area, fireline intensity, flame length, reaction intensity, effective windspeed, and direction of maximum spread. Although both modules predict the same values, their input is at a different level of resolution and they are designed for different applications. SITE aids the user in estimating fine dead fuel moisture, wind, and slope. Its major feature is the estimation of fine dead fuel moisture from weather and shading information. SITE will be used to make fire behavior predictions in cases where detailed site-specific information is available. On the other hand, DIRECT requires direct input of the basic input values (for example, 1-h fuel moisture). DIRECT may be more useful for general fire behavior predictions and "what if" questions.

The core of the SITE and DIRECT modules and, in fact, of the entire BEHAVE system, is Rothermel's (1972) "A Mathematical Model for Predicting Fire Spread in Wildland Fuels." In the manual on the FUEL subsystem of BEHAVE, Burgan and Rothermel (1984) explain in detail the fire model as it applies to fuel modeling. In this section, I will discuss the basic assumptions and limitations of the fire spread model and explain each output value. The basic input values (fuel model, fuel moisture, windspeed, and slope) will be covered individually in following sections.

ASSUMPTIONS AND LIMITATION OF THE SPREAD MODEL

Some basic assumptions inherent in the mathematical model that predicts fir spread limit its application. There are ways to deal with many of the limitations, but you must be aware of them and avoid using the predictions in situations for which they do not apply. When the fire model is discussed, its limitations are usually listed (for example, Rothermel 1972; Albini 1976a, 1976b; Burgan 1979a; Rothermel 1983). But the subject is so important that it is covered here also.

Because the model was designed to predict the spread of a fire, the fire model describes fire behavior in the flaming front (fig. 3). The primary driving force in the calculations is the dead fuel less than one-fourth inch in diameter, the fine fuels that carry the fire. Fuels larger then 3 inches in diameter are not included in the calculations at all. Residence time of the flame at a given point is a function only of the characteristic surface-area-to-volume ratio of the fuel array (Anderson 1969). For the 13 standard NFFL fuel models, residence time ranges from 0.11 to 0.34 minute (Rothermel 1983). Burning of larger fuels persists after the initial front has passed, although this is not included in this model.

The fire model is primarily intended to describe fires advancing steadily, independent of the source of ignition. Special care should be taken in applying predictions to prescribed fire where the behavior is affected by the pattern of ignition. Nevertheless, predictions can be used in conjunction with prescribed fire as described in the applications section.

The fire model describes fire spreading through surface fuels. This includes fuel within about 6 feet of the ground and contiguous to the ground. Surface fuels are often classified as grass, brush, litter, or slash (activity fuel). The fire model cannot be applied to ground fires—for example, smoldering duff fires or fires in peat bogs. Nor can the fire model be applied to crown fires where fire spreads from tree to tree independent of the surface fuel. (In some cases regeneration can be considered to be a surface fuel.) The model can identify when conditions are becoming severe enough to expect crowning and spotting.

Fuel, fuel moisture, wind, and slope are assumed to be constant during the time the predictions are to be applied. Because fires almost always burn under nonuniform conditions, length of projection period and choice of fuel must be carefully considered to obtain useful predictions. The more uniform the conditions, the longer the projection time can be. When fire burns from one fuel type to another, such as out of the grass on lower slopes and into timber, the fuel model as well as fuel moisture, slope, and windspeed must be changed. On the other hand, if the fire is burning in and out of two fuel types repeatedly, the two-fuel-model concept should be used. Wind is variable, but often tends to follow daily patterns. This complex problem is thoroughly discussed by Rothermel (1983). Burning conditions change markedly during a 24-hour diurnal cycle, therefore projection times should be limited to 2- to 4-hour periods when conditions can be expected to be reasonably constant.

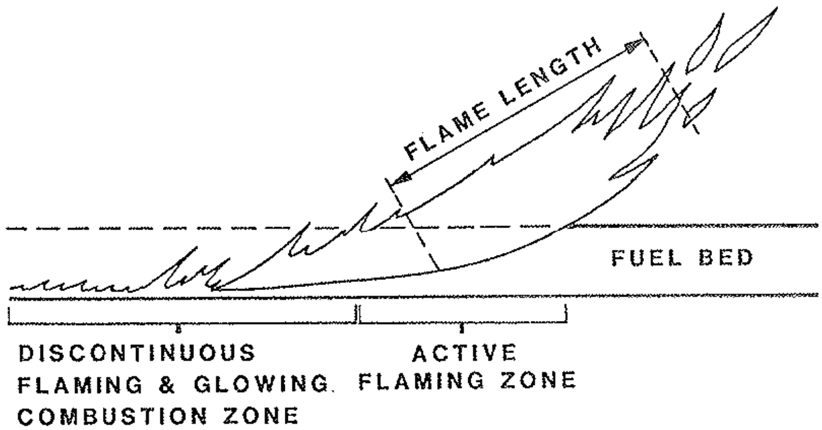


Figure 3.—The active flaming zone in relation to discontinuous flaming and glowing combustion.

INTENSITY

Flame length, fireline intensity, reaction intensity, and heat per unit area are all measures of the intensity of a fire. They have the following units:

flame length, ft
fireline intensity, Btu/ft/s
reaction intensity, Btu/ft^2/min
heat per unit area, Btu/ft^2.

Reaction intensity is a direct output of Rothermel's model (1972), with some revisions by Albini (1976b). **Fireline intensity** was defined by Byram (1959). Using Anderson's (1969) relationship for flame residence time, Rothermel's model can be used to predict Byram's fireline intensity. **Heat per unit area** is obtained from Rothermel's reaction intensity and Anderson's residence time. **Flame length** is directly related to fireline intensity. Flame length and fireline intensity are related to the heat felt by a person standing next to the flame (table 1).

Table 1.—Fire suppression interpretations of flame length and fireline intensity

Flame length	Fireline intensity	Interpretation
Feet	*Btu/ft/s*	
< 4	< 100	Fire can generally be attacked at the head or flanks by persons using handtools. Hand line should hold the fire.
4 – 8	100 – 500	Fires are too intense for direct attack on the head by persons using handtools. Hand line cannot be relied on to hold fire. Equipment such as plows, dozers, pumpers, and retardant aircraft can be effective.
8 – 11	500 – 1,000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
> 11	> 1,000	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

Equations showing the relationships between the three intensities and flame length are given in exhibit 3. **Reaction intensity** is the heat released **per minute** from a square foot of fuel while in the flaming zone. **Heat per unit area** is the heat released from a square foot of fuel while the flaming zone is in that area. Heat per unit area is equal to the reaction intensity times the residence time. **Fireline intensity** is the heat released **per second** from a foot-wide section of fuel extending from the front to the rear of the flaming zone. Fireline intensity is equal to the reaction intensity times the flame depth or heat per unit area times the rate of spread. **Flame length** is a function of fireline intensity.

$$t_r = \frac{384}{\sigma}$$

$$D = R\ t_r$$

$$H_A = I_R\ t_r$$

$$I_B = \frac{I_R\ D}{60}$$

$$= \frac{I_R\ R\ t_r}{60}$$

$$= \frac{H_A\ R}{60}$$

$$F_L = 0.45\ I_B^{0.46}$$

where

σ = characteristic surface-area-to-volume ratio of the fuel array, ft^2/ft^3

t_r = flame residence time, min

R = rate of spread, ft/min (BURN uses ch/h for rate of spread)

D = flame depth, ft

I_R = reaction intensity, $Btu/ft^2/min$

H_A = heat per unit area, Btu/ft^2

I_B = Byram's fireline intensity, Btu/ft/s (the 60 is required for the minutes-to-seconds conversion)

F_L = flame length, ft.

Exhibit 3.—Relationships among reaction intensity, heat per unit area, fireline intensity, and flame length.

The fire characteristics chart (Andrews and Rothermel 1982) illustrates the relationship between rate of spread, heat per unit area, fireline intensity, and flame length. The chart allows you to plot the four values as a single point. DIRECT output values in exhibit 4A are plotted on a fire characteristics chart in exhibit 4B. Notice that as wind increases, rate of spread, flame length, and fireline intensity increase, but heat per unit area remains constant.

In the BURN subsystem, the units of rate of spread are chains per hour. In the FUEL subsystem, the units are feet per minute. The values are nearly equal. Rate of spread in feet per minute is equal to 1.1 times rate of spread in chains per hour. The difference is due to the basic use of the two subsystems. FUEL is a development tool, and rate of spread is generally published in feet per minute. In addition, chains per hour is awkward for the graphics employed in the TSTMDL program. BURN uses chains per hour because these units are generally used in operational settings. The TI-59, nomograms, and S-390 tables also produce rate of spread in chains per hour.

When low-intensity fires burn under high windspeeds, the fire front may begin to "finger" rather than spread with a uniform front. To avoid overprediction of this type of fire, a limit is put on the effective windspeed that is used in the calculations. This value is a function of reaction intensity as described by

A.
```
1--FUEL MODEL                     13 -- HEAVY LOGGING SLASH
2--1-HR FUEL MOISTURE, %           8.0
3--10-HR FUEL MOISTURE, %          8.0
4--100-HR FUEL MOISTURE, %         8.0
7--MIDFLAME WINDSPEED, MI/H        2.0    6.0   10.0
8--PERCENT SLOPE                  30.0
9--DIRECTION OF WIND VECTOR        0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD            0.0   (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL


MIDFLAME I RATE OF   HEAT PER    FIRELINE  FLAME    REACTION   EFFECT.
  WIND   I SPREAD   UNIT AREA   INTENSITY  LENGTH   INTENSITY   WIND
 (MI/H)  I (CH/H)  (BTU/SQ.FT) (BTU/FT/S)   (FT)  (BTU/SQFT/M) (MI/H)
         I
         I
   2.    I    8.      3053.        464.      7.6      9214.       2.9
         I
   6.    I   19.      3053.       1080.     11.2      9214.       6.8
         I
  10.    I   31.      3053.       1763.     14.0      9214.      10.7
```

B.

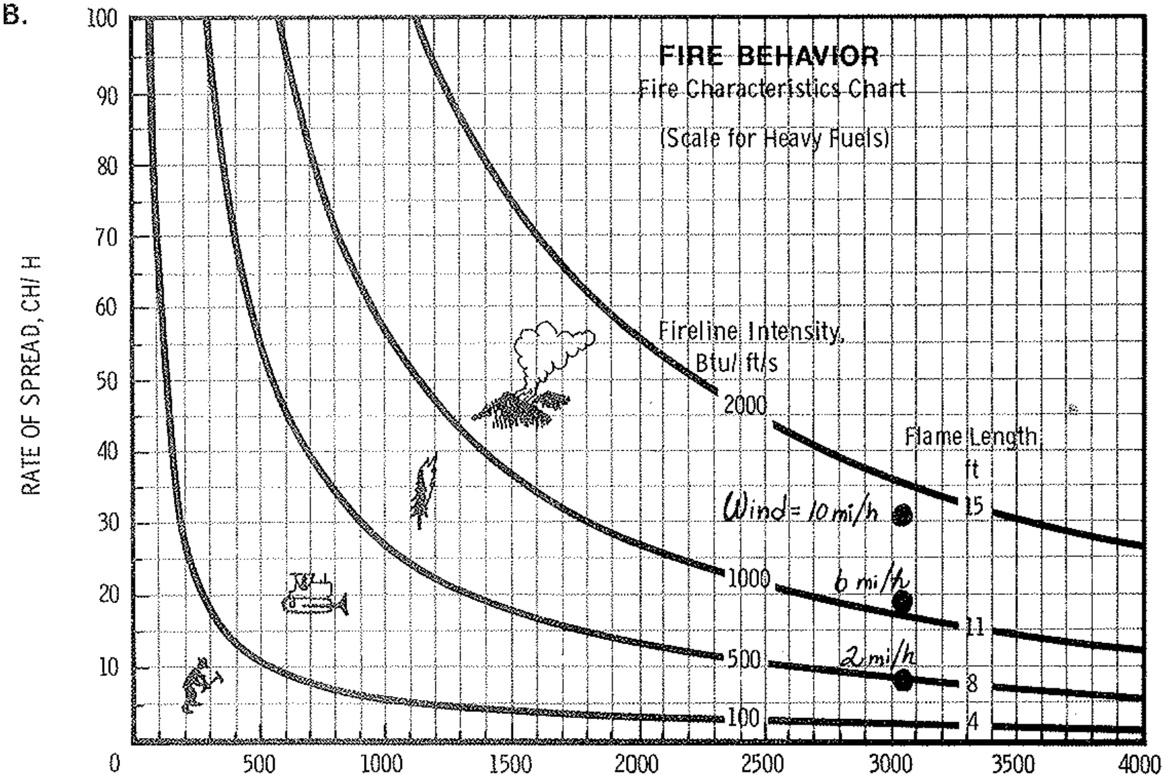


Exhibit 4.—Rate of spread, heat per unit area, fireline intensity, and flame length for three windspeeds plotted on a fire characteristics chart.

Rothermel (1972, p. 33). The TI-59 and the nomograms apply this limit to windspeed alone, whereas the BEHAVE programs put a limit on the combination of wind and slope (effective windspeed). This may lead to a slight difference in predictions. As illustrated in exhibit 5, when you reach this wind limit, the affected values are starred and a footnote is printed. The values for effective windspeed are the ones that are used in the calculations of rate of spread, fireline intensity, and flame length.

```
 1---FUEL MODEL                       1 --- SHORT GRASS (1 FT)
 2--1-HR FUEL MOISTURE, %            6.0
 7---MIDFLAME WINDSPEED, MI/H        0.0    3.0    6.0    9.0   12.0
 8---PERCENT SLOPE                   0.0
 9---DIRECTION OF WIND VECTOR        0.0
10---DIRECTION OF SPREAD             0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM THE WIND VECTOR


MIDFLAME I RATE OF   HEAT PER   FIRELINE  FLAME   REACTION   EFFECT.
  WIND   I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY   WIND
 (MI/H)  I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
         I
         I
   0.    I    4.        91.         7.     1.1      826.      0.0
         I
   3.    I   35.        91.        59.     2.9      826.      3.0
         I
   6.    I  135.        91.       224.     5.4      826.      6.0
         I
   9.    I  270.        91.       449.     7.5      826.      8.4*
         I
  12.    I  270.        91.       449.     7.5      826.      8.4*

           * MEANS YOU HIT THE WIND LIMIT.
```

Exhibit 5.—Windspeed effect is limited to avoid overprediction of low-intensity fires. In this example, 8.4 mi/h is the upper limit, so 9 and 12 mi/h windspeeds have the same effect as 8.4 mi/h wind.

The basic fire model (Rothermel 1972) assumes that wind is blowing directly upslope; that is, wind and slope both have an increasing effect on fire spread in the same direction. FIRE1 allows you to specify the direction of a cross-slope wind and calculate fire behavior in the direction of maximum spread. In addition, it is possible to obtain predictions for any other direction of spread (Andrews and Morris in preparation).

Directions are entered as degrees clockwise from upslope (when there **is** a slope). Direction of the wind vector is the direction of the effect of wind on spread, that is, the direction that the wind is blowing **to**. If the wind is blowing directly upslope, the direction of the wind vector is entered as 0; if the wind is blowing directly downslope, 180 is entered. Figure 4 illustrates directions from 0 to 360 for specifying wind and spread directions. This figure is just for your reference; any value from 0 to 360 can be entered.

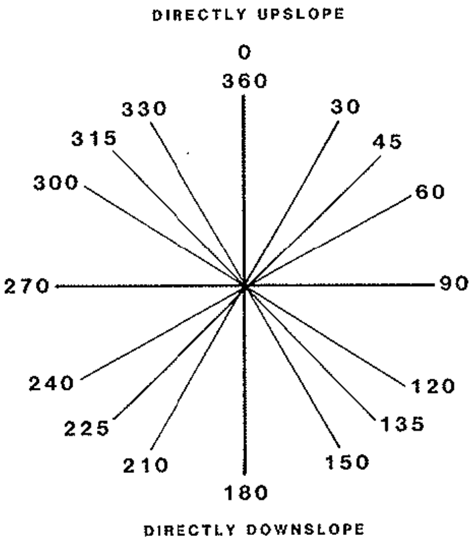


Figure 4.—Diagram of degrees clockwise from uphill for specifying direction of the wind vector and spread direction. (Any value from 0 to 360 can be entered.)

Whenever slope and wind are nonzero, wind direction is requested. Then you are asked whether you want the predictions for the direction of maximum spread. If you answer "no," you will be asked to specify the spread direction, and predictions will be for that specified direction. An example is shown in exhibit 6.

```
1--FUEL MODEL                     2 -- TIMBER (GRASS AND UNDERSTORY)
2--1-HR FUEL MOISTURE, %         2.0
3--10-HR FUEL MOISTURE, %        3.0
4--100-HR FUEL MOISTURE, %       4.0
5--LIVE HERBACEOUS MOIS, %     100.0
7--MIDFLAME WINDSPEED, MI/H      5.0
8--PERCENT SLOPE                20.0
9--DIRECTION OF WIND VECTOR     60.0
    DEGREES CLOCKWISE
     FROM UPHILL
10--DIRECTION OF SPREAD          0.0   60.0 120.0
    CALCULATIONS
    DEGREES CLOCKWISE
     FROM UPHILL


SPREAD  I RATE OF  HEAT PER    FIRELINE  FLAME    REACTION  EFFECT.
DIRECT. I SPREAD  UNIT AREA   INTENSITY  LENGTH  INTENSITY   WIND
 (DEG)  I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
        I
        I
  0.    I   10.       598.        111.      3.9      4333.      1.8
        I
 60.    I   50.       598.        546.      8.2      4333.      5.1
        I
120.    I    9.       598.         95.      3.7      4333.      1.6
```

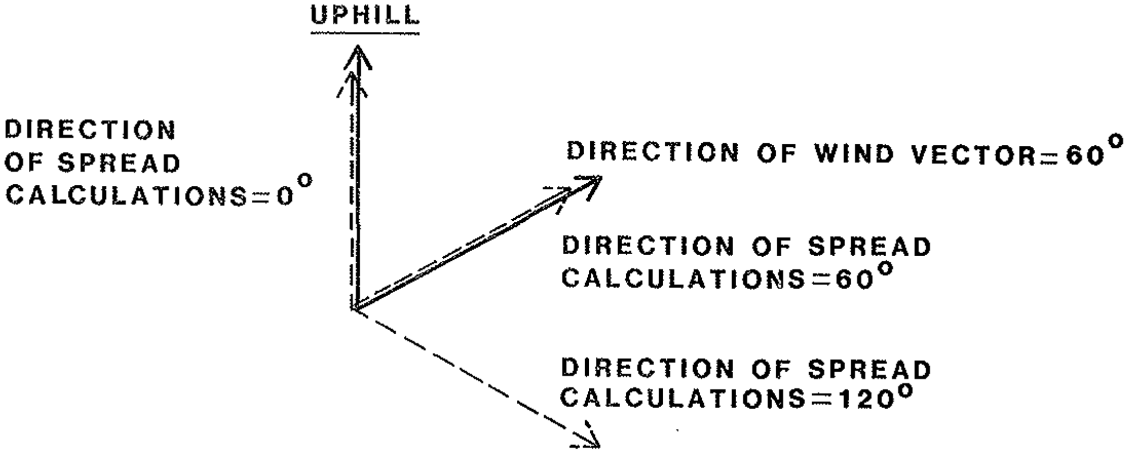


Exhibit 6.—DIRECT run, where the direction for the spread calculations is input. (Arrows indicate direction. Lengths are not relevant.)

On the other hand, you can indicate that you **do** want predictions for the direction of maximum spread. When windspeed, slope, and wind direction are all nonzero (that is, a cross-slope wind), then the direction of maximum spread will be calculated and given as an output value as shown in the example in exhibit 7. Otherwise, the direction of maximum spread is obviously zero and will be printed with the input because no additional calculations are necessary.

Often you will want predictions for fire spreading directly upslope with the wind. When this is the case, enter the wind direction as zero and specify that you want predictions for the direction of maximum spread. The direction of maximum spread will be zero also.

```
1---FUEL MODEL                      2 -- TIMBER (GRASS AND UNDERSTORY)
2---1-HR FUEL MOISTURE, %         2.0
3---10-HR FUEL MOISTURE, %        3.0
4---100-HR FUEL MOISTURE, %       4.0
5---LIVE HERBACEOUS MOIS, %     100.0
7---MIDFLAME WINDSPEED, MI/H      2.0    8.0
8---PERCENT SLOPE                40.0
9---DIRECTION OF WIND VECTOR     50.0
     DEGREES CLOCKWISE
      FROM UPHILL
10---DIRECTION OF SPREAD           DIRECTION OF MAXIMUM SPREAD
     CALCULATIONS                    TO BE CALCULATED
     DEGREES CLOCKWISE
      FROM UPHILL

MIDFLAME I RATE OF   HEAT PER    FIRELINE   FLAME    REACTION   EFFECT.  MAX
  WIND   I SPREAD   UNIT AREA   INTENSITY  LENGTH   INTENSITY   WIND   SPREAD
 (MI/H)  I (CH/H)  (BTU/SQ.FT) (BTU/FT/S)   (FT) (BTU/SQFT/M)(MI/H)   DIREC
         I                                                            (DEG)
         I
   2.    I   22.        598.        243.      5.6      4333.       3.1    20.
         I
   8.    I  120.        598.       1312.     12.2      4333.       8.3    45.
```

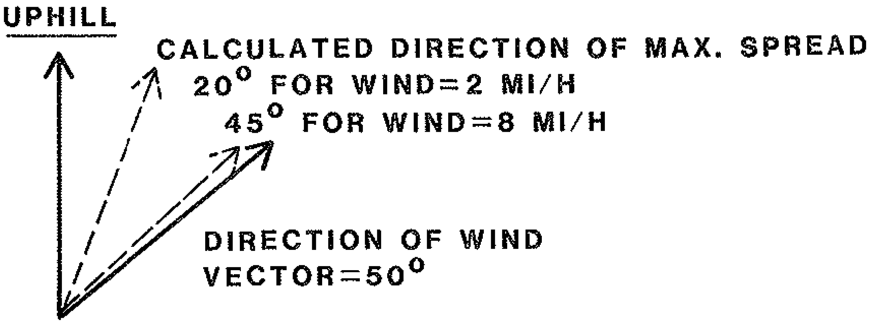


Exhibit 7.—DIRECT run, with cross-slope wind. The direction of maximum spread is calculated. (Arrows indicate direction. Lengths are not relevant.)

EFFECTIVE WINDSPEED

Effective windspeed is a combination of the effects of wind and slope. It is a function of midflame wind, slope, and fuel model as illustrated in exhibits 8A and 8B. The two runs are identical except that exhibit 8A is for fuel model 3 (tall grass) and exhibit 8B is for fuel model 1 (short grass). For fuel model 3, the effective windspeed is 3 mi/h for no wind and 60 percent slope and also for a 3-mi/h wind and no slope (underlined values). That is, for this particular example, no wind and a 60 percent slope is effectively the same as 3 mi/h wind on the flat. Effective windspeed lets you see the relative effects of wind and slope on the predictions. Notice that for a 6-mi/h wind and 80 percent slope, the effective windspeed is 9.0 mi/h for fuel model 3 and 8.1 mi/h for fuel model 1

A.

```
 1---FUEL MODEL                            3 -- TALL GRASS (2.5 FT)
 2---1-HR FUEL MOISTURE, %                6.0
 7---MIDFLAME WINDSPEED, MI/H             0.0    3.0    6.0
 8---PERCENT SLOPE                        0.0   20.0   40.0   60.0   80.0
 9---DIRECTION OF WIND VECTOR             0.0
        DEGREES CLOCKWISE
         FROM UPHILL
10---DIRECTION OF SPREAD                  0.0  (DIRECTION OF MAX SPREAD)
       CALCULATIONS
        DEGREES CLOCKWISE
         FROM UPHILL

=======================================================================
EFFECTIVE WINDSPEED, MI/H
=======================================================================
MIDFLAME I         PERCENT SLOPE
  WIND   I
 (MI/H)  I      0.      20.      40.      60.      80.
         I-------------------------------------------------------------
         I
  0.     I     0.0      0.6      1.6      3.0      4.6
         I
  3.     I     3.0      3.2      4.0      5.1      6.5
         I
  6.     I     6.0      6.2      6.8      7.8      9.0
```

B.

```
 1---FUEL MODEL                            1 -- SHORT GRASS (1 FT)
 2---1-HR FUEL MOISTURE, %                6.0
 7---MIDFLAME WINDSPEED, MI/H             0.0    3.0    6.0
 8---PERCENT SLOPE                        0.0   20.0   40.0   60.0   80.0
 9---DIRECTION OF WIND VECTOR             0.0
        DEGREES CLOCKWISE
         FROM UPHILL
10---DIRECTION OF SPREAD                  0.0  (DIRECTION OF MAX SPREAD)
       CALCULATIONS
        DEGREES CLOCKWISE
         FROM UPHILL

=======================================================================
EFFECTIVE WINDSPEED, MI/H
=======================================================================
MIDFLAME I         PERCENT SLOPE
  WIND   I
 (MI/H)  I      0.      20.      40.      60.      80.
         I-------------------------------------------------------------
         I
  0.     I     0.0      1.4      2.8      4.2      5.5
         I
  3.     I     3.0      3.3      4.1      5.1      6.2
         I
  6.     I     6.0      6.2      6.6      7.2      8.1
```

Exhibit 8.—Comparison of effective windspeed under the same conditions for (A) fuel model 3 and (B) fuel model 1.

(circled values). Notice also that for no wind the relative magnitudes for effective windspeed are reversed for the two fuel models, 4.6 mi/h for fuel model 3 and 5.5 mi/h for fuel model 1 (boxed values).

The effective windspeed printed in the output is for the direction of the spread calculations. For example, in exhibit 6, although wind and slope were assigned single values, the effective windspeed varies with the direction of the spread calculations.

Fuel Models

A fuel model is a set of numerical values that describes a fuel type for the mathematical model that predicts spread rate and intensity (Rothermel 1972). The parameters that can be varied in a fuel model are:

- loading for each fuel particle diameter size class, lb/ft^2
- surface-area-to-volume ratio for each size class, ft^2/ft^3
- fuel bed depth, ft
- heat content of fuel, Btu/lb
- moisture of extinction, percent.

Until now there has essentially been a choice of 13 stylized fire behavior fuel models (Anderson 1982). These are generally referred to as NFFL (Northern Forest Fire Laboratory, recently renamed Intermountain Fire Sciences Laboratory) and sometimes as FBO (Fire Behavior Officer) fuel models. Some special-purpose fuel models have been developed for critical fuel types, including southern California chaparral (Rothermel and Philpot 1973) and palmetto-gallberry (Hough and Albini 1978). The limited number of fuel models has handicapped fire behavior prediction. BEHAVE allows individual users to design custom fire behavior fuel models to represent local fuel conditions. Burgan and Rothermel (1984) describe the FUEL subsystem of BEHAVE and the custom fuel model building process.

NFFL FUEL MODELS

Do not design a custom fuel model until you are convinced that none of the 13 meet your needs. The 13 NFFL fuel models are described by Anderson (1982). Color photographs illustrate examples for each model. Rothermel (1983) lists considerations in selecting a fuel model (which strata is likely to carry the fire, how much green fuel is present, etc.) and provides a selection key. He also describes the two-fuel-model concept. Table 2 shows the parameters for the 13 fuel models (Anderson 1982) and calculated fuel model parameters as described by Burgan and Rothermel (1984). Predicted fire behavior for the 13 models under two sets of environmental conditions is given in exhibit 9.

If you use only the 13 NFFL fuel models in FIRE1, you can ignore the FUEL subsystem of BEHAVE and fuel model files. The 13 standard fuel models are stored as a part of the FIRE1 program.

Table 2.—Fuel model parameters and calculated fuel bed descriptors for the standard 13 NFFL fuel models[1]

Fuel model	Typical fuel complex	Surface-area-to-volume ratio(ft^{-1})/ fuel loading (tons/acre)				Fuel bed depth	Moisture of extinction dead fuels	Characteristic surface area-to-volume ratio	Packing ratio	Packing ratio / Optimum packing ratio
		1-h	10-h	100-h	Live					
						Ft	*Percent*	*Ft^{-1}*		
	Grass and grass-dominated									
1	Short grass (1 ft)	3,500/0.74	—	—	—	1.0	12	3,500	0.00106	0.25
2	Timber (grass and understory)	3,000/2.00	109/1.00	30/0.50	1,500/0.50	1.0	15	2,784	.00575	1.14
3	Tall grass (2.5 ft)	1,500/3.01	—	—	—	2.5	25	1,500	.00172	.21
	Chaparral and shrub fields									
4	Chaparral (6 ft)	2,000/5.01	109/4.01	30/2.00	1,500/5.01	6.0	20	1,739	.00383	.52
5	Brush (2 ft)	2,000/1.00	109/0.50	—	1,500/2.00	2.0	20	1,683	.00252	.33
6	Dormant brush, hardwood slash	1,750/1.50	109/2.50	30/2.00	—	2.5	25	1,564	.00345	.43
7	Southern rough	1,750/1.13	109/1.87	30/1.50	1,500/0.37	2.5	40	1,562	.00280	.34
	Timber litter									
8	Closed timber litter	2,000/1.50	109/1.00	30/2.50	—	.2	30	1,889	.03594	5.17
9	Hardwood litter	2,500/2.92	109/0.41	30/0.15	—	.2	25	2,484	.02500	4.50
10	Timber (litter and understory)	2,000/3.01	109/2.00	30/5.01	1,500/2.00	1.0	25	1,764	.01725	2.35
	Slash									
11	Light logging slash	1,500/1.50	109/4.51	30/5.51	—	1.0	15	1,182	.01653	1.62
12	Medium logging slash	1,500/4.01	109/14.03	30/16.53	—	2.3	20	1,145	.02156	2.06
13	Heavy logging slash	1,500/7.01	109/23.04	30/28.05	—	3.0	25	1,159	.02778	2.68

---

[1] Heat content = 8,000 Btu/lb for all fuel models.

1-h moisture, %	3		12	
10-h moisture, %	4		13	
100-h moisture, %	5		14	
live moisture, %	70		170	
midflame windspeed, mi/h	4		4	
slope, %	30		30	
Fuel model	Rate of spread (ch/h)	Flame length (ft)	Rate of spread (ch/h)	Flame length (ft)
1	97	4.9	0	0.0
2	40	7.1	15	3.6
3	140	15.9	75	10.2
4	100	24.1	20	7.4
5	33	7.5	5	1.7
6	41	7.3	22	4.7
7	35	7.0	15	4.1
8	2	1.3	1	.8
9	10	3.4	5	2.2
10	11	6.3	4	3.6
11	7	4.1	3	2.2
12	17	9.9	9	6.6
13	21	12.9	11	8.5

Exhibit 9.—Predicted rate of spread and flame length for the 13 NFFL fuel models under two sets of environmental conditions.

Custom fire behavior fuel models are developed and stored in a file using the FUEL subsystem (Burgan and Rothermel 1984). (The particulars of fuel model files are covered in appendix C.) To use a custom fuel model with the FIRE1 program, you must use the keyword CUSTOM to specify the name of the file where the custom fuel models are stored. CUSTOM also allows you to see what is stored in the file. An example is shown in exhibit 10. You can either list the numbers and names of fuel models in the file or you can list the parameters for a specific fuel model. You cannot change fuel model parameters with the FIRE1 program. Once you specify the name of the file where your custom fuel models are saved, they are referenced by number in response to the question: FUEL MODEL ? 1-99. Each user can have a private file and can therefore assign any number from 14 to 99 and name to a custom model.

```
TYPE 'CUSTOM' IF YOU ARE GOING TO USE CUSTOM FUEL MODELS.

FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>CUSTOM

A FUEL MODEL FILE IS NOT CURRENTLY ATTACHED TO THIS RUN.

FUEL MODEL FILE NAME ?
>PATDAT

THERE IS NO FUEL MODEL FILE BY THIS NAME.

DO YOU WANT TO TRY ANOTHER FILE NAME ? Y-N
>Y

FUEL MODEL FILE NAME ?
>PAT.DAT

CUSTOM FUEL MODEL FILE NAME: PAT.DAT
FILE DESCRIPTION:
   EXAMPLE FOR USERS MANUAL

DO YOU WANT A LIST OF THE FUEL MODELS THAT ARE STORED
IN THE FILE ? Y-N
>Y


CUSTOM FUEL MODEL FILE NAME: PAT.DAT
FILE DESCRIPTION:
   EXAMPLE FOR USERS MANUAL

            NUMBER  FUEL MODEL NAME

  (STATIC)    23     STATIC GRASS
  (DYNAMIC)   25     DYNAMIC GRASS

DO YOU WANT THE PARAMETER LIST FOR A SPECIFIC
FUEL MODEL ? Y-N
>Y

FUEL MODEL ? 14-99
>23


STATIC CUSTOM MODEL 23 -- STATIC GRASS
FROM FILE NAME: PAT.DAT
FILE DESCRIPTION:
   EXAMPLE FOR USERS MANUAL

      LOAD (T/AC)         S/V RATIOS                   OTHER
  ------------------   -----------------   ----------------------------
  1 HR          1.00   1 HR        3500.   DEPTH (FEET)            1.00
  10 HR         0.00   LIVE HERB   3500.   HEAT CONTENT (BTU/LB)  8000.
  100 HR        0.00   LIVE WOODY     0.   EXT MOISTURE (%)         15.
  LIVE HERB     1.00   S/V = (SQFT/CUFT)
  LIVE WOODY    0.00

  EXPOSED FUEL WIND ADJUSTMENT FACTOR =0.4

DO YOU WANT THE PARAMETER LIST FOR A SPECIFIC
FUEL MODEL ? Y-N
>Y

FUEL MODEL ? 14-99
>25
```

Exhibit 10.—Example use of the keyword CUSTOM. A custom fuel model file is attached to the run and its contents are examined.

```
DYNAMIC CUSTOM MODEL 25 -- DYNAMIC GRASS
FROM FILE NAME: PAT.DAT
FILE DESCRIPTION:
   EXAMPLE FOR USERS MANUAL

      LOAD (T/AC)           S/V RATIOS                     OTHER
  -------------------  -------------------  ----------------------------------
  1 HR          1.00   1 HR         3500.   DEPTH (FEET)                  1.00
  10 HR         0.00   LIVE HERB    3500.   HEAT CONTENT (BTU/LB)        8000.
  100 HR        0.00   LIVE WOODY      0.   EXT MOISTURE (%)               15.
  LIVE HERB     1.00   S/V = (SQFT/CUFT)
  LIVE WOODY    0.00

  EXPOSED FUEL WIND ADJUSTMENT FACTOR =0.4

DO YOU WANT THE PARAMETER LIST FOR A SPECIFIC
FUEL MODEL ? Y-N
>N

FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
```

Exhibit 10. (Con.)

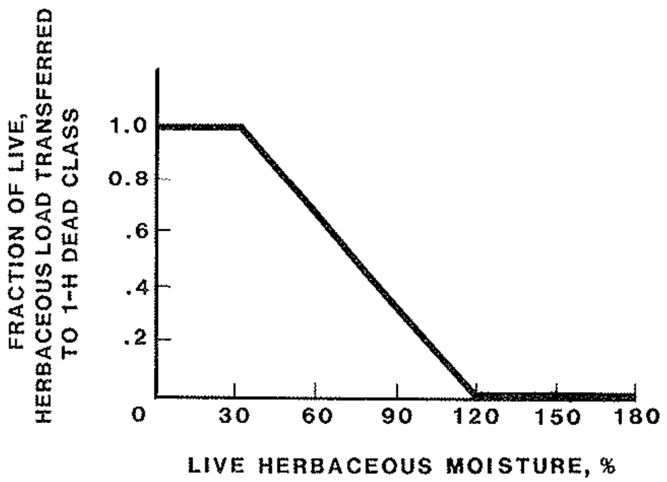


Figure 5.—The fraction of live herbaceous fuel in a dynamic fuel model that is transferred to the 1-h dead class is a function of live herbaceous fuel moisture.

Custom fuel models can be either static or dynamic. The standard 13 models are all static, that is, the fuel model does not change. Dynamic fuel models are meant to account for curing of herbaceous fuels (Burgan 1979b). Load is transferred from the live herbaceous class to the 1-hour timelag dead class (1-h) as a function of the live herbaceous fuel moisture content. The transfer function is shown in figure 5. When the moisture content is greater than 120 percent, all of the fuel that can be in the live herbaceous class remains in that class. When the moisture is 30 percent, all of the live herbaceous load has been transferred to the 1-h dead class. At intermediate values, a fraction of the load has been transferred. For example, when the live herbaceous moisture is 90 percent, 33 percent of the original live herbaceous load has been transferred to the 1-h class. When the fuel model parameters are listed, all of the "transferrable" load is in the live herbaceous class. Notice that in exhibit 10, the parameters for models 23 and 25 are the same, but 23 is static and 25 is dynamic.

The DIRECT runs in exhibit 11 show the differences in fire behavior prediction with changes in live herbaceous fuel moisture. When live herbaceous fuel moisture is 120 percent or greater, the predictions are the same because the models are the same—all of the herbaceous load of the dynamic model 25 is still in the live class. At moisture contents less than 120 percent, some of the live load has been transferred to the 1-h dead class; therefore the predictions are different. The dynamic model 25 has more fuel in the 1-h class, thus rate of spread and flame length predictions are higher.

```
 1--FUEL MODEL                       23 -- STATIC GRASS
 2--1-HR FUEL MOISTURE, %             5.0
 5--LIVE HERBACEOUS MOIS, %          30.0   60.0   90.0  120.0  150.0
 7--MIDFLAME WINDSPEED, MI/H          5.0
 8--PERCENT SLOPE                    10.0
 9--DIRECTION OF WIND VECTOR          0.0
      DEGREES CLOCKWISE
       FROM UPHILL
10--DIRECTION OF SPREAD               0.0   (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL

  LIVE    I RATE OF  HEAT PER   FIRELINE  FLAME   REACTION  EFFECT.
  HERB    I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY  WIND
  MOIS    I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
  (%)     I
          I
  30.     I   80.       325.        477.      7.7      2961.       5.0
          I
  60.     I   53.       293.        283.      6.0      2674.       5.0
          I
  90.     I   40.       284.        208.      5.2      2591.       5.0
          I
 120.     I   32.       277.        163.      4.7      2525.       5.0
          I
 150.     I   25.       251.        114.      4.0      2290.       5.0
```

```
 1--FUEL MODEL                       25 -- DYNAMIC GRASS
 2--1-HR FUEL MOISTURE, %             5.0
 5--LIVE HERBACEOUS MOIS, %          30.0   60.0   90.0  120.0  150.0
 7--MIDFLAME WINDSPEED, MI/H          5.0
 8--PERCENT SLOPE                    10.0
 9--DIRECTION OF WIND VECTOR          0.0
      DEGREES CLOCKWISE
       FROM UPHILL
10--DIRECTION OF SPREAD               0.0   (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL

  LIVE    I RATE OF  HEAT PER   FIRELINE  FLAME   REACTION  EFFECT.
  HERB    I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY  WIND
  MOIS    I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
  (%)     I
          I
  30.     I  105.       291.        558.      8.3      2651.       5.0
          I
  60.     I   85.       316.        492.      7.8      2883.       5.0
          I
  90.     I   53.       302.        295.      6.2      2754.       5.0
          I
 120.     I   32.       277.        163.      4.7      2525.       5.0
          I
 150.     I   25.       251.        114.      4.0      2290.       5.0
```

Exhibit 11.—Example DIRECT run showing the effect of dynamic load transfer on the predictions.

The fact that there are 20 standard NFDRS fuel models (Deeming and others 1977) as well as 13 standard (NFFL) fire behavior fuel models (Anderson 1982) has caused confusion. Use of NFDRS fuel models in BEHAVE can cause serious problems. Reasons are described in appendix D along with a summary of similarities and differences between NFDRS and BEHAVE.

When an area is covered by two very different fuel types in patches, it may not be possible to design a custom model to fit the situation. In this case, the two-fuel-model concept may be appropriate. Two fuel models and their relative percentages of cover are specified. When a custom fuel model is used, it should have been designed with the assumption that the fuel type covers the whole area. The percent cover input in FIRE1 takes care of the weighting by percent cover.

An example run using the two-fuel-model concept is shown in exhibit 12. Separate calculations are done for each of the fuel models; then the rate of spread weighted by percent cover is calculated. The fire speeds up and slows down as it burns through the two fuel models, effectively averaging the rate of spread over the projection period. On the other hand, flame length and intensity are not averaged. Part of the area has one flame length and the rest of the area has another flame length. Valuable information would be lost, especially in terms of suppression interpretations, if the flame lengths were averaged.

When SIZE is linked to SITE or DIRECT and the two-fuel-model concept is being used, the effective windspeed for the fuel model covering the greatest area and the weighted rate of spread are used in the area and perimeter calculations. The maximum of the flame length values for the two fuel models is used for the suppression interpretations for the link to CONTAIN.

```
 1---TWO FUEL MODEL CONCEPT    70%  2 -- TIMBER (GRASS AND UNDERSTORY)
                               30% 10 --- TIMBER (LITTER AND UNDERSTORY)
 2---1-HR FUEL MOISTURE, %       4.0   6.0   8.0
 3---10-HR FUEL MOISTURE, %      5.0
 4---100-HR FUEL MOISTURE, %     5.0
 5---LIVE HERBACEOUS MOIS, %   100.0
 6---LIVE WOODY MOISTURE, %    100.0
 7---MIDFLAME WINDSPEED, MI/H    6.0
 8---PERCENT SLOPE              10.0
 9---DIRECTION OF WIND VECTOR    0.0
      DEGREES CLOCKWISE
       FROM UPHILL
10---DIRECTION OF SPREAD         0.0  (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL

FUEL MODEL  2   (70%)


  1-HR    I RATE OF  HEAT PER   FIRELINE  FLAME   REACTION  EFFECT.
  MOIS    I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY  WIND
  (%)     I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
          I
          I
   4.     I   55.       512.        519.     8.0     3713.      6.0
          I
   6.     I   49.       477.        430.     7.3     3460.      6.0
          I
   8.     I   45.       460.        382.     6.9     3336.      6.0
```

Exhibit 12.—DIRECT run illustrating the two-fuel-model concept. (con.)

```
FUEL MODEL 10   (30%)

  1-HR    I RATE OF  HEAT PER   FIRELINE  FLAME   REACTION  EFFECT.
  MOIS    I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY  WIND
  (%)     I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
          I
          I
   4.     I   12.      1386.        309.    6.3     6366.      6.1
          I
   6.     I   11.      1284.        259.    5.8     5898.      6.1
          I
   8.     I   10.      1217.        227.    5.5     5589.      6.1

FUEL MODEL  2   (70%)        FUEL MODEL 10   (30%)

  1-HR    I    WEIGHTED
  MOIS    I RATE OF SPREAD
  (%)     I     (CH/H)
          I
          I
  4.0     I       42.
          I
  6.0     I       38.
          I
  8.0     I       35.
```

FUEL PARTICLE SIZE CLASSES

The 13 NFFL fuel models were limited to one live and three dead (1-h, 10-h, 100-h) fuel classes. Custom fuel models also have three dead classes but allow for two live classes, herbaceous and woody. For consistency, the live fuel in the 13 models has been classified as either herbaceous or woody. Fuel model 2 has live herbaceous fuel. Models 4, 5, 7, and 10 have live woody fuel. The other models (1, 3, 6, 8, 9, 11, 12, 13) have no live fuel. The 13 fuel models are all static, so the classification of live fuel does not affect the calculations. That is, the live fuel moisture will have the same effect on the predictions whether it is woody or herbaceous because there is no transfer of load to the dead class. Nevertheless, because the moisture content will be requested, stored, and printed as either herbaceous or woody, you should be aware of the classification.

Fuel Moisture

Fuel moisture content is a critical variable in predicting fire behavior. Fuel models consist of as many as three dead and two live classes of fuel. A moisture value must be assigned to each class in the fuel model that is currently being used. The DIRECT module requires direct input of fuel moisture values. The most prominent feature of the SITE module is its ability to estimate fine dead fuel moisture from weather and shading conditions.

LIVE FUEL MOISTURE

Live fuels are classified as either herbaceous or woody. Woody fuel includes shrub foliage and twigs less than one-fourth inch in diameter. Herbaceous fuel includes nonwoody plants such as grasses and forbs. If the fuel model is "dynamic," a portion of the herbaceous fuel, based on its moisture content, is considered dead. This process is explained in a previous section on fuel models. If the fuel model is "static," then there is effectively no difference between woody and herbaceous fuels as far as the mathematical model is concerned. If there are no truly herbaceous fuels in a fuel model, then a custom fuel model can be built with one of the two classes of live fuel used for the foliage and one for the twigs, thereby allowing different moisture values to be used for each class.

As noted by Rothermel (1983), "Live fuel moisture values are a result of physiological changes in the plant. These are mainly due to the time of the season, precipitation events, the temperature trend, and the species." In FIRE1, determination of an appropriate live fuel moisture is up to the user. If no other information is available, live fuel moisture can be estimated by a table of indicators. SITE will print this table upon request (exhibit 13). Direct sampling and measurement of live fuel moisture will give the best estimate. This may be worth the effort for critical prescribed burns. In southern California where fire behavior is especially dependent upon live fuel moisture, there is a system of collection and reporting of live fuel moisture throughout the season (Countryman and Dean 1979). These values are collected for direct input to the NFDRS. They are available for BEHAVE input. Calculated moisture values from the NFDRS can also be used in BEHAVE; however, care must be taken in applying them in mountainous terrain where elevation and aspect will result in moisture values far different from those taken at valley weather stations.

```
(9) DO YOU WANT TO SEE THE LIVE FUEL MOISTURE GUIDELINES ? Y-N
>Y

IF DATA ARE UNAVAILABLE FOR ESTIMATING LIVE FUEL
MOISTURE, THE FOLLOWING ROUGH ESTIMATES CAN BE USED.

     300% = FRESH FOLIAGE, ANNUALS DEVELOPING,
            EARLY IN GROWING CYCLE

     200% = MATURING FOLIAGE, STILL DEVELOPING
            WITH FULL TURGOR

     100% = MATURE FOLIAGE, NEW GROWTH COMPLETE AND
            COMPARABLE TO OLDER PERENNIAL FOLIAGE

      50% = ENTERING DORMANCY, COLORATION STARTING,
            SOME LEAVES MAY HAVE DROPPED FROM STEM

(9) LIVE WOODY MOISTURE, % ? 30-300
>80
```

Exhibit 13.—Live fuel moisture guidelines that can be printed by SITE upon request.

An example of the effect of live fuel moisture on the predictions for fuel model 5 is given in exhibit 14. Notice that in this example when live woody moisture increases from 40 to 80 percent, the difference in fire behavior is significant; and when moisture increases from 240 to 280 percent there is little change in fire behavior. Notice also that when the moisture is 160 percent or greater, the heat per unit area and reaction intensity remain constant, but rate of spread continues to decrease. When the live fuel moisture is low, it burns and contributes to the rate of fire spread. When the moisture reaches a critical level (the calculated live fuel moisture of extinction [Albini 1976b, p. 16]), however, the live fuel does not burn, but continues to act as a heat sink, lowering the rate of spread.

Dead fuels are categorized according to timelag, based on the length of time required for a fuel particle to change moisture by a specified amount when subjected to a change in its environment. Fine dead fuel less than one-fourth inch in diameter comprises the 1-hour timelag (1-h) class. This includes needles, leaves, cured herbaceous plants, and fine dead stems. Dead fuel one-fourth to 1 inch in diameter is 10-h; 1- to 3-inch fuel is 100-h. Fuels larger than 3 inches in diameter are not included in the calculations for spread and intensity.

```
 1---FUEL MODEL                        5 -- BRUSH (2 FT)
 2---1-HR FUEL MOISTURE, %            5.0
 3---10-HR FUEL MOISTURE, %           9.0
 6---LIVE WOODY MOISTURE, %          40.0  80.0 120.0 160.0 200.0 240.0 280.0
 7---MIDFLAME WINDSPEED, MI/H         9.0
 8---PERCENT SLOPE                   15.0
 9---DIRECTION OF WIND VECTOR         0.0
      DEGREES CLOCKWISE
       FROM UPHILL
10---DIRECTION OF SPREAD              0.0  (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL

 LIVE    I RATE OF  HEAT PER   FIRELINE  FLAME   REACTION  EFFECT.
WOODY    I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY  WIND
 MOIS    I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
 (%)     I
         I
 40.     I  111.       753.      1535.    13.1     3300.       9.1
         I
 80.     I   69.       700.       890.    10.2     3069.       9.1
         I
120.     I   35.       475.       308.     6.3     2081.       9.1
         I
160.     I   15.       255.        71.     3.2     1119.       9.1
         I
200.     I   13.       255.        59.     2.9     1119.       9.1
         I
240.     I   11.       255.        51.     2.7     1119.       9.1
         I
280.     I   10.       255.        45.     2.6     1119.       9.1
```

Exhibit 14.—DIRECT run showing the effect of live fuel moisture on fire behavior predictions.

Fine dead fuel moisture is one of the primary factors controlling fire behavior at the flaming front. The spread model reflects this fact in the weight it puts on the moisture content of 1-h class compared to 10-h and 100-h. Exhibit 15 shows an example of the relative effect of 1-h and 10-h moistures on rate of spread and flame length predictions. When 10-h is set at 4 percent and 1-h varies from 2 to 14 percent (second column), the resulting rate of spread varies from 51 to 14 ch/h. On the other hand, when 1-h moisture is set at 4 percent and 10-h moisture varies from 2 to 14 percent (second row), rate of spread is always 41 ch/h. Notice also that when the 1-h fuel is wetter, 14 percent, the 10-h fuel moisture has a greater effect on the results.

However, because the fire model is not very sensitive to the moisture contents of 10-h and 100-h fuel, do not conclude that 1-h fuel is the only important component of a fuel model. Figure 6 is a graph from the TSTMDL program of the BEHAVE system (Burgan and Rothermel 1984) showing predicted rate of spread for a range of 10-h fuel loads. This illustrates that when moisture contents are set, the predicted rate of spread can vary significantly, depending on the 10-h fuel load that is present in the fuel model. The conditions for figure 6 correspond to those in exhibit 15. One-hour and 10-h moisture contents are 4 percent; fuel model 2 has 1 ton/acre of 10-h fuels. Therefore, the boxed rate of spread in exhibit 15 (41 ch/h) corresponds to the circled point on the graph in figure 6. (The FIRE1 program gives spread rate in chains per hour while the TSTMDL program uses feet per minute.)

```
 1---FUEL MODEL                       2 -- TIMBER (GRASS AND UNDERSTORY)
 2---1-HR FUEL MOISTURE, %          2.0    4.0    6.0    8.0   10.0   12.0   14.0
 3---10-HR FUEL MOISTURE, %         2.0    4.0    6.0    8.0   10.0   12.0   14.0
 4---100-HR FUEL MOISTURE, %        6.0
 5---LIVE HERBACEOUS MOIS, %      100.0
 7---MIDFLAME WINDSPEED, MI/H       5.0
 8---PERCENT SLOPE                 15.0
 9---DIRECTION OF WIND VECTOR       0.0
      DEGREES CLOCKWISE
       FROM UPHILL
10---DIRECTION OF SPREAD            0.0  (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL

================================================================================
RATE OF SPREAD, CH/HR
================================================================================
  1-HR    I           10-HR MOIS,   %
  MOIS    I
  (%)     I      2.      4.      6.      8.     10.     12.     14.
          I----------------------------------------------------------------------
          I
  2.      I     51.     51.     50.     50.     50.     50.     49.
          I
  4.      I     41.     41.     41.     41.     41.     41.     41.
          I
  6.      I     37.     37.     37.     37.     36.     36.     36.
          I
  8.      I     34.     34.     34.     34.     34.     33.     33.
          I
 10.      I     31.     30.     30.     30.     30.     30.     30.
          I
 12.      I     24.     24.     24.     24.     23.     23.     23.
          I
 14.      I     14.     14.     14.     13.     13.     12.      7.

================================================================================
FLAME LENGTH, FT
================================================================================
  1-HR    I           10-HR MOIS,   %
  MOIS    I
  (%)     I      2.      4.      6.      8.     10.     12.     14.
          I----------------------------------------------------------------------
          I
  2.      I     8.2     8.2     8.2     8.1     8.1     8.1     8.1
          I
  4.      I     7.0     7.0     7.0     7.0     6.9     6.9     6.9
          I
  6.      I     6.4     6.4     6.4     6.4     6.4     6.4     6.3
          I
  8.      I     6.1     6.1     6.1     6.0     6.0     6.0     6.0
          I
 10.      I     5.6     5.6     5.6     5.5     5.5     5.5     5.5
          I
 12.      I     4.7     4.6     4.6     4.5     4.5     4.5     4.4
          I
 14.      I     2.9     2.8     2.8     2.7     2.6     2.4     1.5
```

Exhibit 15.—DIRECT run showing the relative effect of 1-h and 10-h fuel moisture on fire behavior predictions.

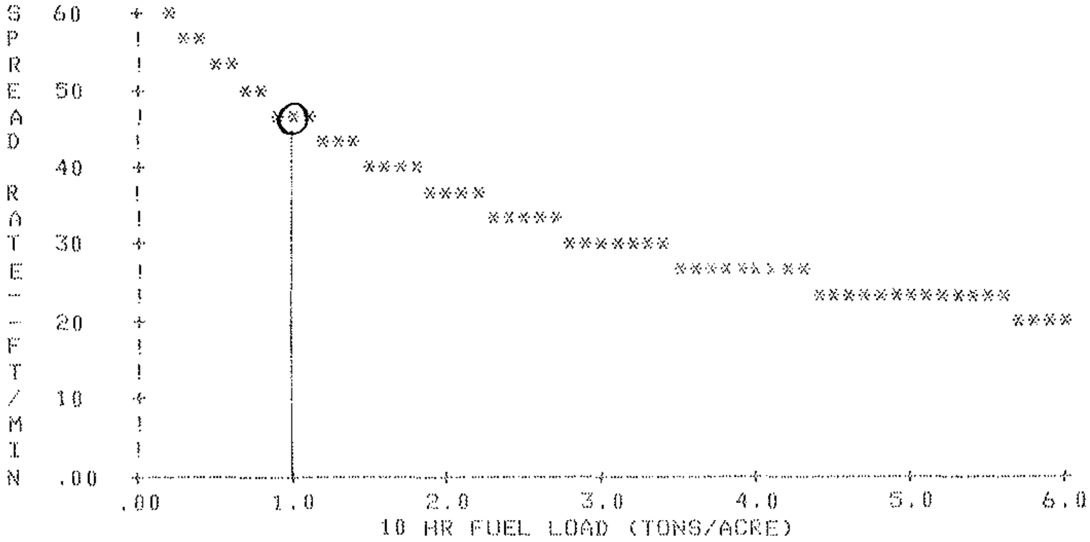


Figure 6.—Graph from TSTMDL showing the effect of a change in 10-h fuel load on spread rate predictions when fuel moisture is held constant.

FINE DEAD FUEL MOISTURE MODEL

Because 1-h moisture content is so important in the spread calculations, a lot of effort has gone into mathematical prediction models. Tables for 1-h fuel moisture have been developed for use by Fire Behavior Officers (FBO) and are described by Rothermel (1983). These tables are well suited for field use and work quite well under the hot, dry conditions typical of escaped wildfire. But BEHAVE will be used for many applications beyond FBO type predictions. Therefore a new model has been developed (Rothermel and others in press) to predict the moisture of fine dead fuel with greater accuracy over a larger range of conditions and times than possible with the FBO procedures. The model is based on the Canadian fine fuel moisture code (FFMC), with changes to allow for drying of surface fuels by solar radiation, initialization methods without a complete record of weather data prior to the startup time, and methods for estimating fine fuel moisture at any time of the day or night.

The Canadian FFMC was developed for shaded conditions. The FBO system is patterned after the NFDRS system, which was designed for worst-case exposed conditions. Rothermel and others (in press) present validation showing that the new moisture model in BEHAVE preserves the capabilities of the Canadian FFMC in shaded conditions and improves it significantly in sunny conditions. Similarly, the BEHAVE moisture model is shown to be at least as good as the FBO methods in dry, sunny conditions and superior in the shade. Test data were available from Idaho, Texas, Arizona, and Alaska.

Some important aspects that affect fuel moisture are not in this model but will likely be considered in future revisions. The most significant of these are the effects of moisture in the duff and soil beneath the litter layer and the effects of cooling due to nighttime radiation losses and dew formation. Other considerations omitted at this time are differences in moisture because fuels are either standing (such as grass) or lying on the ground, differences between freshly fallen and old litter, and differences caused by fuel coating, such as bark or wax.

The label "1-hour timelag" is applied to dead fuel, 0 to one-quarter inch in diameter. Byram (1963) demonstrated that the moisture content of dead fuels drying under constant conditions follows an exponential decay curve. He defined the timelag interval as the time required for fuels to lose approximately two-thirds (actual value is 1/e where e = base of natural logarithms) of their initial moisture content. Because conditions are never constant, fuel moisture is continually seeking an equilibrium value which is based on the current temperature and relative humidity. Van Wagner (1974) showed that an estimate of the moisture content of fine fuels should consider the fuel moisture content on the previous day. Therefore the new moisture model requires much more information than the weather conditions at the time of the estimation.

For the purposes of the moisture model used in SITE, a "burn day" goes from 1200 to 1200 as shown in figure 7. Burn day −1 ("burn day minus one") is the previous 24-hour period from 1200 to 1200. Burn day is set up this way because of the input requirements for diurnal adjustments as described later. All times are solar time. In most cases, local standard time can be used.

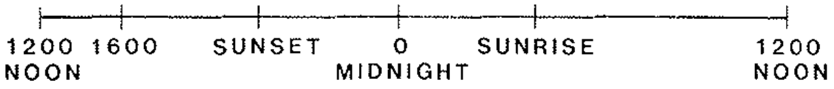


Figure 7.—"Burn day" goes from 1200 to 1200.

The major sections of the model include correction of temperature and humidity for the elevation difference between the site of the weather readings and fire site, correction of temperature and humidity for solar heating, initialization of the moisture content, calculation of early afternoon moisture, and diurnal adjustment of fuel moisture (fig. 8). Figures 9 and 10 show the flow of the fine fuel moisture model along with the SITE input values that are utilized at each step.

It is often necessary to use temperature and humidity readings that are not taken at the site where the fuel moisture value is needed. For a well-mixed atmosphere (no inversion), the adiabatic lapse rate is used to adjust temperature and humidity according to elevation differences. If the elevation difference is less than 1,000 ft, no correction is applied.

One of the primary features of the model is a correction for solar heating used to adjust the temperature and humidity measured at standard weather shelter height to the conditions at fuel level. The input values that determine solar heating are date, latitude, slope, elevation, aspect, canopy cover, cloud cover, haziness, and windspeed.

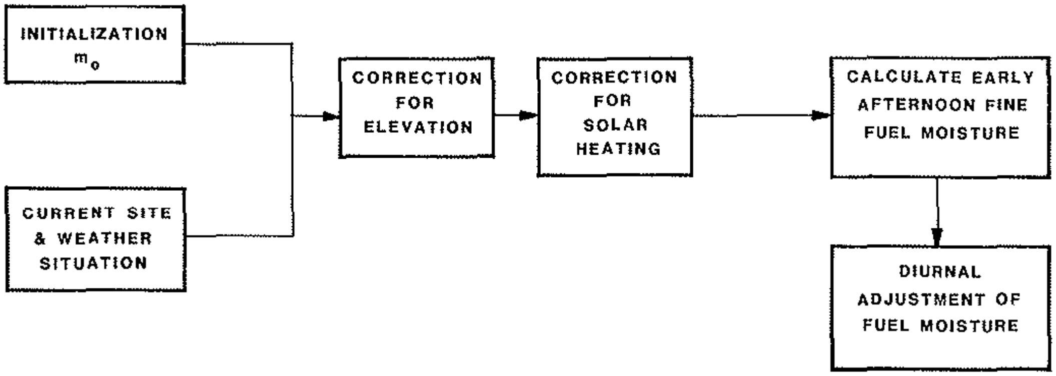


Figure 8.—General flow diagram of the fine fuel moisture model (from Rothermel and others in press).

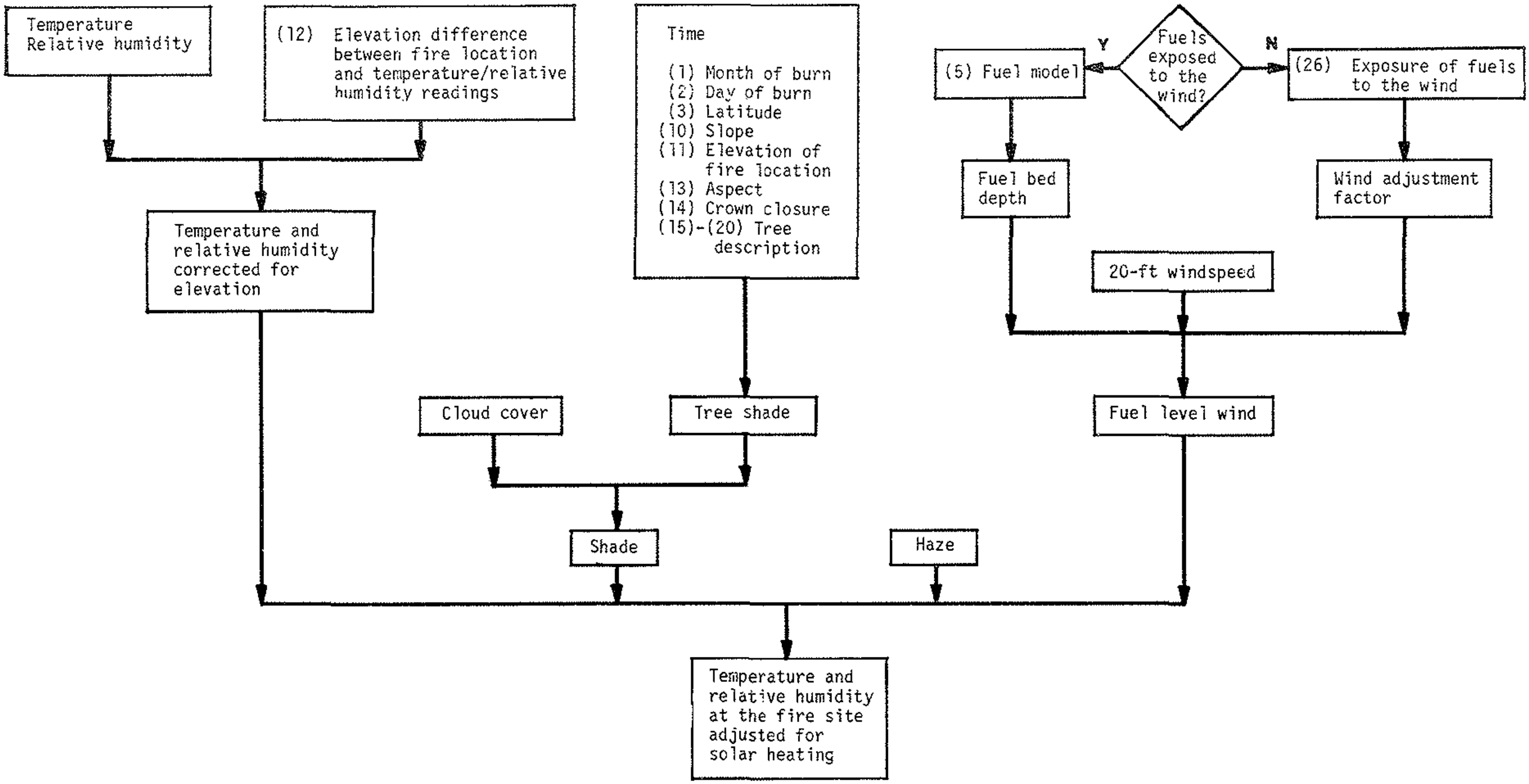


Figure 9.—Flow diagram of the part of the fine fuel moisture model that adjusts temperature and relative humidity for elevation and solar heating. This adjustment is used several places in the model. SITE input values and line numbers are shown at each step.

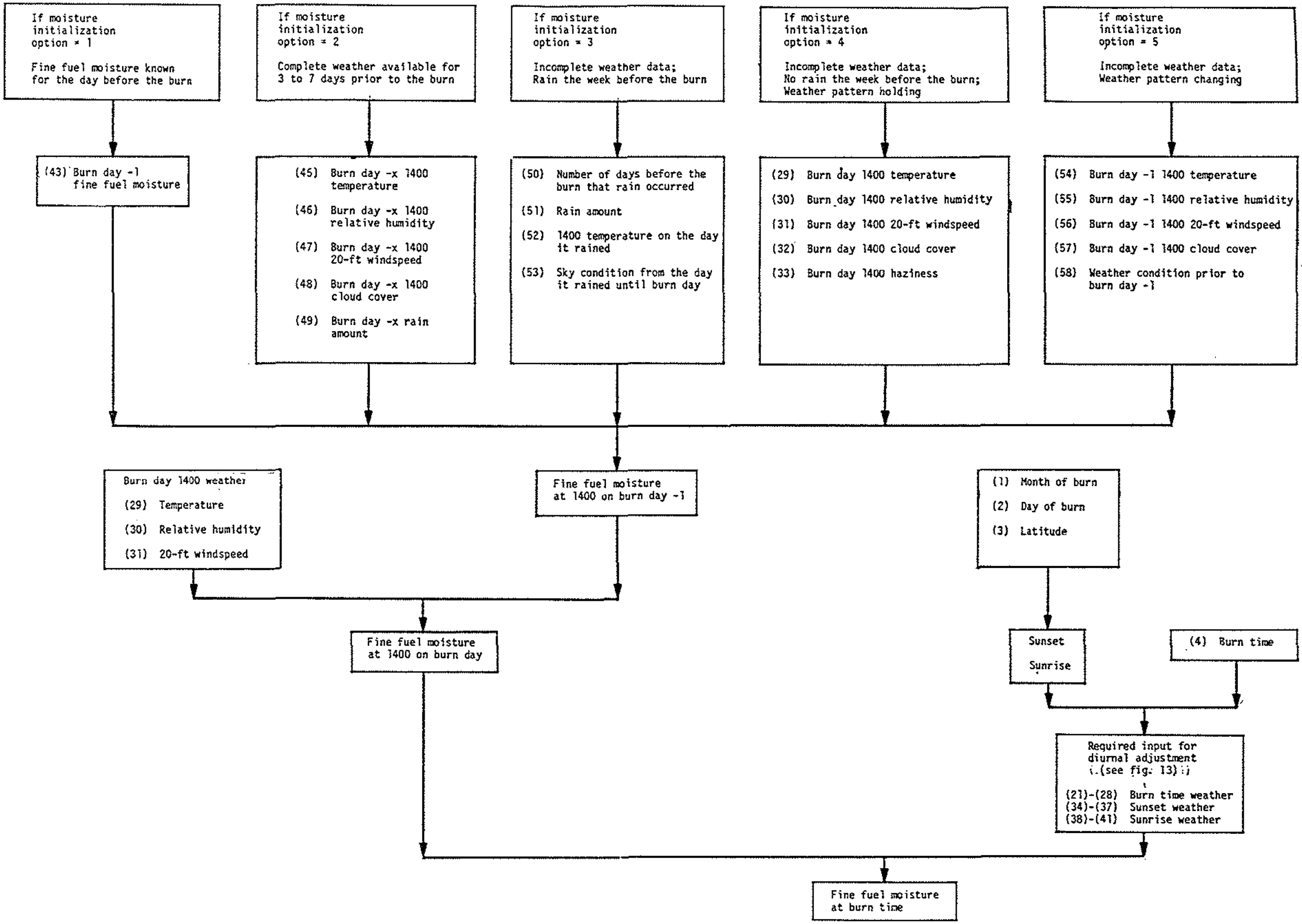


Figure 10.—Flow diagram of the fine fuel moisture model showing moisture initialization, calculation of 1400 moisture on burn day, and diurnal adjustment of fuel moisture. SITE input values and line numbers are shown at each step.

Canopy cover is described in terms of crown closure, presence or absence of foliage, shade tolerance, tree type (coniferous or deciduous), average tree height, ratio of crown length to tree height, and ratio of crown length to crown diameter. Aids to estimating crown closure and crown ratios are given in figures 11 and 12. In addition, SITE facilitates the estimation of latitude by converting a two-letter State abbreviation to an average latitude as shown in exhibit 16.

Windspeed is used in adjusting temperature and humidity for solar heating because turbulent mixing cools fuel being heated by the sun. When fuels are exposed to the wind, an equation developed by Albini and Baughman (1979) is

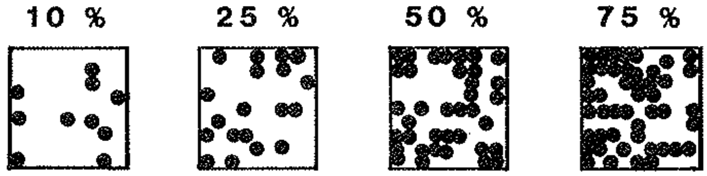
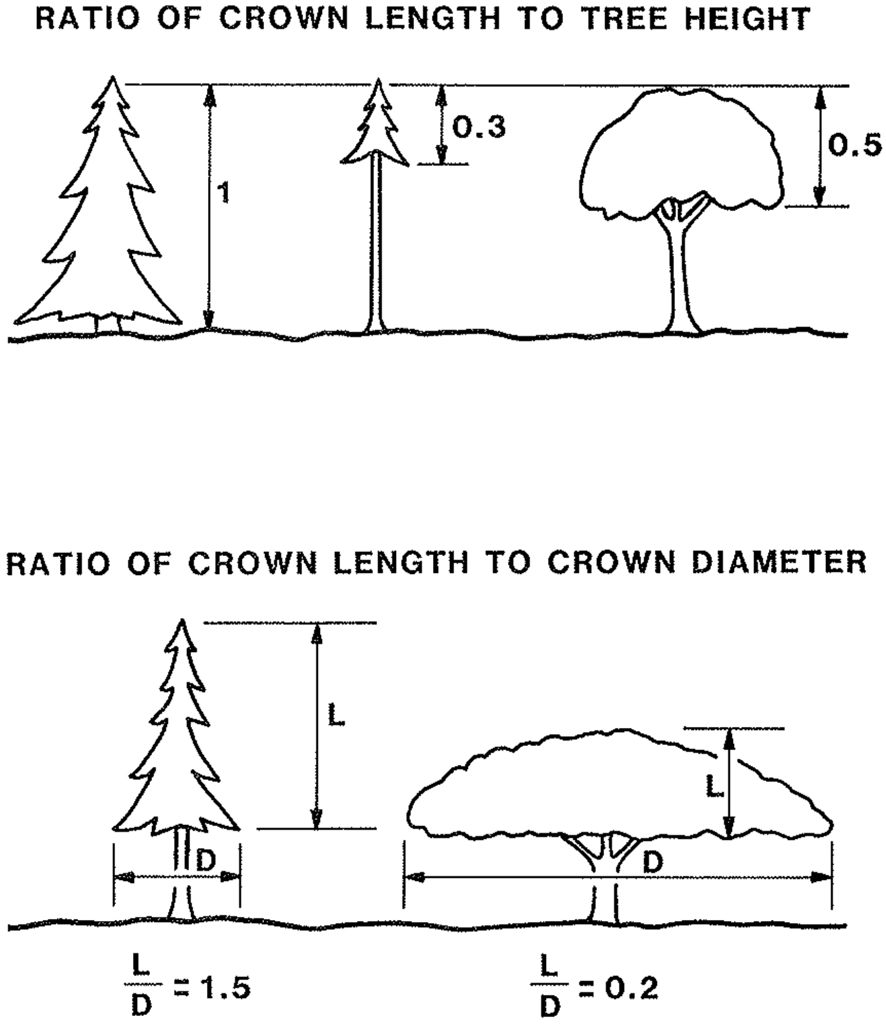


Figure 11.—Aid to estimating canopy closure, an input to SITE.


RATIO OF CROWN LENGTH TO TREE HEIGHT

RATIO OF CROWN LENGTH TO CROWN DIAMETER

Figure 12.—Aid to estimating ratio of crown length to tree height and ratio of crown length to crown diameter, input values to SITE.

State	Abbreviation	Latitude	State	Abbreviation	Latitude
Alabama	AL	33	Montana	MT	46
Alaska	AK	65	Nebraska	NE	42
Arizona	AZ	35	Nevada	NV	40
Arkansas	AR	35	New Hampshire	NH	44
California	CA	38	New Jersey	NJ	40
Colorado	CO	40	New Mexico	NM	35
Connecticut	CT	41	New York	NY	44
Delaware	DE	44	North Carolina	NC	36
Florida	FL	25	North Dakota	ND	46
Georgia	GA	33	Ohio	OH	40
Hawaii	HI	20	Oklahoma	OK	35
Idaho	ID	45	Oregon	OR	43
Illinois	IL	40	Pennsylvania	PA	40
Indiana	IN	40	Rhode Island	RI	41
Iowa	IA	42	South Carolina	SC	34
Kansas	KS	39	South Dakota	SD	44
Kentucky	KY	39	Tennessee	TN	36
Louisiana	LA	32	Texas	TX	35
Maine	ME	46	Utah	UT	40
Maryland	MD	39	Vermont	VT	44
Massachusetts	MA	42	Virginia	VA	38
Michigan	MI	44	Washington	WA	46
Minnesota	MN	46	West Virginia	WV	38
Mississippi	MS	32	Wisconsin	WI	44
Missouri	MO	39	Wyoming	WY	43

Exhibit 16.—Two-letter State abbreviations and the latitude that is assigned by SITE.

used to estimate fuel-level windspeed from the 20-ft windspeed. When fuels are sheltered from the wind, the wind-adjustment factor is used to find the fuel level wind.

The adjustments to temperature and relative humidity described above and shown in figure 9 are used in several places in the model. Figure 10 shows the moisture initialization, calculation of the 1400 moisture, and diurnal adjustment of the moisture content. These sections of the model are described below.

Initialization sets the fuel moisture at 1400 on the day before the burn (burn day −1). Choice of one of the initialization options depends on the information that is available; option 1 requires that the initial fine fuel moisture be input directly. This value might be obtained by measurement of a fuel sample. Option 2 calculates the initial moisture from complete weather records for 3 to 7 days prior to the day of the burn (temperature, humidity, windspeed, cloud cover, and rain amount). If complete weather data are not available, options 3, 4, or 5 can be used. Option 3 is used when there is rain the week prior to the burn. Because of calculations about the air mass, this option can be used only if there has been no frontal passage since the rain. Input consists of days since rain, amount of rain, early afternoon temperature on the day it rained, and sky condition between the day of rain and burn day (clear, cloudy, or partly cloudy). Option 4 is used when it did not rain the week prior to the burn and weather conditions are persistent from day to day. No additional input is required for this option. The burn day weather is used to estimate the initial moisture value. Option 5 is used when it does not rain the week prior to the burn and weather conditions are variable. Input consists of an estimate of the early afternoon weather conditions for the day prior to the burn (temperature, humidity, windspeed, and cloud cover), and the general weather pattern prior to that: (1) hot and dry, (2) cool and wet, or (3) between 1 and 2.

The early afternoon (1400) moisture content is calculated from the initial fuel moisture described above and the temperature, humidity, and windspeed on burn day. The calculations utilize the Canadian FFMC.

In order to determine the moisture content at any other time of day or night, additional input is required as shown in figure 13. Temperature and relative humidity values at each hour are predicted from sinusoidal curves linking the 1400 weather to the burn time weather as shown in figure 14.

The fine fuel moisture model is now part of the SITE module. There are plans to add a new module (MOISTURE) to the next update of BEHAVE, consisting only of the moisture model without the spread and intensity predictions. Options for table or graphic output will be offered.

There are 58 items on the SITE worksheet. Most of these are for the moisture model. Because there are options on the required input, depending on the information that is available, it is never necessary to input all 58 values. In fact SITE can be run with as few as 15 values specified as shown in the run in appendix A. The worksheet for SITE shows the conditions that require each input value. A line-by-line description of each input variable is in appendix B.

Burn time between	**1200 and 1600**	**1600 and sunset**		**sunset and sunrise**			**sunrise and 1200**			
Conditions required for	**1400 = BT***	**1400**	**BT**	**1400**	**SS**	**BT**	**1400**	**SS**	**SR**	**BT**
Temperature	x	x	x	x	x	x	x	x	x	x
Relative humidity	x	x	x	x	x	x	x	x	x	x
Windspeed	x	x	x	x	x	x	x	x	x	x
Cloud cover	x	x	x	x	x		x	x	x	x
Haziness	x	x		x			x			x

BT = burn time

SS = sunset

SR = sunrise

*Conditions are assumed to be constant from 1200 to 1600.

Figure 13.—Chart indicating weather parameters needed according to the specified burn time.

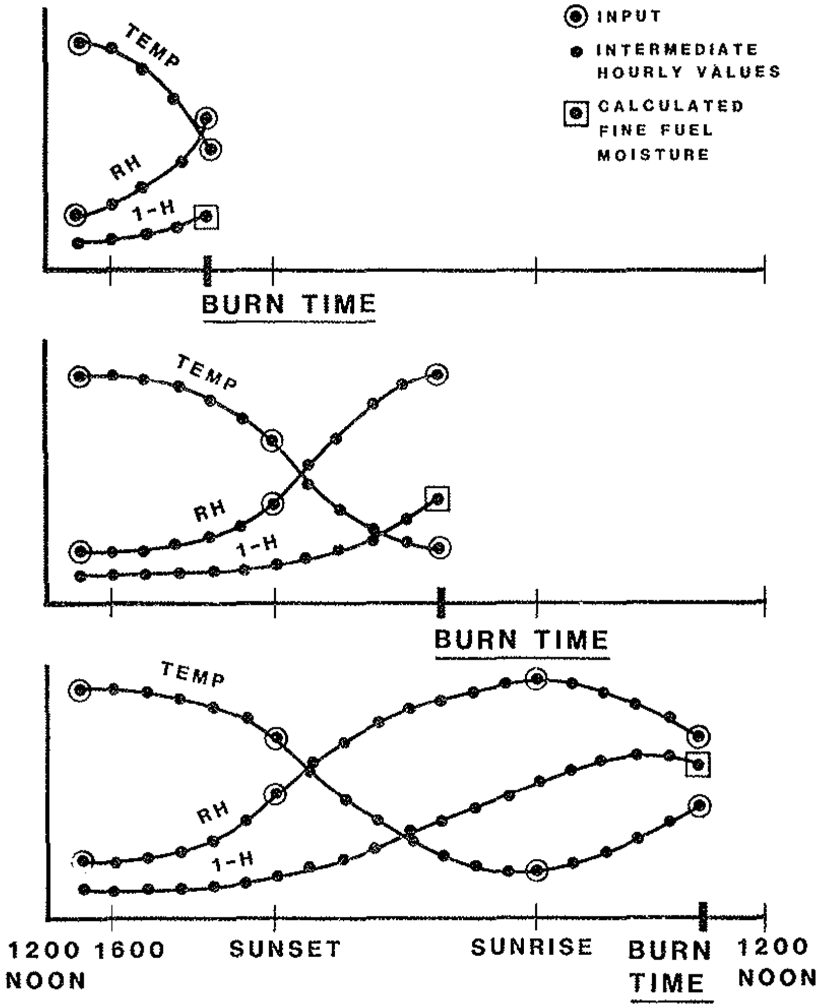


Figure 14.—Temperature and relative humidity at each hour are predicted from sinusoidal curves linking input values. These hourly values are used in calculating fine fuel moisture.

In "How to Predict the Spread and Intensity of Forest and Range Fires," Rothermel (1983) discusses "procedures for obtaining the necessary wind information from weather forecasts and for interpreting measurements made at the fire site to produce the required windspeed input to the fire model." Rothermel's publication describes real-time fire behavior prediction from a Fire Behavior Officer's point of view. The situation is simplified if you are using fire behavior prediction to answer "what if" planning questions. In any case you should study the wind section in Rothermel (1983) so that you will fully understand what is behind the question: MIDFLAME WINDSPEED, MI/H?

The windspeed input to the fire model is the speed of the wind without influence of the fire. The effects of indrafts on a steadily spreading fire are built into the model. Therefore you do not have to consider the fire's influence upon the wind. However, the model does **not** handle the interactions between two fire fronts or the effect of drafts caused by a "mass" fire. This emphasizes the fact that you should not use the predictions in fire situations for which the fire model was not designed, such as prescribed fires, where the method and pattern of ignition are used to control fire behavior.

In the United States, land management agencies measure wind at a standard height of 20 ft above the ground, adjusted for depth of vegetation (Fischer and Hardy 1976). The windspeed required by the fire model is at a height above the surface fuel that would be equivalent to the midlevel height of flames from the expected fire, namely midflame windspeed. Midflame windspeed can be calculated from 20-ft windspeed and a wind adjustment factor based on fuel model, topography, and canopy cover (table 3) (Albini and Baughman 1979).

Table 3.—Wind adjustment table. The appropriate adjustment factor is multiplied by the 20-ft windspeed to obtain midflame windspeed

Shelter	Fuel model	Adjustment factor
Exposed Fuels		
Fuel exposed directly to the wind—no overstory or sparse overstory; fuel beneath timber that has lost its foliage; fuel beneath timber near clearings or clearcuts; fuel on high ridges where trees offer little shelter from wind	4	0.6
	13	.5
	1,3,5,6,11,12 (2,7)[1] (8,9,10)[2]	.4
Partially Sheltered Fuels		
Fuels beneath patchy timber where it is not well sheltered; fuel beneath standing timber at midslope or higher on a mountain with wind blowing directly at the slope	All	.3
Fully Sheltered Fuels		
Fuel sheltered beneath standing timber on flat or gentle slope or near base of mountain with steep slopes	All Open stands	.2
	Dense stands	.1

[1] These fuels are usually partially sheltered.
[2] These fuels are usually fully sheltered.

DIRECT requires direct input of midflame windspeed. DISPATCH asks for the 20-ft windspeed and the wind adjustment factor. SITE asks for 20-ft windspeed. If you know the degree of exposure of fuels to the wind, it can be entered directly, otherwise SITE will help you determine it. The information that SITE uses in determining the wind adjustment factor is diagrammed in figure 15.

The adjustment factor for exposed fuels depends on the fuel model, but the adjustment factors for sheltered and partially sheltered fuels do not. The fuel models included in table 3 are the 13 NFFL models. Adjustment factors for custom fuel models are calculated as described by Rothermel (1983, p. 138) and stored in the fuel model file. They are printed with the parameters when you use the keyword CUSTOM (exhibit 10). You may want to add the factors for your favorite custom models to table 3 for future reference.

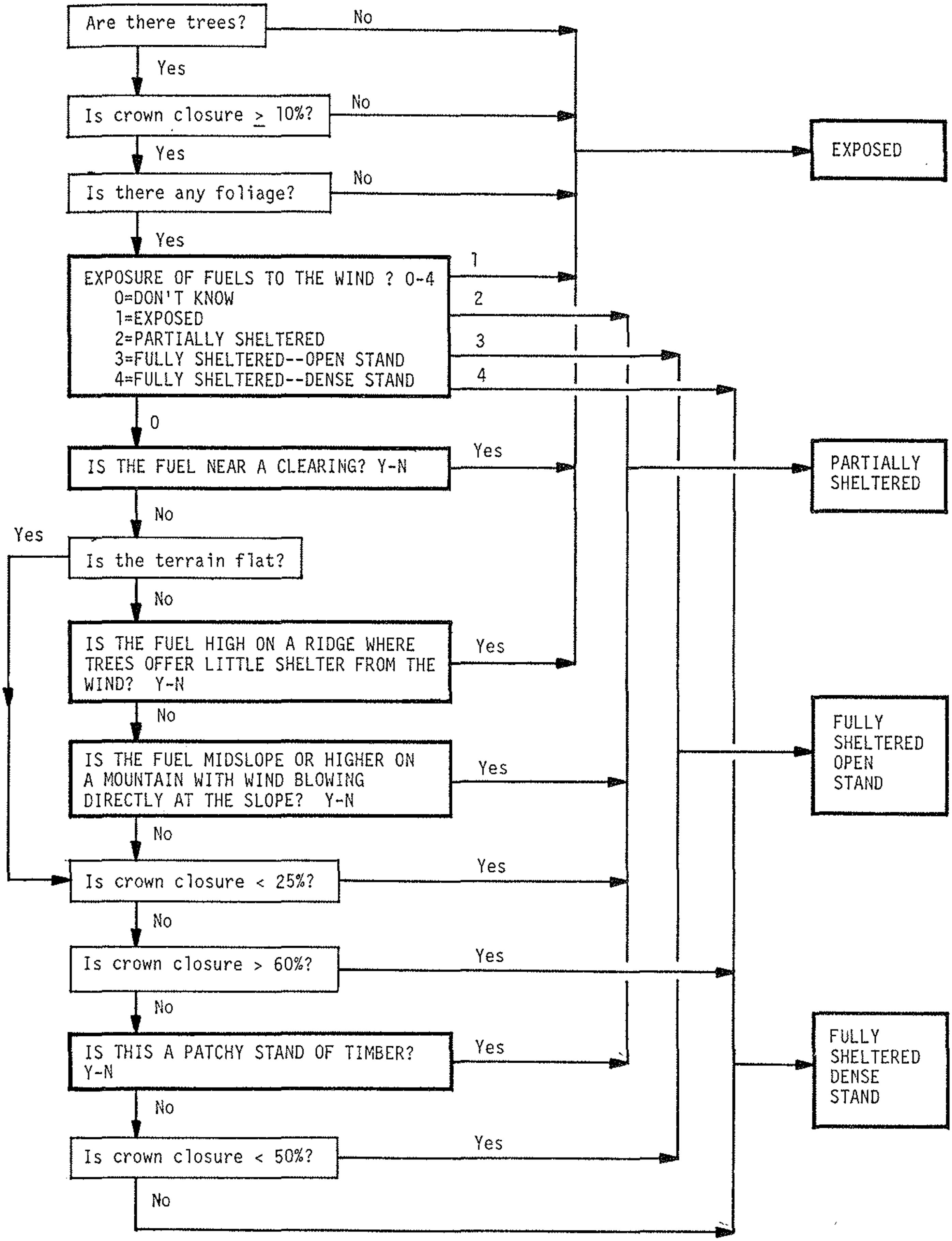


Figure 15.—Information that is used in SITE to determine wind adjustment factor. Questions printed in capital letters are asked directly of the user. Others are based on information entered previously.

Slope

Rothermel (1983) discusses the effect of slope on fire behavior, the relative effect of wind and slope, and how to deal with rough terrain. The slope value used by the spread model is the maximum percent slope of the terrain immediately above the fire. Predictions for cross-slope fire spread are accomplished by specifying the relative directions of slope, wind, and spread as described in a previous section.

DIRECT requires direct entry of percent slope. SITE allows you to enter measurements from a topographic map to calculate percent slope as described by Rothermel (1983). An example is given in exhibit 17. You are asked to describe the map that you are using in terms of the map scale and the contour interval. The map scale can be specified either as a representative fraction or as inches per mile. You can specify one of eight common map scales by entering a single digit or you can enter a value for the map scale directly. For the specific area for which you want to determine percent slope, you enter a distance in inches and the number of contour intervals over that distance.

```
(10) DO YOU WANT TO ENTER MAP MEASUREMENTS TO
     CALCULATE PERCENT SLOPE ? Y-N
>Y

(10) MAP SCALE ? 0-8
       0=DIRECT ENTRY      1-8=CODE

           REP.FRAC.   IN/MI          REP.FRAC.   IN/MI
       1= 1:253,440    1/4       5= 1:24,000     2.64
       2= 1:126,720    1/2       6= 1:21,120     3
       3= 1:63,360      1        7= 1:15,840     4
       4= 1:31,680      2        8= 1:7,920      8
>5

(10) CONTOUR INTERVAL, FT ? 10-500
>20

(10) MAP DISTANCE  INCHES ? .1-10
>.4

(10) NUMBER OF CONTOUR INTERVALS ? 1-100
>15


MAP SCALE = 1: 24000. = 2.64 IN/MI =  2000. FT/IN
RISE IN ELEVATION    =  300. FT
HORIZONTAL DISTANCE =  800. FT

SLOPE = 37.%
```

Exhibit 17.—Example of the slope determination aid in SITE.

Area and Perimeter (SIZE)

The shape of a fire that starts from a point source, such as lightning or a firebrand, is roughly elliptical. Anderson (1983) has developed double ellipse equations to describe the shape. The equations used in FIRE1 are for a simple ellipse (Andrews and Morris in preparation). This simplification was necessary so that the assumptions of the containment model would be met and so that there would be consistency with the direction equations. This also allows calculations of area and perimeter when winds are blowing across the slope.

Area and perimeter of a point-source fire can be calculated from forward rate of spread, effective windspeed, and elapsed time from ignition. Conditions are assumed to be relatively constant over the projection period. The fire is assumed to be spreading steadily in surface fuels during the lapsed time. This does not include the time that an ignition may smolder before it begins to spread. Rate of spread and elapsed time give the forward spread distance. Effective windspeed determines the shape of the fire.

Rate of spread and effective windspeed are calculated by DIRECT and SITE. These values can be used along with the additional input of time in the SIZE calculations. An example of SIZE linked to DIRECT is shown in exhibit 18A. The fire shapes that correspond to these calculations are given in figure 16A.

It is also possible to use SIZE as an independent module. In this case rate of spread, effective windspeed, and elapsed time are entered directly as input. An example of an independent run of SIZE is given in exhibit 18B. The corresponding fire shapes are in figure 16B. This illustrates the effect of effective windspeed on fire shape, because all of these fires have the same forward rate of spread. The fires are narrower under higher windspeeds. Notice also that backing spread distance decreases with increasing windspeed.

A.

```
 1--FUEL MODEL                       9 -- HARDWOOD LITTER
 2--1-HR FUEL MOISTURE, %            4.0
 3--10-HR FUEL MOISTURE, %           5.0
 4--100-HR FUEL MOISTURE, %          5.0
 7--MIDFLAME WINDSPEED, MI/H         4.0    6.0    8.0
 8--PERCENT SLOPE                    0.0
 9--DIRECTION OF WIND VECTOR         0.0
10--DIRECTION OF SPREAD              0.0  (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM THE WIND VECTOR

MIDFLAME I RATE OF   HEAT PER    FIRELINE   FLAME    REACTION   EFFECT.
  WIND   I SPREAD  UNIT AREA   INTENSITY   LENGTH  INTENSITY    WIND
 (MI/H)  I (CH/H) (BTU/SQ.FT) (BTU/FT/S)   (FT)  (BTU/SQFT/M)  (MI/H)
         I
         I
   4.    I    8.       416.         57.      2.9      2691.        4.0
         I
   6.    I   14.       416.        108.      3.9      2691.        6.0
         I
   8.    I   23.       416.        172.      4.8      2691.        8.0

 1--RATE OF SPREAD, CH/H            OUTPUT FROM DIRECT, RANGE=    8. TO   23.
 2--EFFECTIVE WIND, MI/H            OUTPUT FROM DIRECT, RANGE=   4.0 TO   8.0
 3--ELAPSED TIME, HR                1.5

MIDFLAME I    AREA  PERIMETER  LENGTH-   FORWARD   BACKING    MAXIMUM
  WIND   I    (AC)    (CH)    TO-WIDTH   SPREAD    SPREAD     WIDTH
 (MI/H)  I                     RATIO    DISTANCE  DISTANCE   OF FIRE
         I                                (CH)      (CH)       (CH)
         I
   4.    I     5.8     29.       2.0       11.3       0.8        6.1
         I
   6.    I    15.3     51.       2.5       21.2       0.9        8.8
         I
   8.    I    31.6     77.       3.0       33.8       1.0       11.6
```

B.

```
 1--RATE OF SPREAD, CH/H            14.0
 2--EFFECTIVE WIND, MI/H             4.0    6.0    8.0
 3--ELAPSED TIME, HR                 1.5

 EFFECT. I    AREA  PERIMETER  LENGTH-   FORWARD   BACKING    MAXIMUM
  WIND   I    (AC)    (CH)    TO-WIDTH   SPREAD    SPREAD     WIDTH
 (MI/H)  I                     RATIO    DISTANCE  DISTANCE   OF FIRE
         I                                (CH)      (CH)       (CH)
         I
   4.    I     20.     55.       2.0       21.0       1.5       11.3
         I
   6.    I     15.     50.       2.5       21.0       0.9        8.8
         I
   8.    I     12.     48.       3.0       21.0       0.6        7.2
```

Exhibit 18.— (A)Example of SIZE linked to DIRECT; (B) SIZE run independently.

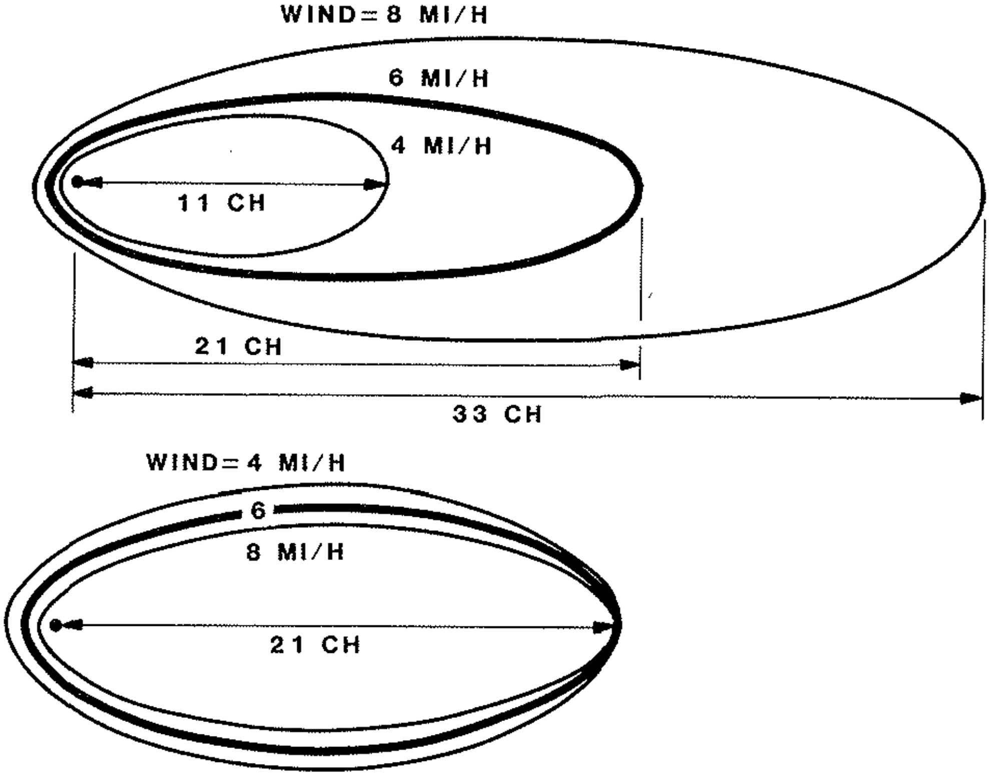


Figure 16.—(A) Fire shapes that correspond to the run in exhibit 18A; (B) fire shapes that correspond to the run in exhibit 18B.

As shown in exhibit 18B, when rate of spread is input as a **constant** value, area and perimeter decrease with an increase in effective windspeed due to the change in fire shape. When SIZE is run independently, effective windspeed does not affect rate of spread; but when SIZE is linked to either DIRECT or SITE, effective windspeed is used in the rate-of-spread calculations. Therefore, in exhibit 18A area and perimeter increase with increasing windspeed. Notice in the DIRECT run in exhibit 18A that the calculated rate of spread for a midflame windspeed of 6 mi/h is 14 ch/h. Because the slope is zero, midflame windspeed is equal to effective windspeed. The constant rate of spread for exhibit 18B was also 14 ch/h. Therefore, the calculated area and perimeter for these cases is the same, 15 acres. (When any of the values for area in a table is less than 10 acres, area is printed to the nearest 0.1 acre, otherwise it is rounded to the nearest acre.)

Refer to exhibit 2 to review the two places in the FIRE1 keyword hierarchy where SIZE can be entered as a keyword. The usual way to use SIZE is to link it to DIRECT or SITE. But you can use SIZE independently when you want to calculate specific rate of spread and effective windspeed conditions or if you want to examine the area and perimeter model itself.

Fire Containment (CONTAIN)

The CONTAIN module is used to estimate requirements for fire suppression activities. CONTAIN predicts final fire size, given forward rate of spread, initial fire size, fire shape length-to-width ratio, and control-line construction rate. It can also be used to find the line construction rate needed to hold the burned area to a fixed value (Albini and Chase 1980; Albini and others 1978). The containment model in BEHAVE is different from the more generalized simulation model used in the Forest Service Fire Planning and Analysis process (FSH 5109.19).

In order to formulate the containment problem as a mathematical model, some basic limiting assumptions were made:

1. The fire has an elliptical shape at the time of attack.
2. Conditions are constant over the time that fireline is being constructed.
3. The containment line is constructed at the edge of the fire.
4. The fire is attacked either at the head or the rear. Work then proceeds simultaneously on both sides of the fire at an equal pace.

Application of the containment model should be limited to situations that reasonably match the above conditions; that is, initial attack on spot fires that can be contained in one burning period. Because fires are usually attacked directly (fireline is constructed within a few feet of the fire), the model cannot be applied to high-intensity fires. Major application of predictions from CONTAIN include contingency planning, initial attack dispatching, and preliminary fire control planning.

Predictions can be made for either head or rear attack. Exhibit 19 shows the calculated final fire size under a range of line building rates for the

```
 1---RUN OPTION                        2. COMPUTE BURNED AREA
 2---MODE OF ATTACK                    1. HEAD
 3---RATE OF SPREAD, CH/H             10.0
 4---INITIAL FIRE SIZE, ACRES         10.0
 5---LENGTH-TO-WIDTH RATIO             2.0
 7---LINE BUILDING RATE, CH/H         20.0   30.0   40.0   50.0

  LINE     I   TOTAL     CONTAINMENT     FINAL
BUILDING   I   LENGTH       TIME         FIRE
  RATE     I   OF LINE     (HOURS)       SIZE
 (CH/H)    I    (CH)                    (ACRES)
           I
           I
  20.      I     -2.        -2.0          -2.
           I
  30.      I     48.         1.6          17.
           I
  40.      I     45.         1.1          15.
           I
  50.      I     43.         0.9          14.

         -2 = FORWARD RATE OF SPREAD IS EITHER GREATER THAN
                OR NEARLY EQUAL TO LINE BUILDING RATE PER FLANK.
```

```
 1---RUN OPTION                        2. COMPUTE BURNED AREA
 2---MODE OF ATTACK                    2. REAR
 3---RATE OF SPREAD, CH/H             10.0
 4---INITIAL FIRE SIZE, ACRES         10.0
 5---LENGTH-TO-WIDTH RATIO             2.0
 7---LINE BUILDING RATE, CH/H         20.0   30.0   40.0   50.0

  LINE     I   TOTAL     CONTAINMENT     FINAL
BUILDING   I   LENGTH       TIME         FIRE
  RATE     I   OF LINE     (HOURS)       SIZE
 (CH/H)    I    (CH)                    (ACRES)
           I
           I
  20.      I     -2.        -2.0          -2.
           I
  30.      I    120.         4.0          67.
           I
  40.      I     79.         2.0          34.
           I
  50.      I     65.         1.3          25.

         -2 = FORWARD RATE OF SPREAD IS EITHER GREATER THAN
                OR NEARLY EQUAL TO LINE BUILDING RATE PER FLANK.
```

Exhibit 19.—Example independent CONTAIN runs for head and rear attack.

two modes of attack, head and rear. Figure 17 illustrates initial and final fire shapes. These diagrams correspond to the CONTAIN runs in exhibit 19 for line-building rate of 40 ch/h. The only difference between the two examples is the point of initial attack.

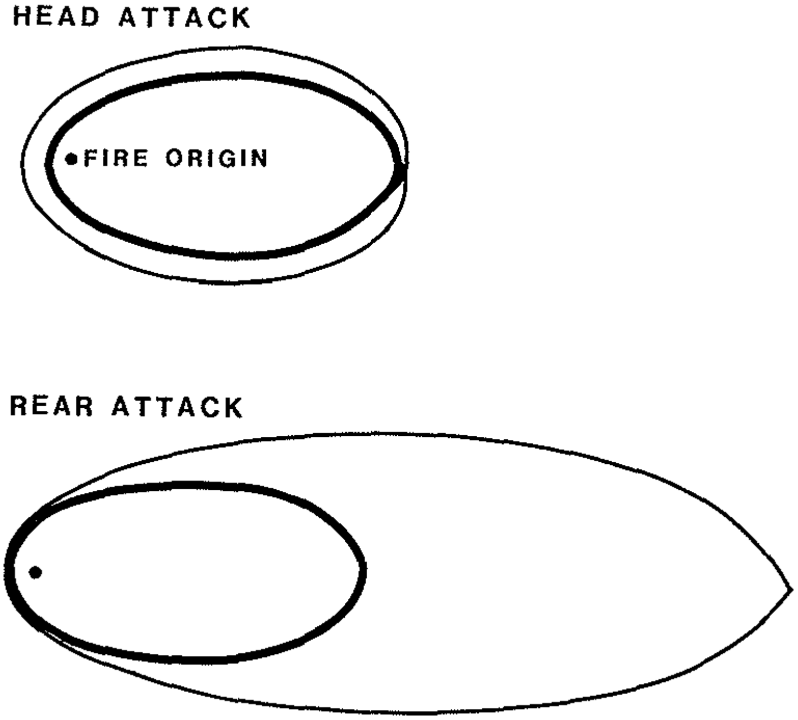


Figure 17.—Initial and final fire shapes corresponding to CONTAIN predictions in exhibit 19.

In order to calculate the final fire size, the line-building rate must be specified (as in exhibit 19). Guidelines for line-building rate are not programmed into BEHAVE. Line construction rates for NFDRS fuel models are published in Fire Management Analysis and Planning Handbook (FSH 5109.19). Similar tables utilizing the 13 NFFL fuel models have been prepared by Schmidt and Rinehart (1982). Phillips and Barney (1984) have published bulldozer production rates for various dozer sizes, fuels, and slopes. Haven and others (1982) compared studies of crews using handtools to build firelines, finding wide variation in construction rates. They reported that rates at which hand crews construct firelines can vary widely because of differences in fuels, fire and measurement conditions, and fuel resistance-to-control classification schemes. Barney (1983) presented a conceptual model of fireline production in an attempt to overcome problems found in earlier production data. But until more definitive guidelines are available for line-building rates, it is up to you as a BEHAVE user to supply an appropriate value based on experience and local guidelines.

CONTAIN uses **total** line-building rate, as opposed to line-building rate **per flank** as used in the TI-59 program. Therefore, within BEHAVE, the line-building rate is divided in half and applied to each flank of the fire. The line-building rate **per flank** must be greater than the forward rate of spread of the fire (see exhibit 19). Otherwise the control forces will never catch the fire whether it is attacked at the head or the rear. And understandably the target fire size must be larger than the initial fire size.

CONTAIN can be used independently, as it is with the TI-59 program (Albini and Chase 1980). The examples in exhibit 19 are independent runs of CONTAIN. Alternatively, CONTAIN can be linked to SIZE and either DIRECT or SITE as shown in exhibit 20. When CONTAIN is linked to other modules, some of the input values are calculated rather than input directly as they are when CONTAIN is used independently. Rate of spread comes from DIRECT or SITE and initial fire size and length-to-width ratio come from SIZE. In addition, fireline intensity from DIRECT or SITE is available for each containment calculation. Recall that this value is related to suppression capabilities (table 1). The containment calculations are done as usual, but footnotes indicate when the fire may be too intense for direct attack. In exhibit 20, part 1, flame lengths of 4 to 8 ft have been indicated on the table. The containment values (exhibit 20, part 3) that correspond to these locations on the table are designated by an *.

At first glance, you may question the fact that containment time increases as fuel moisture increases and as wind decreases (exhibit 20, part 3). But remember that we have specified a burned area target of 10 acres. The fire will be contained when it reaches 10 acres, not before. It takes fewer resources, that is a lower line-building rate (exhibit 20, part 3), to contain a slowly spreading fire (exhibit 20, part 1) at 10 acres than it would to contain a fast-spreading fire at 10 acres.

Notice that the total length of line (exhibit 20, part 3) is constant for low windspeeds under the entire range of 1-h moisture values (see the first three columns). This is because the initial fire size (exhibit 20, part 2) is almost constant and is very small compared to the burned area target of 10 acres.

Part 1. DIRECT.

```
 1--FUEL MODEL                  10 -- TIMBER (LITTER AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %        2.0    4.0    6.0    8.0   10.0   12.0   14.0
 3--10-HR FUEL MOISTURE, %       8.0
 4--100-HR FUEL MOISTURE, %     12.0
 6--LIVE WOODY MOISTURE, %      50.0
 7--MIDFLAME WINDSPEED, MI/H     0.0    1.0    2.0    3.0    4.0    5.0    6.0
 8--PERCENT SLOPE                6.0
 9--DIRECTION OF WIND VECTOR     0.0
      DEGREES CLOCKWISE
       FROM UPHILL
10--DIRECTION OF SPREAD          0.0  (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL

=========================================================================
RATE OF SPREAD, CH/HR
=========================================================================
  1-HR     I        MIDFLAME WIND, MI/H
  MOIS     I
  (%)      I      0.     1.     2.     3.     4.     5.     6.
           I-------------------------------------------------------------
           I
  2.       I      2.     3.     5.     8.    12.    16.    20.
           I
  4.       I      1.     3.     5.     7.    11.    14.    18.
           I
  6.       I      1.     2.     4.     7.    10.    13.    16.
           I
  8.       I      1.     2.     4.     6.     9.    12.    15.
           I
 10.       I      1.     2.     4.     6.     8.    11.    14.
           I
 12.       I      1.     2.     4.     6.     8.    10.    13.
           I
 14.       I      1.     2.     3.     5.     7.    10.    13.
=========================================================================
FLAME LENGTH, FT
=========================================================================
  1-HR     I        MIDFLAME WIND, MI/H
  MOIS     I
  (%)      I      0.     1.     2.     3.     4.     5.     6.
           I-------------------------------------------------------------
           I
  2.       I     2.6    3.5    4.6    5.7    6.7    7.6    8.5
           I
  4.       I     2.4    3.2    4.2    5.2    6.1    6.9    7.7
           I
  6.       I     2.2    3.0    3.9    4.8    5.6    6.4    7.1
           I
  8.       I     2.1    2.8    3.7    4.5    5.3    6.0    6.7
           I
 10.       I     2.0    2.7    3.5    4.3    5.1    5.8    6.5
           I
 12.       I     1.9    2.6    3.4    4.2    4.9    5.6    6.2
           I
 14.       I     1.8    2.5    3.3    4.0    4.7    5.4    6.0
```

Exhibit 20.—Example CONTAIN run linked to DIRECT and SIZE.

```
 1--RATE OF SPREAD, CH/H          OUTPUT FROM DIRECT. RANGE=    1. TO    20.
 2--EFFECTIVE WIND, MI/H          OUTPUT FROM DIRECT. RANGE=  0.1 TO    6.0
 3--ELAPSED TIME, HR              0.5

=====================================================================
AREA, ACRES
=====================================================================
  1-HR    I        MIDFLAME WIND, MI/H
  MOIS    I
  (%)     I     0.      1.      2.      3.      4.      5.      6.
          I-----------------------------------------------------------
          I
  2.      I    0.1     0.2     0.5     1.0     1.6     2.4     3.4
          I
  4.      I    0.1     0.2     0.4     0.7     1.3     1.9     2.7
          I
  6.      I    0.1     0.1     0.3     0.6     1.0     1.6     2.2
          I
  8.      I    0.1     0.1     0.3     0.5     0.9     1.3     1.9
          I
 10.      I    0.1     0.1     0.2     0.5     0.8     1.2     1.7
          I
 12.      I    0.1     0.1     0.2     0.4     0.7     1.1     1.5
          I
 14.      I    0.0     0.1     0.2     0.4     0.6     1.0     1.4
=====================================================================
PERIMETER, CHAINS
=====================================================================
  1-HR    I        MIDFLAME WIND, MI/H
  MOIS    I
  (%)     I     0.      1.      2.      3.      4.      5.      6.
          I-----------------------------------------------------------
          I
  2.      I     4.      5.      8.     12.     15.     20.     24.
          I
  4.      I     3.      5.      7.     10.     14.     17.     21.
          I
  6.      I     3.      4.      7.      9.     12.     16.     19.
          I
  8.      I     3.      4.      6.      9.     11.     15.     18.
          I
 10.      I     3.      4.      6.      8.     11.     14.     17.
          I
 12.      I     3.      3.      5.      8.     10.     13.     16.
          I
 14.      I     2.      3.      5.      7.     10.     12.     15.
```

Exhibit 20. (Con.)

```
 1--RUN OPTION                      1. COMPUTE LINE BUILDING RATE
 2--MODE OF ATTACK                  1. HEAD
 3--RATE OF SPREAD, CH/H            OUTPUT FROM DIRECT. RANGE=     1. TO    20.
 4--INITIAL FIRE SIZE, ACRES        OUTPUT FROM SIZE.   RANGE=     0. TO     3.
 5--LENGTH-TO-WIDTH RATIO           OUTPUT FROM SIZE.   RANGE=   1.0 TO    2.5
 6--BURNED AREA TARGET, AC         10.0

=====================================================================
TOTAL LENGTH OF LINE, CHAINS
=====================================================================
  1-HR    I        MIDFLAME WIND, MI/H
  MOIS    I
  (%)     I     0.      1.      2.      3.      4.      5.      6.
          I----------------------------------------------------------
          I
   2.     I    38.     43.     46.*    48.*    49.*    49.*    47.#
          I
   4.     I    38.     43.     46.*    49.*    50.*    51.*    51.*
          I
   6.     I    38.     43.     46.*    49.*    51.*    52.*    53.*
          I
   8.     I    38.     43.     46.     49.*    51.*    53.*    54.*
          I
  10.     I    38.     43.     46.     49.*    51.*    53.*    55.*
          I
  12.     I    38.     43.     46.     49.*    51.*    54.*    55.*
          I
  14.     I    38.     43.     46.     49.*    52.*    54.*    56.*
          I
=====================================================================
CONTAINMENT TIME, HOURS
=====================================================================
  1-HR    I        MIDFLAME WIND, MI/H
  MOIS    I
  (%)     I     0.      1.      2.      3.      4.      5.      6.
          I----------------------------------------------------------
          I
   2.     I   11.4     7.1     4.2*    2.8*    2.1*    1.5*    1.2#
          I
   4.     I   13.0     8.1     4.8*    3.3*    2.4*    1.8*    1.4*
          I
   6.     I   14.5     9.0     5.3*    3.6*    2.7*    2.1*    1.6*
          I
   8.     I   15.8     9.7     5.7     3.9*    2.9*    2.3*    1.8*
          I
  10.     I   16.9    10.3     6.1     4.2*    3.1*    2.4*    2.0*
          I
  12.     I   17.9    10.8     6.4     4.4*    3.3*    2.6*    2.1*
          I
  14.     I   19.0    11.5     6.8     4.6*    3.4*    2.7*    2.2*
          I

          * = FIRE IS TOO INTENSE FOR DIRECT ATTACK BY
                HAND CREWS.
              EQUIPMENT SUCH AS DOZERS, PUMPERS, PLOWS,
                AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

          # = CONTROL EFFORTS AT THE HEAD OF THE FIRE
               WILL PROBABLY BE INEFFECTIVE.
```

Exhibit 20. (Con.)

Part 3. CONTAIN. (Con.)

```
=====================================================================
LINE BUILDING RATE, CH/H
=====================================================================
  1-HR     I        MIDFLAME WIND, MI/H
  MOIS     I
  (%)      I      0.       1.       2.       3.       4.       5.       6.
           I----------------------------------------------------------------
           I
   2.      I      3.       6.      11.*     17.*     24.*     32.*     40.#
           I
   4.      I      3.       5.      10.*     15.*     21.*     28.*     36.*
           I
   6.      I      3.       5.       9.*     14.*     19.*     25.*     32.*
           I
   8.      I      2.       4.       8.      13.*     18.*     24.*     30.*
           I
  10.      I      2.       4.       8.      12.*     17.*     22.*     28.*
           I
  12.      I      2.       4.       7.      11.*     16.*     21.*     27.*
           I
  14.      I      2.       4.       7.      11.*     15.*     20.*     25.*
           I

                 * = FIRE IS TOO INTENSE FOR DIRECT ATTACK BY
                       HAND CREWS.
                     EQUIPMENT SUCH AS DOZERS, PUMPERS, PLOWS,
                       AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

                 # = CONTROL EFFORTS AT THE HEAD OF THE FIRE
                      WILL PROBABLY BE INEFFECTIVE.
```

Exhibit 20. (Con.)

Maximum Spotting Distance (SPOT)

The SPOT module predicts maximum spot fire distance from torching trees or burning piles of debris, given a description of the terrain, forest cover, and windspeed. Maximum spotting distance predictions are useful in writing prescriptions, locating the fire line, and positioning "spot fire chasers."

Albini (1979) developed and later (1981) extended the basic model. Chase (1981) wrote a program for the TI-59. Rothermel (1983) discusses the spotting problem in general and presents a simplified nomogram solution for field use. An additional model for predicting spotting distance from spreading surface fires has been developed (Albini 1983), but is not yet in BEHAVE. It has been programmed for the TI-59 (Chase 1984), however, and will be part of the next BEHAVE update.

The maximum spotting distance calculation can be applied under conditions of long-range spotting. In this case, embers are carried well beyond the fireline and start new fires that for some time grow and spread independent of the originating fire. The spotting model is applicable under conditions of intermediate fire severity in which spotting distance up to a mile or two might be expected. The model does not apply to those extreme cases in which spotting may occur up to tens of miles from the main front, as in running crown fires, fires in heavy slash or chaparral under extreme winds, and fires in which fire whirls loft burning material high into the air.

It is also important to recognize factors that are **not** included in the model. The model does not address the probability of trees torching out, but rather what would happen **if** trees torch out. The model does not include probability of spot fire ignition, that is, whether the firebrand material lands in an area with easily ignited fuels, and whether enough spark or ember remains to cause ignition.

The prediction is for **maximum** spotting distance because ideal conditions are assumed. The wind is assumed to be blowing steadily in one direction. Firebrands are assumed to be sufficiently small to be carried some distance, yet large enough to still be viable when coming to rest. Any variation from the ideal assumed in the model would serve only to decrease the spot-fire distance. If a source produces 20 firebrands, 19 of which fall within 2 ch of the source and one that travels a mile, it is the "one" that we are predicting. We are calculating "maximum spotting distance" under "ideal" conditions.

The firebrand may have come from torching trees which produce a transitory flame. The firebrand source can also be a group of trees torching together if they produce one flame. This does not include spotting from crown fires, in which case the fire is spreading from tree to tree with a different type of flame structure. The firebrand may also come from a burning pile of debris which produces a continuous flame. This may be a pile of logging slash or a jackpot of debris.

The input of mean cover height is intended to characterize the general forest cover of the terrain as it influences the wind field that will transport the firebrand. If the area has broken forest cover, half the treetop height of the forest-covered portion can be entered as the mean cover height. Zero can be used if the firebrand will be traveling over short grass, bare ground, or water. The windspeed required by the model is the 20-ft windspeed. That means 20 ft above the surface, which in a forested area is 20 ft above the treetops (not the ground).

Mountainous terrain is assumed to look like a wash-board (a sine curve) (fig. 18). Ridgetop-to-valley-bottom elevational difference, and ridgetop-to-valley-bottom horizontal distance, are used to define the shape. Elevational difference is entered in feet, and is used only to a multiple of 1,000 (0, 1,000, 2,000, 3,000, 4,000). Horizontal distance is entered in miles as would be shown on a map. There are four choices for spotting source, depending on the location of the torching tree or burning pile in relation to the wind direction: ridgetop; midslope, leeward side; valley bottom; midslope, windward side.

When the firebrand source is a torching tree, a description of the tree is needed because the flame descriptors are based on the conformation of the crown. The descriptors include species, d.b.h., height, and number of trees. The descriptors are assumed to be the same for every tree in a group of trees torching together. Only those tree species for which good foliage weight data were available are included. Additional species may be added if appropriate data become available. Until that time, you must choose one of the species on the list based on similarity. For example, grand fir can be used for noble, red, and Pacific silver firs, subalpine fir for white fir, western white pine for sugar pine and Monterey pine, and ponderosa pine for Jeffrey, Coulter, and Digger pine.

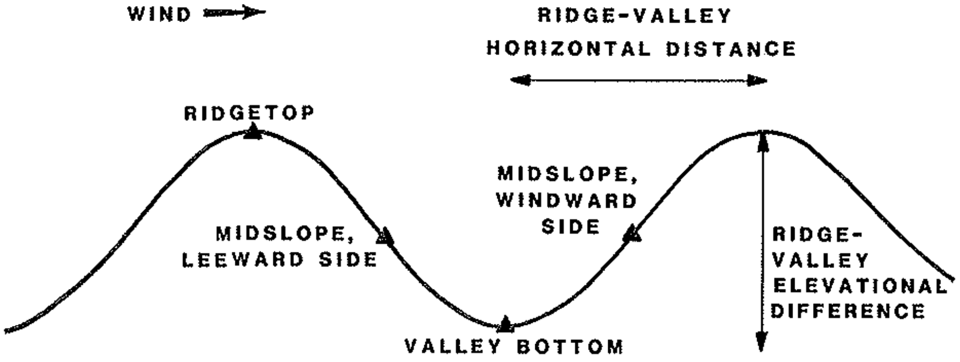


Figure 18.—Mountainous terrain and spotting source location for the maximum spotting distance model.

Continuous flame height is a required input if the source of the firebrand is a burning pile. This is the distance from the ground to the tip of the flame as illustrated in figure 19.

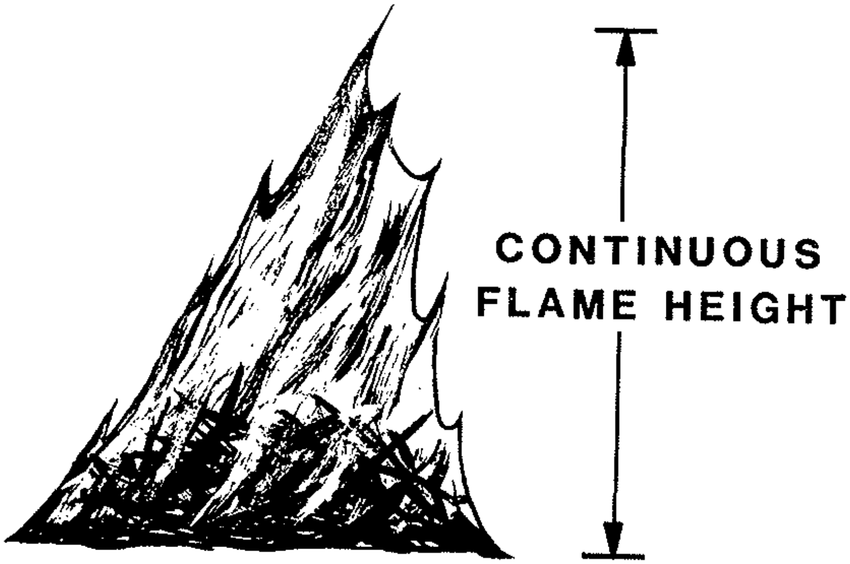


Figure 19.—Continuous flame height for the pile-burning option is the distance from the ground to the tip of the flame.

FIRE1 is designed to be flexible enough to be used for a variety of applications, one of these being dispatch of initial attack forces. The keywords allow this flexibility. In a dispatch situation, however, when things are rushed, a more streamlined system would be appropriate. When the inputs are available, DISPATCH can be run in under a minute. The keyword DISPATCH is essentially an automatic link of DIRECT, SIZE, and CONTAIN minus some of the options.

—Only single values can be input, that is, table output is not possible.

—The two-fuel-model concept cannot be used.

—One-hour, 10-hour, 100-hour fuel are all assumed to have the same moisture content.

—Live woody and live herbaceous fuel moisture are assumed to be the same.

—Live fuel moisture is always requested, even if there is no live fuel in the current fuel model.

—Twenty-foot windspeed and wind adjustment factor are input rather than midflame windspeed. The 20-ft wind might be available from a weather report, with wind adjustment factor being preassigned and noted on a map.

—Wind and spread directions are not requested. All calculations are for upslope spread with the wind.

—The containment calculations require line-building rate as input; final fire size is calculated.

—The containment calculations are done for both head and rear attack.

—The containment calculations are not done if the calculated fireline intensity indicates that the fire will be too intense for direct attack.

An example DISPATCH run is included in appendix A.

APPLICATION

Within the limits imposed by the mathematical models described in the previous section, application of BEHAVE is essentially up to the user. Running the programs is easy. But understanding the basis of the predictions and applying them properly requires skill.

Computer systems have played an important role in fire management activities (Rothermel 1980). A computer does not tire of routine calculations. Given a set of data, it will be consistent in coming up with the same answer. (The same cannot be said for humans.) Systems offer an organized way of looking at things. An individual's experience can be applied to wildfire predictions, but it is hard to apply this type of knowledge to planning or analysis situations.

BEHAVE can be viewed as an expert assistant (Andrews and Latham 1984), but the fire manager always makes the final decision. Predictions from the computer must be tempered with real-world fire experience. BEHAVE will willingly process numbers that are supplied and then produce impressive-looking tables. But what do the predictions mean? What is a flame length of 4.2 ft? It is vital that the fire manager make interpretations in terms of the application at hand.

Decisions based on predictions must consider the resolution of the input that is used. Consider windspeed. In predicting spread rate, the value for midflame windspeed might be obtained by direct measurement near the fire. It might be estimated from a spot weather forecast or even from a general weather forecast. For planning purposes a range of windspeeds might be used: "What is the predicted rate of spread for a range of windspeeds from 2 to 10 mi/h?"

BEHAVE differs somewhat from other fire management systems because of the flexibility of design. Many others were designed for a single specific purpose. The following discussion of possible applications of BEHAVE illustrates its flexibility. I will specifically cover use of BEHAVE for dispatch, wildfire, prescribed fire, and training.

Dispatch

Initial attack dispatch is an appropriate application of fire behavior prediction models. At first report of a smoke, a dispatcher may have no information about the fire other than location. Nevertheless, fire behavior can be predicted from information available from maps, weather reports, and so on.

Although it takes less than a minute to enter data into DISPATCH and get predictions, deciding what input values to use will take additional time that in some cases cannot be afforded. Whether calculations are done at the time of a fire call will depend on response time standards.

As mentioned in an earlier section, the DISPATCH module of FIRE1 is only an example of how BEHAVE could be used in a dispatch office. An alternative to using DISPATCH at the time of a fire report is to do calculations using DIRECT, SIZE, and CONTAIN in the morning based on weather forecasts. Tables of predictions would then be available for use during the day as conditions change.

Wildfire

Wildfire prediction was the initial application of the fire behavior prediction system. The system was developed through the Fire Behavior Officer (FBO) S-590 course utilizing tables and nomograms. Refinement of the system was based on field application. Methods are published in "How to Predict . . ." (Rothermel 1983). These methods are automated in BEHAVE. Given that there is computer access in the fire camp, BEHAVE can be a great aid to the FBO in predicting wildfire behavior.

The well-established methods for predicting wildfire growth and intensity require extensive fire experience. The FBO course emphasizes the final products of the written fire behavior forecast, oral briefings to the fire team, and a map of predicted fire growth. An important aspect of using predictions for real-time wildfire prediction is translating calculated values into a form that can be used by the plans chief. A briefing is no place to report that the predicted fireline intensity is 537 Btu/ft/s.

Some aspects of wildfire can be predicted using models, others cannot. BEHAVE provides predictions of spread rate, flame length, and intensity of surface fires. Fireline intensity can be used to indicate the likelihood of severe fire behavior; and spotting distance can be predicted. However, none of the models in BEHAVE can be used to predict the behavior of crown fires. Other aspects of fire behavior do not readily lend themselves to mathematical models. They are best handled by personal experience and "rules-of-thumb." For example, a person can learn to recognize conditions that can lead to the formation of fire whirls.

In addition to an FBO's predictions for the fire team, fire behavior predictions can be used to make initial decisions on the appropriate suppression response on a wildfire. This means the kind, amount, and timing of suppression action on a wildfire that most efficiently meets fire management direction under current and expected burning conditions. It may range in objective from prompt control to confinement (FSM 5105 7/83 AMEND 67). Suppression action could be minimal, and may be limited to surveillance.

In current Forest Service terminology, prescribed fire is divided into two major categories: planned and unplanned ignition (FSM 5105 7/83 AMEND 67). In both cases an approved plan must be in effect before the fire can take place. Fire behavior predictions can be an important element in the plan.

This category of fire includes fires that are started at random, generally by lightning. If ignition occurs in an area that is covered by an approved fire management plan when conditions are within the prescription, the fire is considered a prescribed fire. Otherwise it is a wildfire. BEHAVE can be used to set the prescription and to predict the behavior of an on-going fire (Andrews and Burgan 1985).

Planning.—Unplanned ignition prescribed fires may have the potential to burn for weeks or even months. Setting up the prescription can involve looking at historical fire occurrence and weather to determine how large fires would have gotten if suppression action had not been taken. This kind of gaming was used in developing the Absaroka-Beartooth Wilderness Plan (USDA Forest Service 1982). This involves using BEHAVE and FBO techniques to project fire growth.

It is not always necessary to map an area covered by a fire management plan by custom fuel models. It is appropriate, however, if there are large areas of the same fuel type not matched by one of the standard 13 NFFL fuel models. Even small areas might deserve the effort that it takes to design a custom fuel model if it is in a critical location where the best possible fire behavior predictions are required. But for an area that is large and varied, such as the Absaroka-Beartooth Wilderness, it is not cost effective to map the entire area with custom fuel models. It may be possible to build a fuel model after an ignition when the fire is expected to last for weeks and daily projections are desired. Even if projections of growth are not critical, this offers a good opportunity to build and refine fuel models with immediate feedback on success.

Real-Time Prediction.—Unplanned ignition prescribed fires offer a unique opportunity to apply fire behavior prediction technology developed for wildfires or free-burning fires on which no suppression action is being taken. Monitoring of the fire will of course involve observing what the fire is doing. But monitoring could also include projecting what the fire is expected to do the next day. This would be especially important if the fire is nearing a boundary of the area included in the management plan. Contingency plans can be based on fire behavior predictions. These techniques were used on the Independence Fire of 1979 as documented by Andrews (1980) and Keown (1985).

PLANNED IGNITION PRESCRIBED FIRE

Fires that are started by a deliberate management action are planned ignition prescribed fires. This is the traditional kind of prescribed fire, and the only kind that many fire managers are associated with.

Pattern of Ignition.—The option in DIRECT of being able to calculate the behavior of a fire in a direction other than that of maximum spread can, in some limited cases, be used to determine the preferred pattern of ignition. Exhibit 21 shows the predictions for a head fire, flanking fire, and backing fire. If scorch height (which is related to flame length) (Van Wagner 1973) is an important factor in a prescription, then the predicted flame length for various spread directions can be used to determine the preferred pattern of ignition. (Scorch height, SCORCH, will be added to BEHAVE later.) In this example, a head fire would result in unacceptably high flame lengths. A backing fire gives acceptable flame lengths but the rate of spread is quite slow. A flanking fire also gives acceptable flame lengths, but with a higher rate of spread. Based on these predictions, the decision might be made to ignite the fire in a strip down the slope, letting the fire spread to the sides.

```
 1---FUEL MODEL                     12 -- MEDIUM LOGGING SLASH
 2---1-HR FUEL MOISTURE, %           5.0
 3---10-HR FUEL MOISTURE, %          6.0
 4---100-HR FUEL MOISTURE, %         7.0
 7---MIDFLAME WINDSPEED, MI/H        4.0
 8---PERCENT SLOPE                  20.0
 9---DIRECTION OF WIND VECTOR        0.0
       DEGREES CLOCKWISE
        FROM UPHILL
10---DIRECTION OF SPREAD             0.0  90.0 180.0
      CALCULATIONS
       DEGREES CLOCKWISE
        FROM UPHILL

 SPREAD  I RATE OF  HEAT PER   FIRELINE  FLAME   REACTION  EFFECT.
 DIRECT. I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY  WIND
  (DEG)  I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
         I
         I
    0.   I   13.      2302.       528.     8.0     6863.      4.3
         I
   90.   I    2.      2302.        65.     3.1     6863.      0.0
         I
  180.   I    1.      2302.        34.     2.3     6863.      0.0
```

Exhibit 21.—Fire behavior predictions for a head, flanking, and backing fire.

The behavior of the fire is often controlled by the pattern of ignition. One of the basic assumptions of the fire spread model is thereby violated because these fires are not free-burning, steady-state fires spreading independent of the source of ignition. Nevertheless, with care and experience, steady-state fire behavior predictions can be used as a baseline for prescribed fire planning. These predictions can be viewed as what the fire would be expected to do on its own. The pattern and method of ignition can then be used to increase or decrease the fire behavior. For example, strips could be ignited so that the fire is never able to reach its full steady-state potential. On the other hand, one line of fire could be used to create indrafts that effectively increase the windspeed on another portion of the fire, thereby causing the fire to exceed its steady-state potential. Rothermel (in preparation) presents some fire behavior considerations of aerial ignition.

In some cases, steady-state predictions might indicate that a prescribed fire would be unsuccessful. With an ignition method such as helitorch, however, it is possible to get enough fire into an area fast enough to have a successful burn. If the same ignition is used under conditions when the steady-state predictions are higher, the conditions may actually be too severe for aerial ignition.

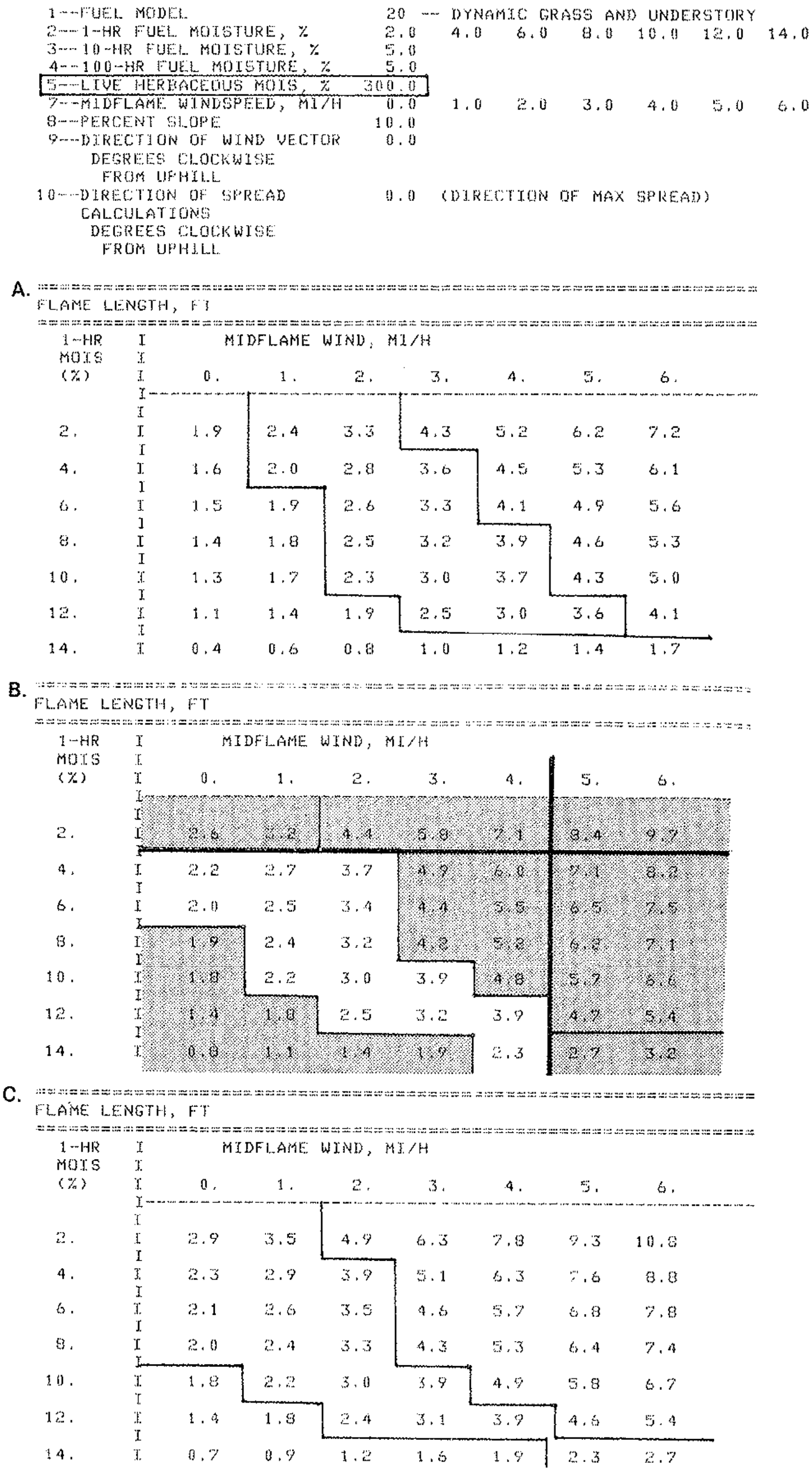
At present there are no prediction models or even formalized "rules-of-thumb" to guide the translation of steady-state predictions to actual fire behavior under various firing patterns. Interpretation must be based on personal experience.

Prescription Window.—A prescription sets the conditions under which a burn can be conducted. This often includes acceptable ranges for temperature, relative humidity, windspeed, and so on. When prescription limits occur simultaneously on the high flammability side, a fire may be hotter than desirable. The converse is true on the low flammability side. It is possible to increase the number of potential burning days by looking at tradeoffs between variables. An approach in setting up a prescription window is to work backwards, deciding what the desired steady-state fire behavior is, then determining what conditions would cause it.

Exhibit 22 gives flame length predictions for ranges of 1-h moisture and midflame windspeed. Each table is for a different live fuel moisture. Conditions that lead to flame length predictions of 2 to 4 ft are blocked out, showing the tradeoff between 1-h moisture and midflame windspeed. Notice in exhibit 22B, when 1-h fuels are wet, 12 percent, midflame windspeeds of 2 to 4 mi/h are acceptable. When the 1-h fuels are dry, 4 percent, the acceptable windspeed range is 0 to 2 mi/h.

The difference among the three tables shows the predicted results of burning at different times of the year. Exhibit 22A is for live fuel moisture of 300 percent. This would apply to early stages of the growing cycle when foliage is fresh and annuals are developing. Exhibit 22B is for live fuel moisture of 100 percent when new growth is complete. Exhibit 22C gives predictions when all herbaceous fuels are cured (30 percent live moisture).

Since this is a dynamic fuel model, as described in an earlier section on custom fuel models, all of the herbaceous load is still in the live class when the live fuel moisture is 300 percent. Part of the live herbaceous fuel load has been transferred to the 1-h class when the moisture is 100 percent. All of the live herbaceous fuel is considered dead when the live herbaceous moisture is specified to be 30 percent.



```
 1--FUEL MODEL                 20 -- DYNAMIC GRASS AND UNDERSTORY
 2--1-HR FUEL MOISTURE, %      2.0   4.0   6.0   8.0  10.0  12.0  14.0
 3--10-HR FUEL MOISTURE, %     5.0
 4--100-HR FUEL MOISTURE, %    5.0
 5--LIVE HERBACEOUS MOIS, %  300.0
 7--MIDFLAME WINDSPEED, MI/H   0.0   1.0   2.0   3.0   4.0   5.0   6.0
 8--PERCENT SLOPE             10.0
 9--DIRECTION OF WIND VECTOR   0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD        0.0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL
```

A.

```
==========================================================================
FLAME LENGTH, FT
==========================================================================
  1-HR    I        MIDFLAME WIND, MI/H
  MOIS    I
  (%)     I     0.      1.      2.      3.      4.      5.      6.
          I-------------------------------------------------------------
          I
   2.     I    1.9     2.4     3.3     4.3     5.2     6.2     7.2
          I
   4.     I    1.6     2.0     2.8     3.6     4.5     5.3     6.1
          I
   6.     I    1.5     1.9     2.6     3.3     4.1     4.9     5.6
          I
   8.     I    1.4     1.8     2.5     3.2     3.9     4.6     5.3
          I
  10.     I    1.3     1.7     2.3     3.0     3.7     4.3     5.0
          I
  12.     I    1.1     1.4     1.9     2.5     3.0     3.6     4.1
          I
  14.     I    0.4     0.6     0.8     1.0     1.2     1.4     1.7
```

B.

```
==========================================================================
FLAME LENGTH, FT
==========================================================================
  1-HR    I        MIDFLAME WIND, MI/H
  MOIS    I
  (%)     I     0.      1.      2.      3.      4.      5.      6.
          I
          I
   2.     I    2.6     3.2     4.4     5.9     7.1     8.4     9.7
          I
   4.     I    2.2     2.7     3.7     4.9     6.0     7.1     8.2
          I
   6.     I    2.0     2.5     3.4     4.4     5.5     6.5     7.5
          I
   8.     I    1.9     2.4     3.2     4.3     5.2     6.2     7.1
          I
  10.     I    1.8     2.2     3.0     3.9     4.8     5.7     6.6
          I
  12.     I    1.4     1.8     2.5     3.2     3.9     4.7     5.4
          I
  14.     I    0.8     1.1     1.4     1.9     2.3     2.7     3.2
```

C.

```
==========================================================================
FLAME LENGTH, FT
==========================================================================
  1-HR    I        MIDFLAME WIND, MI/H
  MOIS    I
  (%)     I     0.      1.      2.      3.      4.      5.      6.
          I-------------------------------------------------------------
          I
   2.     I    2.9     3.5     4.9     6.3     7.8     9.3    10.8
          I
   4.     I    2.3     2.9     3.9     5.1     6.3     7.6     8.8
          I
   6.     I    2.1     2.6     3.5     4.6     5.7     6.8     7.8
          I
   8.     I    2.0     2.4     3.3     4.3     5.3     6.4     7.4
          I
  10.     I    1.8     2.2     3.0     3.9     4.9     5.8     6.7
          I
  12.     I    1.4     1.8     2.4     3.1     3.9     4.6     5.4
          I
  14.     I    0.7     0.9     1.2     1.6     1.9     2.3     2.7
```

Exhibit 22.—DIRECT runs can be used to define a prescription window; (A) live herbaceous fuel moisture = 300 percent; (B) live herbaceous fuel moisture = 100 percent; (C) live herbaceous fuel moisture = 30 percent.

These tables use 1-h fuel moisture rather than 10-h moisture for good reason. Moisture content of the 1-h fuels has much more effect on the rate of spread and flame length predictions than does 10-h. (See exhibit 15 for an example of the relative effects.) Many prescribed burners put ½-inch sticks (10-h fuel) on a site to monitor trends in fuel moisture. Prescription windows might include limits on the moisture of fuel 10-h and larger for burnout and fuel consumption, smoke production, fire effects considerations, or because of experience of the burner. But 10-h moisture should not be used to set a prescription window that is based on flame length or rate-of-spread predictions.

Although the tables in exhibit 22 show the tradeoff among only three variables (1-h, live, wind) as they affect flame length, this integrates a lot of information. Live fuel moisture reflects time of year and 1-h moisture integrates many site and weather variables, including temperature, relative humidity, and precipitation. Although "1 hour timelag" indicates a short response time, the new 1-h model uses weather information from up to 7 previous days to predict the moisture of the fine fuels less than ¼-inch in diameter. The 1-h moisture model provides a consistent way of integrating the effects of many variables into a single number that can be used as a prescription variable as shown in exhibit 22. There are tradeoffs in conditions that lead to a 1-h moisture value, just as there are tradeoffs in wind and moisture that lead to a flame length value. The 1-h fuel moisture model now in SITE will be available in the next BEHAVE update in a module by itself (MOISTURE). Table and graphic output will be available, making it easier to use in prescription writing.

It is possible to show other fire behavior limitations on the same table (exhibit 22B). For example, it may not be desirable to burn under low 1-h moisture conditions (2 percent or less) no matter what the flame length projections are because of the high risk of a firebrand out of the area causing a spot fire. (Probability of Ignition, IGNITE, will be added to BEHAVE later.) Burning under high windspeeds (5 mi/h or greater) may not be acceptable because of the chance of a firebrand blowing out of the burn area into a critical area (based on spotting distance predictions from SPOT).

These tables are primarily used for fire control aspects of prescribed fire. BEHAVE will help with fire behavior aspects, the constraints, of a prescription. Other considerations depend on the land management objectives of the burn, such as to regenerate trees, increase capacity of wildlife habitat, or protect resources from wildfire. It is possible that conflicts will arise in setting the prescription. An example is the conflict between the objective to minimize fuel consumption by burning at high fuel moistures and the constraint to control smoke production. Resolution of these conflicts must be based on priorities of the objectives and constraints (Brown in preparation).

Contingency Planning.—The contingency plan is a critical element of a prescribed fire plan. If a prescribed fire escapes, it is important to be able to estimate what it will do and what resources must be available to control it. Predicting the behavior of a spot fire outside of the designated burn area is an appropriate application for BEHAVE. All of the predictions currently in the FIRE1 program can be used: SPOT for potential spotting distance, DIRECT or SITE for spread and intensity of the escaped fire, SIZE for the potential fire size in a given time, and CONTAIN for the attack forces that should be on hand in the event of an escape. Of course all of the predictions are limited by the models as described in earlier sections.

Predictions from SPOT can be used to estimate the maximum distance from the burn that a spot fire might be expected to occur. At present the model can be used if the spotting is from torching trees or from burning piles. The burning piles might be logging slash or natural accumulations of dead and down material encountered in an underburn. It might also be a log deck on the edge of a clearcut. A torching tree might be the source of the firebrand when an occasional tree torches in an underburn or on the edge of a clearcut. Remember that spotting under the conditions covered by the spot model is only one way that a prescribed fire can escape. The fire might just jump the line or spots might be carried outside of the area by a fire whirl.

Sources of firebrands can be indicated on a map with a sketch of potential spotting distance. This map can be used to place patrols for spot fires during the burn. The location can also be used in setting the conditions (fuel model, fuel moisture, wind and slope) to be used in the DIRECT or SITE calculations for spread and intensity of a spot fire.

If DIRECT is used to set up tables to define a prescription window (exhibit 22), then similar tables could be used to predict the behavior of an escaped fire under a range of conditions. Even if the fire inside of the block is controlled by the ignition method, the behavior of an escaped fire should more closely match the DIRECT predictions. If the burn is in a grass or shrub fuel type, it is possible that the same table could be used because the spot will likely be into the same fuel type. On the other hand, if the prescribed fire is in logging slash, the spot fire may be in adjacent timber. Then not only would the fuel model and possibly the slope change, but the canopy cover would cause differences in fuel moisture and midflame windspeed.

The predictions from DIRECT give potential spread rate and intensity. Flame length and fireline intensity can be used for fire suppression interpretations, giving an indication of whether direct attack would be successful. And if the escaped fire is in timber, this will indicate whether torching and other severe fire behavior is probable.

The SIZE calculations indicate how large a spot fire would be expected to get in a given period of time. The time would be based on how long you think it would take your forces to get to the fire and begin suppressing it.

CONTAIN can then be used to estimate the attack forces that should be available to contain the spot fire at a specified size. The size is set at whatever you decide is acceptable. The smaller the size, the more people that need be available.

The DIRECT, SIZE, CONTAIN run shown in exhibit 20 is the sequence that would be used for contingency plan predictions.

Custom Fuel Models.—Custom fuel models are not needed for every block to be burned. A single fuel model can be used for many situations. Development of a new fuel model is more involved than sampling the fuel in an area, "plugging" it into the computer, and getting a fuel model. A vital step is incorporating the fire experience of the user in this general fuel type in the test and refinement of the fuel model (TSTMDL program of the FUEL subsystem of BEHAVE). The 13 NFFL fuel models are adequate for many decisions. In some cases, however, none of the 13 models fit the situation. For example, logging slash with a significant component of live shrubs and herbaceous fuels may require a custom fuel model.

A change in emphasis from strictly fire control to fire management brings about an increased need for predicting fire behavior as it relates to fire effects. Fire effects includes such things as seed survival and vegetation response after a fire. BEHAVE as it now stands has very limited application to fire effects.

Because the fire spread model was designed to predict the growth of a fire for fire suppression applications, it characterizes the behavior in the flaming front. Therefore, it is of limited use for predicting fire effects. Nevertheless, a few such predictions are possible. For example, scorch height has been correlated to fireline intensity (Van Wagner 1973), which relates well to flame length. In general, flame length and fireline intensity are best related to the effect of fire on items in the flame and in the hot convective gases above the flame. In light fuels, heat per unit area could be used to measure heat directed to the surface and related to fire effects in the duff and soil (Rothermel and Deeming 1980).

To illustrate why flame length is a poor indicator of below-ground fire effects (soil temperature), consider the two points plotted on the fire characteristics chart in figure 20. Both fires have the same fireline intensity and flame length. But, fire A is a fast-spreading fire, with a low heat per unit area, while fire B is a slow-spreading fire, with a high heat per unit area. Fire A could be in grass and fire B in logging slash. The slow-moving fire B will concentrate considerable heat on the site as compared to the fast-moving fire A.

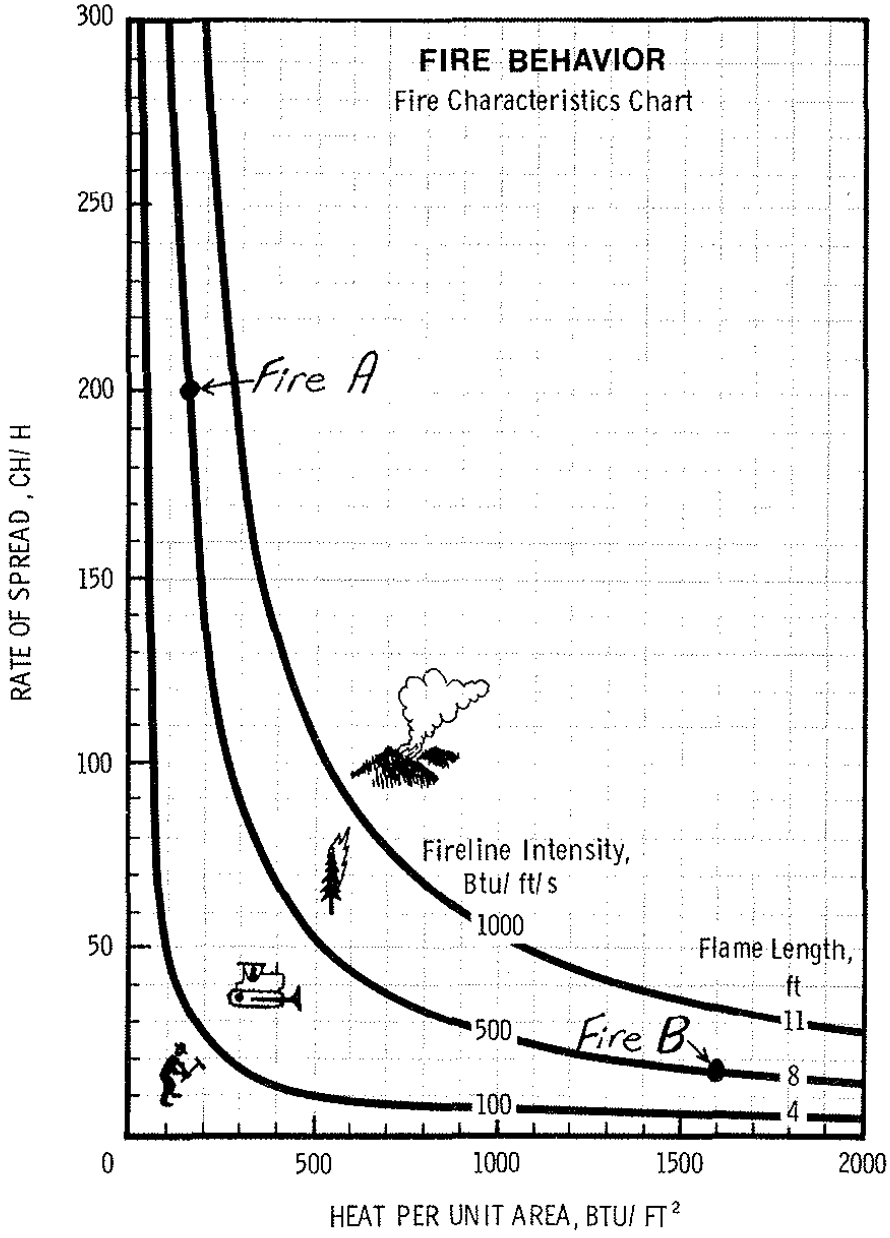


Figure 20.—Fire A and fire B have the same flame length and fireline intensity, but very different rate of spread and heat per unit area.

Many aspects of fire effects are dependent upon the fire behavior after the flaming front has passed, in the burnout of large fuels and smoldering combustion of the duff. Research is in progress in these areas.

Any new prediction models that are added to BEHAVE will likely be limited to fire **behavior**. Fire behavior can be modeled based on physical principles. Fire effects are primarily related to biological systems and the same kind of modeling does not apply. For example, heat flux and time-temperature models might be developed and added to BEHAVE; the relationship to seed and root survival will not.

More fire effects studies are being related to quantitative measures of fire behavior, rather than just a record of fire or no-fire, hot or cool, spring or fall burn. This, in addition to work on mathematical fire behavior models that are designed to be related to fire effects, should strengthen the link between fire behavior and fire effects in the future.

Training

BEHAVE has a place in both classroom training and on-the-job training. BEHAVE is now being included in college curricula to train new fire professionals. Besides giving newcomers a head start at becoming fire behavior experts, BEHAVE can also give oldtimers a new perspective on fire. They begin to translate their "feel for fire" into quantitative terms that can be better communicated to others.

BEHAVE can be used as part of training in relation to any of the specific applications discussed above. It is especially useful for "what if" games. For example, it might be used to train a seasonal dispatcher who has minimal fire experience. BEHAVE offers a focal point for discussion and helps illustrate the factors that are important in affecting fire behavior.

Before an individual uses BEHAVE as an operational fire management tool, he or she should spend some time on personal training. I am not referring to operation of the programs, but rather to using BEHAVE enough to know how the models can be applied. This involves looking at the effect of a change in an input value on the predictions and getting a feel for what the prediction models in BEHAVE can do.

BEHAVE and Other Computer Programs

As shown by the preceding discussion on applications, BEHAVE is a flexible system. When used in conjunction with personal fire experience, it can be used for many aspects of fire management. There are other special purpose computer programs, however, that have a place in fire management activities (Rothermel 1980).

The most prominent might be the National Fire-Danger Rating System (NFDRS) (Deeming and others 1977). It is basically a seasonal weather processor designed to give indexes related to fire potential. Its primary application is broad-area fire planning. Details on NFDRS are given in appendix D. Another system related to fire behavior is the National Fuel Appraisal Process (Radloff and others 1982), which is a method of evaluating the fire hazard aspects of fuel management alternatives. The index of fire hazard used is "expected area burned per year." The Fuel Appraisal Process is based on Rothermel's (1972) fire spread model, as are NFDRS and BEHAVE. But the packaging and application of the systems are very different.

In some cases, BEHAVE will be incorporated into larger computer systems. The Forestry Weather Interpretation System (FWIS) (Paul 1981) includes a fire behavior prediction component (which will be BEHAVE) as well as weather observations and forecasts, smoke management, and air quality. FWIS is primarily used in the southeastern United States. Another system that will incorporate BEHAVE is the Bureau of Land Management's Initial Attack Management System (IAMS) (German 1984). The goal of the IAMS system is to provide the local district and State fire managers all the fire-related management information they need, in real time, on which to base their fire suppression decisions. In addition, IAMS will provide a means for short- and long-range fire and resource management planning and research.

This is not meant to be an exhaustive list of computer programs available for fire management activities. It should, however, give you some perspective on how BEHAVE can be used as a fire management tool.

REFERENCES

Albini, Frank A. Estimating wildfire behavior and effects. General Technical Report INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976a. 92 p.

Albini, Frank A. Computer-based models of wildland fire behavior: a user's manual. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976b. 68 p.

Albini, Frank A. Spot fire distance from burning trees—a predictive model. General Technical Report INT-56. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 73 p.

Albini, Frank A. Spot fire distance from isolated sources—extensions of a predictive model. Research Note INT-309. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 9 p.

Albini, Frank A. Potential spotting distance from wind-driven surface fires. Research Paper INT-309. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 27 p.

Albini, Frank A.; Baughman, Robert G. Estimating windspeeds for predicting wildland fire behavior. Research Paper INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 12 p.

Albini, Frank A.; Chase, Carolyn H. Fire containment equations for pocket calculators. Research Note INT-268. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 17 p.

Albini, F. A.; Korovin, G. N.; Gorovaya, E. H. Mathematical analysis of forest fire suppression. Research Paper INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1978. 19 p.

Anderson, Hal E. Heat transfer and fire spread. Research Paper INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 20 p.

Anderson, Hal E. Aids to determining fuel models for estimating fire behavior. General Technical Report INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 22 p.

Anderson, Hal E. Predicting wind-driven wild land fire size and shape. Research Paper INT-305. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 26 p.

Andrews, Patricia L. Testing the fire behavior model. In: Proceedings, sixth conference on fire and forest meteorology; 1980 April 22-24; Seattle, WA. Washington, DC: Society of American Foresters; 1980: 70-77.

Andrews, Patricia L.; Burgan, Robert E. "BEHAVE" in the wilderness! In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William E.; Mutch, Robert W., tech. coords. Proceedings—symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. General Technical Report INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985: 306-309.

Andrews, Patricia L.; Latham, Don J. BEHAVE: a knowledge-based expert system for predicting wildland fire behavior. In: Proceedings, summer computer simulation conference; 1984 July 23-25; Boston, MA. Vol. 2. La Jolla, CA: Society for Computer Simulation; 1984: 1213-1218.

Andrews, Patricia L.; Morris, Glen A. Equations for wildland fire behavior prediction: a summary. In preparation. On file at: Intermountain Fire Sciences Laboratory, U.S. Department of Agriculture, Forest Service, Missoula, MT.

Andrews, Patricia L.; Rothermel, Richard C. Charts for interpreting wildland fire behavior characteristics. General Technical Report INT-131. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 21 p.

Barney, Richard J. Fireline production: a conceptual model. Research Paper INT-310. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 7 p.

Brown, James K. A process for designing fire prescriptions. In: Proceedings, prescribed fire by aerial ignition workshop; 1984 October 29-November 1; Missoula, MT. Missoula, MT: Intermountain Fire Council, National Wildfire Coordinating Group; [in preparation].

Burgan, Robert E. Fire danger/fire behavior computations with the Texas Instruments TI-59 calculator: user's manual. General Technical Report INT-61. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979a. 25 p.

Burgan, Robert E. Estimating live fuel moisture for the 1978 National Fire Danger Rating System. Research Paper INT-226. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979b. 17 p.

Burgan, Robert E.; Rothermel, Richard C. BEHAVE: fire behavior prediction and fuel modeling system—FUEL subsystem. General Technical Report INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 126 p.

Byram, G. M. Combustion of forest fuels. In: Davis, K. P., ed. Forest fire control and use. New York: McGraw-Hill; 1959: 90.

Byram, George M. An analysis of the drying process in forest fuel material. Unpublished paper presented at the 1963 international symposium on humidity and moisture; 1963 May 20-23; Washington, DC. 38 p.

Chase, Carolyn H. Spot fire distance equations for pocket calculators. Research Note INT-310. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 21 p.

Chase, Carolyn H. Spotting distance from wind-driven surface fires—extensions of equations for pocket calculators. Research Note INT-346. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 21 p.

Countryman, Clive M.; Dean, William A. Measuring moisture content in living chaparral: a field user's manual. General Technical Report PSW-36. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1979. 27 p.

Deeming, John E.; Burgan, Robert E.; Cohen, Jack D. The National Fire-Danger Rating System—1978. General Technical Report INT-39. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 63 p.

Fischer, William C.; Hardy, Charles E. Fire-weather observers' handbook. Agriculture Handbook 494. Washington, DC: U.S. Department of Agriculture, Forest Service; 1976. 152 p.

German, Stephen C. Initial Attack Management System (IAMS) information package. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Boise Interagency Fire Center, Division of Information Services; 1985. 44 p. Unpublished report.

Haven, Lisa; Hunter, T. Parkin; Storey, Theodore G. Production rates for crews using handtools on firelines. General Technical Report PSW-62. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1982. 8 p.

Hough, W. A.; Albini, F. A. Predicting fire behavior in palmetto-gallberry fuel complexes. Research Paper SE-174. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1978. 44 p.

Keown, Larry D. The Independence Fire: a case study. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings—symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. General Technical Report INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985: 239-247.

National Wildfire Coordinating Group. S-390 fire behavior student guide and text. Boise, ID: Boise Interagency Fire Center; 1981. 145 p.

Paul, James T. A real-time weather system for forestry. Bulletin of the American Meteorological Society. 62(10): 1466-1472; 1981.

Phillips, Clinton B.; Barney, Richard J. Updating bulldozer fireline production rates. General Technical Report INT-166. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 21 p.

Radloff, David L.; Yancik, Richard F.; Walters, Kenneth G. User's guide to the National Fuel Appraisal Process. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1982. 41 p.

Rothermel, Richard C. A mathematical model for predicting fire spread in wildland fuels. Research Paper INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 40 p.

Rothermel, Richard C. Fire behavior systems for fire management. In: Proceedings, sixth conference on fire and forest meteorology; 1980 April 22-24; Seattle, WA. Washington, DC: American Society of Foresters; 1980: 58-64.

Rothermel, Richard C. How to predict the spread and intensity of forest and range fires. General Technical Report INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 161 p.

Rothermel, Richard C. Fire behavior considerations of aerial ignition. In: Proceedings, prescribed fire by aerial ignition workshop; 1984 October 29-November 1; Missoula, MT. Missoula, MT: Intermountain Fire Council, National Wildfire Coordinating Group; [in preparation].

Rothermel, Richard C.; Deeming, John E. Measuring and interpreting fire behavior for correlation with fire effects. General Technical Report INT-93. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 4 p.

Rothermel, Richard C.; Philpot, Charles W. Predicting changes in chaparral flammability. Journal of Forestry. 71(10): 640-643; 1973.

Rothermel, Richard C.; Wilson, Ralph A., Jr.; Morris, Glen A. Fine fuel moisture model. Research Paper. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; [in press].

Schmidt, R. Gordon; Rinehart, George C. Line production estimating guides for fire behavior fuel models. Fire Management Notes. Summer 1982: 6-9.

U.S. Department of Agriculture, Forest Service. A prescribed fire management plan for the Absaroka Beartooth Wilderness, Gallatin and Custer National Forests. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1982. 44 p.

Van Wagner, C. E. Height of crown scorch in forest fires. Canadian Journal of Forest Research. 3: 373-378; 1973.

Van Wagner, C. E. Structure of the Canadian forest fire weather index. Publication 1333. Ottawa: Canadian Department of Environment, Forestry Service; 1974. 44 p.

APPENDIX A: EXAMPLE USER SESSION WITH THE **FIRE1** PROGRAM OF THE **BEHAVE** SYSTEM

The following is a computer printout of a user session with the FIRE1 program of the BEHAVE system. It provides an overview of how the program works: how to choose a module, enter and change input, obtain output, and so on.

Lines that begin with a > (the prompt symbol) were typed by the user. All others were printed by the computer. The prompt symbol may be different on another computer.

Getting access to the program is a function of the computer being used and therefore is not described in this manual.

```
WELCOME TO THE
  BEHAVE SYSTEM
    BURN SUBSYSTEM
      FIRE1 PROGRAM (VERSION 2.1 -- SEPT 1984)

DEVELOPED BY THE
  FIRE BEHAVIOR RESEARCH WORK UNIT
  NORTHERN FOREST FIRE LABORATORY
  MISSOULA, MONTANA
```

The version number will change as the program is updated.

```
ARE YOU USING A TERMINAL WITH A SCREEN ? Y-N
>N

TYPE 'CUSTOM' IF YOU ARE GOING TO USE CUSTOM FUEL MODELS.

FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>DIRECT
```

Specify the module that you want to use.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT
```

All of the input required for the DIRECT module will be requested.

```
(1) FUEL MODEL ? 0-99 OR QUIT
      (ENTER 0 FOR TWO FUEL MODEL CONCEPT INPUT.)
>12.1

NON-INTEGER VALUE =       12.1
DOESN'T MAKE SENSE. TRY AGAIN.

(1) FUEL MODEL ? 0-99 OR QUIT
      (ENTER 0 FOR TWO FUEL MODEL CONCEPT INPUT.)
>12
```

Immediate error checking. The question is reasked until you give a valid answer.

```
(2) 1-HR FUEL MOISTURE, % ? 1-60
>5.25

ILLEGAL INPUT:5.25
TRY AGAIN.

(2) 1-HR FUEL MOISTURE, % ? 1-60
>5.2
```

If a fractional value makes sense, it can be entered to no more accuracy than tenths (one decimal point)

```
(3) 10-HR FUEL MOISTURE, % ? 1-60
>70

THE VALUE     70.0
IS OUTSIDE THE LEGAL RANGE      1.0 TO     60.0
TRY AGAIN.

(3) 10-HR FUEL MOISTURE, % ? 1-60
>7
```

Valid answers are always listed after the question mark.

```
(4) 100-HR FUEL MOISTURE, % ? 1-60
>M

ILLEGAL INPUT:M
TRY AGAIN.

(4) 100-HR FUEL MOISTURE, % ? 1-60
> 7
```

Input must be entered without imbedded blanks.

```
ILLEGAL INPUT: 7
TRY AGAIN.

(4) 100-HR FUEL MOISTURE, % ? 1-60
>7

(7) MIDFLAME WINDSPEED, MI/H ? 0-99
>5.

(8) PERCENT SLOPE ? 0-100
>10
```

Integers can be entered with or without a decimal point.

```
(9) DIRECTION OF WIND VECTOR,
     DEGREES CLOCKWISE FROM UPHILL ? 0-360
>0

(10) DO YOU WANT FIRE BEHAVIOR PREDICTIONS FOR
     THE DIRECTION OF MAXIMUM SPREAD ? Y-N
>Y
```

This indicates that you want predictions for the usual "upslope spread with the wind"

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

You should alwas list the input before a run.

```
 1--FUEL MODEL                    12 -- MEDIUM LOGGING SLASH
 2--1-HR FUEL MOISTURE, %          5.2
 3--10-HR FUEL MOISTURE, %         7.0
 4--100-HR FUEL MOISTURE, %        7.0
 7--MIDFLAME WINDSPEED, MI/H       5.0
 8--PERCENT SLOPE                 10.0
 9--DIRECTION OF WIND VECTOR       0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD            0.0   (DIRECTION OF MAX SPREAD)
     CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL
```

Summary of the input you just entered.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

To do the calculations and print the results.

```
     RATE OF SPREAD, CH/H------------     14.
     HEAT PER UNIT AREA, BTU/SQ.FT--   2265.
     FIRELINE INTENSITY, BTU/FT/S---    593.
     FLAME LENGTH, FT----------------     8.5
     REACTION INTENSITY, BTU/SQ.FT/M  6751.
     EFFECTIVE WINDSPEED, MI/H-------     5.1
```

The fire behavior predictions.

```
IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'
```

We will try this later.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>INPUT
```

Enter a whole new set of input to DIRECT.

```
~~(1)~~ FUEL MODEL ? 0-99 OR QUIT
      (ENTER 0 FOR TWO FUEL MODEL CONCEPT INPUT.)
>2

(2) 1-HR FUEL MOISTURE, % ? 1-60
>2,20,2
```

Starting value, Ending value, Step size

```
A MAXIMUM OF 7 VALUES ARE ALLOWED.
```

Limit due to screen size

```
THE FOLLOWING VALUES WILL BE USED
   2.0     4.0     6.0     8.0    10.0    12.0    14.0
```

For your approval.

```
OK ? Y-N
>Y

(3) 10-HR FUEL MOISTURE, % ? 1-60
>5

(4) 100-HR FUEL MOISTURE, % ? 1-60
>6

(5) LIVE HERBACEOUS MOIS, % ? 30-300
>100

(7) MIDFLAME WINDSPEED, MI/H ? 0-99
>5

(8) PERCENT SLOPE ? 0-100
>20

(9) DIRECTION OF WIND VECTOR,
      DEGREES CLOCKWISE FROM UPHILL ? 0-360
>80
```

Cross-slope wind

```
(10) DO YOU WANT FIRE BEHAVIOR PREDICTIONS FOR
     THE DIRECTION OF MAXIMUM SPREAD ? Y-N
>Y

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

```
 1--FUEL MODEL                       2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %           2.0    4.0    6.0    8.0   10.0   12.0  14.0
 3--10-HR FUEL MOISTURE, %          5.0
 4--100-HR FUEL MOISTURE, %         6.0
 5--LIVE HERBACEOUS MOIS, %       100.0
 7--MIDFLAME WINDSPEED, MI/H        5.0
 8--PERCENT SLOPE                  20.0
 9--DIRECTION OF WIND VECTOR       80.0
      DEGREES CLOCKWISE
       FROM UPHILL
10--DIRECTION OF SPREAD           DIRECTION OF MAXIMUM SPREAD
      CALCULATIONS                  TO BE CALCULATED
      DEGREES CLOCKWISE
       FROM UPHILL
```

Each value is used in the calculations. So the output is in the form of a table.

Last time it was obviously zero. This time it has to be calculated.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

These are the same values calculated in the prev. run.

```
 1-HR    I RATE OF   HEAT PER    FIRELINE   FLAME    REACTION   EFFECT.  MAX
 MOIS    I SPREAD   UNIT AREA   INTENSITY   LENGTH   INTENSITY   WIND   SPREAD
 (%)     I (CH/H)  (BTU/SQ.FT)  (BTU/FT/S)   (FT)  (BTU/SQFT/M)(MI/H)   DIREC
         I                                                              (DEG)
         I
  2.     I   49.       595.        538.      8.1      4313.       5.0     76.
         I
  4.     I   40.       512.        379.      6.9      3713.       5.0     76.
         I
  6.     I   36.       477.        314.      6.3      3460.       5.0     76.
         I
  8.     I   33.       460.        279.      6.0      3336.       5.0     76.
         I
 10.     I   30.       430.        234.      5.5      3119.       5.0     76.
         I
 12.     I   24.       357.        154.      4.6      2588.       5.0     76.
         I
 14.     I   13.       213.         53.      2.8      1542.       5.0     76.

IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>CHANGE
```

You can change one or more input value and leave the rest alone

```
CHANGE WHICH LINE ? 0-10
  (0 MEANS NO MORE CHANGES)
>7
```

Notice that in the above list that line 7 is windspeed.

```
(7) MIDFLAME WINDSPEED, MI/H ? 0-99
>0,5,1

THE FOLLOWING VALUES WILL BE USED
   0.0     1.0     2.0     3.0     4.0     5.0
OK ? Y-N
>Y
```

```
CHANGE WHICH LINE ? 0-10
  (0 MEANS NO MORE CHANGES)
>0
```

This time we changed only windspeed.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

Be sure you have what you think you have.

```
 1--FUEL MODEL                   2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %       2.0   4.0   6.0   8.0  10.0  12.0  14.0
 3--10-HR FUEL MOISTURE, %      5.0
 4--100-HR FUEL MOISTURE, %     6.0
 5--LIVE HERBACEOUS MOIS, %   100.0
 7--MIDFLAME WINDSPEED, MI/H    0.0   1.0   2.0   3.0   4.0   5.0
 8--PERCENT SLOPE              20.0
 9--DIRECTION OF WIND VECTOR   80.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD        DIRECTION OF MAXIMUM SPREAD
     CALCULATIONS                TO BE CALCULATED
     DEGREES CLOCKWISE
      FROM UPHILL
```

Ranges for two input variables

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN

TABLE VARIABLE ? 0-7

 0=NO MORE TABLES      4=FLAME LENGTH
 1=RATE OF SPREAD      5=REACTION INTENSITY
 2=HEAT PER UNIT AREA  6=EFFECTIVE WINDSPEED
 3=FIRELINE INTENSITY  7=DIRECTION OF MAX SPREAD
>1
==================================================================
RATE OF SPREAD, CH/HR
==================================================================
  1-HR   I       MIDFLAME WIND, MI/H
  MOIS   I
  (%)    I     0.     1.     2.     3.     4.     5.
         I--------------------------------------------------------
         I
  2.     I     6.     7.    13.    22.    34.    49.
         I
  4.     I     5.     6.    10.    18.    28.    40.
         I
  6.     I     5.     5.     9.    16.    25.    36.
         I
  8.     I     4.     5.     8.    15.    23.    33.
         I
 10.     I     4.     4.     8.    13.    20.    30.
         I
 12.     I     3.     4.     6.    10.    16.    24.
         I
 14.     I     2.     2.     3.     6.     9.    13.
```

Table output. Pick the prediction that you want to look at.

These are the rate of spread predictions for each combination of 1-h moisture and windspeed

```
TABLE VARIABLE ? 0-7

 0=NO MORE TABLES      4=FLAME LENGTH
 1=RATE OF SPREAD      5=REACTION INTENSITY
 2=HEAT PER UNIT AREA  6=EFFECTIVE WINDSPEED
 3=FIRELINE INTENSITY  7=DIRECTION OF MAX SPREAD
>4
```

To see another table.

```
=============================================================
FLAME LENGTH, FT
=============================================================
 1-HR   I       MIDFLAME WIND, MI/H
 MOIS   I
 (%)    I    0.     1.     2.     3.     4.     5.
        I----------------------------------------------------
        I
  2.    I   3.1    3.4    4.3    5.6    6.8    8.1
        I
  4.    I   2.7    2.9    3.7    4.7    5.8    6.9
        I
  6.    I   2.4    2.6    3.4    4.4    5.3    6.3
        I
  8.    I   2.3    2.5    3.2    4.1    5.1    6.0
        I
 10.    I   2.1    2.3    3.0    3.8    4.7    5.5
        I
 12.    I   1.8    1.9    2.4    3.1    3.9    4.6
        I
 14.    I   1.1    1.2    1.5    1.9    2.4    2.8
```

Flame length predictions this time

```
TABLE VARIABLE ? 0-7

 0=NO MORE TABLES      4=FLAME LENGTH
 1=RATE OF SPREAD      5=REACTION INTENSITY
 2=HEAT PER UNIT AREA  6=EFFECTIVE WINDSPEED
 3=FIRELINE INTENSITY  7=DIRECTION OF MAX SPREAD
>0
```

Only print the tables you want to see.

```
IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>QUIT
```

Get out of the DIRECT module.

```
FINISH DIRECT -- BACK TO FIRE1
```

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>SIZE
```

Choose a different calculation module.

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT
```

This time SIZE input will be requested.

```
(1) FORWARD RATE OF SPREAD, CH/H ? .1-500 OR QUIT
>10

(2) EFFECTIVE WINDSPEED, MI/H ? 0-99
>0,6,2

THE FOLLOWING VALUES WILL BE USED
   0.0     2.0     4.0     6.0
OK ? Y-N
>Y

(3) ELAPSED TIME, HR ? .1-8
>1
```

Input when SIZE is independent from DIRECT. (We will link to DIRECT later.)

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST



 1---RATE OF SPREAD, CH/H        10.0
 2---EFFECTIVE WIND, MI/H         0.0    2.0    4.0    6.0
 3---ELAPSED TIME, HR             1.0

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

Shape of the ellipse.

```
 EFFECT.  I    AREA   PERIMETER  LENGTH-   FORWARD   BACKING    MAXIMUM
  WIND    I    (AC)     (CH)     TO-WIDTH   SPREAD    SPREAD     WIDTH
 (MI/H)   I                       RATIO    DISTANCE  DISTANCE   OF FIRE
          I                                  (CH)      (CH)       (CH)
          I
   0.     I   31.4      63.        1.0       10.0      10.0       20.0
          I
   2.     I    6.9      30.        1.5       10.0       1.5        7.6
          I
   4.     I    4.5      26.        2.0       10.0       0.7        5.4
          I
   6.     I    3.4      24.        2.5       10.0       0.4        4.2

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT
```

Get out of the SIZE module.

```
FINISH SIZE -- BACK TO FIRE1
```

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>CONT

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) RUN OPTION ? 1-2 OR QUIT
      1=COMPUTE LINE BUILDING RATE
      2=COMPUTE BURNED AREA
>1

(2) MODE OF ATTACK ? 1-2
      1=HEAD
      2=REAR
>2

(3) FORWARD RATE OF SPREAD, CH/H ? .1-500
>10

(4) INITIAL FIRE SIZE, ACRES ? .1-100
>2,10,2

THE FOLLOWING VALUES WILL BE USED
    2.0     4.0     6.0     8.0    10.0
OK ? Y-N
>Y

(5) LENGTH-TO-WIDTH RATIO ? 1-7
>2

(6) BURNED AREA TARGET, ACRES ? .1-2000
>10

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST



 1--RUN OPTION                  1. COMPUTE LINE BUILDING RATE
 2--MODE OF ATTACK              2. REAR
 3--RATE OF SPREAD, CH/H       10.0
 4--INITIAL FIRE SIZE, ACRES    2.0    4.0    6.0    8.0   10.0
 5--LENGTH-TO-WIDTH RATIO       2.0
 6--BURNED AREA TARGET, AC     10.0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

Now we will run CONTAIN as an independent module. Only the first four characters of *any* keyword need be entered.

```
INITIAL  I   TOTAL     CONTAINMENT    LINE
 FIRE    I  LENGTH        TIME       BUILDING
 SIZE    I  OF LINE      (HOURS)       RATE
(ACRES)  I   (CH)                     (CH/H)
         I
         I
  2.     I    45.          1.4          33.
         I
  4.     I    42.          0.8          49.
         I
  6.     I    40.          0.5          80.
         I
  8.     I    39.          0.2         172.
         I
 10.     I    -1.         -1.0          -1.

        -1 = INITIAL AREA IS EITHER LARGER THAN OR NEARLY
                 EQUAL TO THE BURNED AREA TARGET.
```

The burned area target is 10 acres too. See line 6 in LIST.

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH CONTAIN -- BACK TO FIRE1



FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>SPOT
```

Now let's try the SPOT module.

```
SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) FIREBRAND SOURCE ? 1-4 OR QUIT
     1=TORCHING TREES
     2=BURNING PILE
     3=SPREADING SURFACE FIRE
     4=RUNNING CROWN FIRE
>2
```

The questions that are asked depend on the firebrand source.

```
(2) MEAN COVER HEIGHT, FT ? 0-300
      (IF FOREST IS OPEN, DIVIDE BY 2.
       OTHERWISE, RETAIN FULL HEIGHT.)
>50

(3) 20-FOOT WINDSPEED, MI/H ? 0-99
>10,20,2

THE FOLLOWING VALUES WILL BE USED
  10.0    12.0    14.0    16.0    18.0    20.0
OK ? Y-N
>Y
```

```
(4) RIDGE/VALLEY ELEVATIONAL DIFFERENCE, FT ? 0-4000
>1000

(5) RIDGE/VALLEY HORIZONTAL DISTANCE, MI ? 0-4
>1

(6) SPOTTING SOURCE LOCATION ? 0-3
     0=MIDSLOPE, WINDWARD SIDE
     1=VALLEY BOTTOM
     2=MIDSLOPE,LEEWARD SIDE
     3=RIDGETOP
>2

(11) CONTINUOUS FLAME HEIGHT, FT ? 1-100
>30,80,10

THE FOLLOWING VALUES WILL BE USED
  30.0   40.0   50.0   60.0   70.0   80.0
OK ? Y-N
>Y

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST


 1--FIREBRAND SOURCE            2. BURNING PILE
 2--MEAN COVER HEIGHT, FT      50.0
 3--20-FT WINDSPEED, MI/H      10.0  12.0  14.0  16.0  18.0  20.0
 4--RIDGE/VALLEY ELEVATIONAL 1000.0
      DIFFERENCE, FT.
 5--RIDGE/VALLEY HORIZONTAL     1.0
      DISTANCE, MI.
 6--SPOTTING SOURCE LOCATION    2. MIDSLOPE, LEEWARD SIDE
11--CONTINUOUS FLAME HT, FT    30.0  40.0  50.0  60.0  70.0  80.0

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

Because there is only one output from SPOT you don't have to specify the table variable.

```
=================================================================
MAXIMUM SPOTTING DISTANCE, MI
=================================================================
  20-FT       I       CONTINUOUS FLAME HEIGHT, FT
WINDSPEED     I
  (MI/H)      I    30.    40.    50.    60.    70.    80.
              I-------------------------------------------------
              I
    10.       I    0.2    0.2    0.2    0.3    0.3    0.3
              I
    12.       I    0.2    0.2    0.3    0.3    0.4    0.4
              I
    14.       I    0.2    0.3    0.3    0.4    0.4    0.5
              I
    16.       I    0.2    0.3    0.4    0.4    0.5    0.5
              I
    18.       I    0.3    0.3    0.4    0.5    0.5    0.6
              I
    20.       I    0.3    0.4    0.5    0.5    0.6    0.7
```

```
SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>CHANGE

CHANGE WHICH LINE ? 0-11
  (0 MEANS NO MORE CHANGES)
>1

(1) FIREBRAND SOURCE ? 1-4 OR QUIT
     1=TORCHING TREES
     2=BURNING PILE
     3=SPREADING SURFACE FIRE
     4=RUNNING CROWN FIRE
>3

THIS OPTION WILL BE ADDED LATER.
THE INPUT IS FUEL MODEL, WINDSPEED, AND FIRELINE INTENSITY.
```

Spotting distance from a wind-driven surface fire is part of BURN - Part 2.

```
(1) FIREBRAND SOURCE ? 1-4 OR QUIT
     1=TORCHING TREES
     2=BURNING PILE
     3=SPREADING SURFACE FIRE
     4=RUNNING CROWN FIRE
>4

WE CAN'T PREDICT SPOTTING DISTANCE FROM A RUNNING CROWN FIRE YET.
A RUNNING CROWN FIRE IS VERY DIFFERENT FROM A TORCHING TREE.
```

This is included just for emphasis. No current work is addressing this question.

```
(1) FIREBRAND SOURCE ? 1-4 OR QUIT
     1=TORCHING TREES
     2=BURNING PILE
     3=SPREADING SURFACE FIRE
     4=RUNNING CROWN FIRE
>1

CHANGE WHICH LINE ? 0-11
  (0 MEANS NO MORE CHANGES)
>0

BECAUSE OF THE CHANGES YOU MADE,
  ADDITIONAL INPUT IS REQUIRED...

(7) TORCHING TREE SPECIES ? 1-6
     1=ENGELMANN SPRUCE
     2=DOUGLAS FIR, SUBALPINE FIR
     3=HEMLOCK
     4=PONDEROSA PINE, LODGEPOLE PINE
     5=WHITE PINE
     6=BALSAM FIR, GRAND FIR
>2

(8) TORCHING TREE DBH, IN ? 5-40
>14

(9) TORCHING TREE HEIGHT, FT ? 10-300
>50

(10) NUMBER OF TREES TORCHING TOGETHER ? 1-30
>2
```

I specified "no more changes." But the torching tree option requires more input than does the burning pile option.

```
SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST


 1--FIREBRAND SOURCE             1. TORCHING TREE
 2--MEAN COVER HEIGHT, FT       50.0
 3--20-FT WINDSPEED, MI/H       10.0   12.0   14.0   16.0   18.0   20.0
 4--RIDGE/VALLEY ELEVATIONAL 1000.0
       DIFFERENCE, FT.
 5--RIDGE/VALLEY HORIZONTAL      1.0
       DISTANCE, MI.
 6--SPOTTING SOURCE LOCATION     2. MIDSLOPE, LEEWARD SIDE
 7--TORCHING TREE SPECIES        2. DOUGLAS FIR, SUBALPINE FIR
 8--TORCHING TREE DBH, IN       14.0
 9--TORCHING TREE HEIGHT, FT    50.0
10--NUMBER OF TREES              2.0
       TORCHING TOGETHER

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN


     20-FT       I  MAXIMUM
   WINDSPEED     I  SPOTTING
     (MI/H)      I  DISTANCE
                 I    (MI)
                 I
      10.        I    0.2
                 I
      12.        I    0.2
                 I
      14.        I    0.3
                 I
      16.        I    0.3
                 I
      18.        I    0.3
                 I
      20.        I    0.4

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>TERSE
TERSE PROMPT OPTION SET.

SPOT KEYWORD?
>INPUT

(1) FIREBRAND SOURCE ? 1-4 OR QUIT
>1

(2) MEAN COVER HEIGHT, FT ? 0-300
>50
```

The TERSE mode is set until WORDY is typed.

Valid keywords are not listed.

Code definitions are not listed.

```
(3) 20-FOOT WINDSPEED, MI/H ? 0-99
>10,20,2

THE FOLLOWING VALUES WILL BE USED
  10.0   12.0   14.0   16.0   18.0   20.0
OK ? Y-N
>Y

(4) RIDGE/VALLEY ELEVATIONAL DIFFERENCE, FT ? 0-4000
>1000

(5) RIDGE/VALLEY HORIZONTAL DISTANCE, MI ? 0-4
>1

(6) SPOTTING SOURCE LOCATION ? 0-3
>2

(7) TORCHING TREE SPECIES ? 1-6
>2
```

Code definitions are not listed when you use the TERSE mode.

```
(8) TORCHING TREE DBH, IN ? 5-40
>14

(9) TORCHING TREE HEIGHT, FT ? 10-300
>50

(10) NUMBER OF TREES TORCHING TOGETHER ? 1-30
>2

SPOT KEYWORD?
>LIST
```

LIST and RUN look the same whether you are in TERSE or WORDY mode.

```
 1--FIREBRAND SOURCE           1. TORCHING TREE
 2--MEAN COVER HEIGHT, FT     50.0
 3--20-FT WINDSPEED, MI/H     10.0  12.0  14.0  16.0  18.0  20.0
 4--RIDGE/VALLEY ELEVATIONAL 1000.0
       DIFFERENCE, FT.
 5--RIDGE/VALLEY HORIZONTAL    1.0
       DISTANCE, MI.
 6--SPOTTING SOURCE LOCATION   2. MIDSLOPE, LEEWARD SIDE
 7--TORCHING TREE SPECIES      2. DOUGLAS FIR, SUBALPINE FIR
 8--TORCHING TREE DBH, IN     14.0
 9--TORCHING TREE HEIGHT, FT  50.0
10--NUMBER OF TREES            2.0
       TORCHING TOGETHER

SPOT KEYWORD?
>RUN
```

```
      20-FT        I  MAXIMUM
    WINDSPEED      I  SPOTTING
      (MI/H)       I  DISTANCE
                   I    (MI)
                   I
       10.         I    0.2
                   I
       12.         I    0.2
                   I
       14.         I    0.3
                   I
       16.         I    0.3
                   I
       18.         I    0.3
                   I
       20.         I    0.4

SPOT KEYWORD?
>WORDY
WORDY PROMPT OPTION SET.
```

Back to WORDY mode.

```
SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH SPOT -- BACK TO FIRE1
```

Now the valid Keywords are listed.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>SITE

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) MONTH OF BURN ? 1-12 OR QUIT
>QUIT

SITE INPUT TERMINATED.

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH SITE -- BACK TO FIRE1
```

Let's try the SITE module.
On second thought, let's wait till later.
This gives you an escape.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>QUIT
```

← QUIT as a FIRE1 keyword means that you are through running the program.

```
DO YOU  R E A L L Y  WANT TO TERMINATE THIS RUN? Y-N
>N
```

This gives you an escape.

```
OK.......
```

When you terminate the run, the input you entered is lost.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>DIRECT

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

← But we didn't terminate, so the DIRECT input we entered earlier is still there.

```
 1--FUEL MODEL                      2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %         2.0    4.0    6.0    8.0   10.0   12.0   14.0
 3--10-HR FUEL MOISTURE, %        5.0
 4--100-HR FUEL MOISTURE, %       6.0
 5--LIVE HERBACEOUS MOIS, %     100.0
 7--MIDFLAME WINDSPEED, MI/H      0.0    1.0    2.0    3.0    4.0    5.0
 8--PERCENT SLOPE                20.0
 9--DIRECTION OF WIND VECTOR     80.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD          DIRECTION OF MAXIMUM SPREAD
     CALCULATIONS                  TO BE CALCULATED
     DEGREES CLOCKWISE
      FROM UPHILL

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>CHANGE

CHANGE WHICH LINE ? 0-10
  (0 MEANS NO MORE CHANGES)
>2

(2) 1-HR FUEL MOISTURE, % ? 1-60
>4

CHANGE WHICH LINE ? 0-10
  (0 MEANS NO MORE CHANGES)
>0
```

} We will rerun this with a single value for 1-h fuel moisture.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

```
 1--FUEL MODEL                          2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %             4.0
 3--10-HR FUEL MOISTURE, %            5.0
 4--100-HR FUEL MOISTURE, %           6.0
 5--LIVE HERBACEOUS MOIS, %         100.0
 7--MIDFLAME WINDSPEED, MI/H          0.0     1.0     2.0     3.0     4.0     5.0
 8--PERCENT SLOPE                    20.0
 9--DIRECTION OF WIND VECTOR         80.0
      DEGREES CLOCKWISE
       FROM UPHILL
10--DIRECTION OF SPREAD             DIRECTION OF MAXIMUM SPREAD
      CALCULATIONS                    TO BE CALCULATED
      DEGREES CLOCKWISE
       FROM UPHILL

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN


MIDFLAME I RATE OF  HEAT PER    FIRELINE   FLAME    REACTION   EFFECT.   MAX
  WIND   I SPREAD  UNIT AREA   INTENSITY   LENGTH  INTENSITY    WIND   SPREAD
 (MI/H)  I (CH/H) (BTU/SQ.FT) (BTU/FT/S)   (FT) (BTU/SQFT/M) (MI/H)   DIREC
         I                                                            (DEG)
         I
   0.    I    5.       512.         48.      2.7      3713.       1.1      0.
         I
   1.    I    6.       512.         56.      2.9      3713.       1.4     34.
         I
   2.    I   10.       512.         97.      3.7      3713.       2.1     61.
         I
   3.    I   18.       512.        168.      4.7      3713.       3.1     71.
         I
   4.    I   28.       512.        262.      5.8      3713.       4.0     74.
         I
   5.    I   40.       512.        379.      6.9      3713.       5.0     76.

IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'
```

OK. This time we will link SIZE to DIRECT.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
       SIZE
>SIZE

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
       HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(3) ELAPSED TIME, HR. ? .1-8
>1.5

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
       HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

Refer to the Keyword Hierarchy (Exhibit 2).

Time is the only additional input required for SIZE. Rate of spread and effective windspeed are calculated by DIRECT.

This is given mainly for reference when you are using a screen and the DIRECT output table on the previous page is no longer visible.

```
 1--RATE OF SPREAD, CH/H          OUTPUT FROM DIRECT. RANGE=    5. TO   40.
 2--EFFECTIVE WIND, MI/H          OUTPUT FROM DIRECT. RANGE=   1.1 TO   5.0
 3--ELAPSED TIME, HR              1.5

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

The range for this input variable is carried over from DIRECT.

```
MIDFLAME I   AREA  PERIMETER  LENGTH--  FORWARD  BACKING   MAXIMUM
  WIND   I   (AC)    (CH)    TO-WIDTH   SPREAD   SPREAD     WIDTH
 (MI/H)  I                     RATIO   DISTANCE DISTANCE   OF FIRE
         I                               (CH)     (CH)      (CH)
         I
   0.    I    5.3     26.       1.3       7.6      1.7        7.3
         I
   1.    I    6.8     30.       1.3       9.0      1.8        8.1
         I
   2.    I   16.0     46.       1.5      15.5      2.1       11.5
         I
   3.    I   38.2     74.       1.8      26.8      2.6       16.6
         I
   4.    I   78.5    108.       2.0      41.9      3.0       22.3
         I
   5.    I  141.9    150.       2.3      60.6      3.3       28.3

IF YOU WANT TO CONTINUE WITH THE CONTAINMENT CALCULATIONS
  TYPE 'CONTAIN'

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      CONTAIN
>CHANGE

(3) ELAPSED TIME, HR. ? .1-8
>.5,3,.5
```

Since there is only one SIZE input that can be changed, you are not asked for the line number.

```
THE FOLLOWING VALUES WILL BE USED
   0.5    1.0    1.5    2.0    2.5    3.0
OK ? Y-N
>Y

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST

 1--RATE OF SPREAD, CH/H          OUTPUT FROM DIRECT. RANGE=    5. TO   40.
 2--EFFECTIVE WIND, MI/H          OUTPUT FROM DIRECT. RANGE=   1.1 TO   5.0
 3--ELAPSED TIME, HR              0.5   1.0   1.5   2.0   2.5   3.0

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

```
TABLE VARIABLE ? 0-6

 0=NO MORE TABLES        3=LENGTH-TO-WIDTH RATIO
 1=AREA                  4=FORWARD SPREAD DISTANCE
 2=PERIMETER             5=BACKING SPREAD DISTANCE
                         6=MAXIMUM WIDTH OF FIRE
>1

=======================================================================
AREA, ACRES
=======================================================================
MIDFLAME I        ELAPSED TIME TO ATTACK,  HR
  WIND   I
 (MI/H)  I      0.5     1.0     1.5     2.0     2.5     3.0
         I---------------------------------------------------------------
         I
  0.     I     0.6     2.4     5.3     9.5    14.8    21.3
         I
  1.     I     0.8     3.0     6.8    12.2    19.0    27.4
         I
  2.     I     1.8     7.1    16.0    28.5    44.6    64.2
         I
  3.     I     4.2    17.0    38.2    68.0   106.2   152.9
         I
  4.     I     8.7    34.9    78.5   139.5   218.0   313.9
         I
  5.     I    15.8    63.1   141.9   252.3   394.2   567.6
```

Area is printed to tenths when any prediction is less than 10 acres.

```
TABLE VARIABLE ? 0-6

 0=NO MORE TABLES        3=LENGTH-TO-WIDTH RATIO
 1=AREA                  4=FORWARD SPREAD DISTANCE
 2=PERIMETER             5=BACKING SPREAD DISTANCE
                         6=MAXIMUM WIDTH OF FIRE
>0
```

Length-to-width-ratio is automatically saved for CONTAIN— even though it is not printed.

```
IF YOU WANT TO CONTINUE WITH THE CONTAINMENT CALCULATIONS
  TYPE 'CONTAIN' <-------------------------------------------
```

Now we will link CONTAIN to SIZE and DIRECT.

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      CONTAIN
>CONTAIN

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT <-----------------------------------------------------
```

Some of the input required for CONTAIN has been calculated by DIRECT and SIZE.

```
(1) RUN OPTION ? 1-2 OR QUIT
      1=COMPUTE LINE BUILDING RATE
      2=COMPUTE BURNED AREA
>2

(2) MODE OF ATTACK ? 1-2
      1=HEAD
      2=REAR
>1

(7) LINE BUILDING RATE, CH/H ? .1-200
>50
```

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      ~~HELP~~,~~KEY~~,~~TERSE~~,~~WORDY~~,~~PAUSE~~,~~NOPAUSE~~
>LIST


 1--RUN OPTION                     2. COMPUTE BURNED AREA
 2--MODE OF ATTACK                 1. HEAD
 3--RATE OF SPREAD, CH/H           OUTPUT FROM DIRECT. RANGE=     5. TO    40.
 4--INITIAL FIRE SIZE, ACRES       OUTPUT FROM SIZE.   RANGE=     1. TO   568.
 5--LENGTH-TO-WIDTH RATIO          OUTPUT FROM SIZE.   RANGE=   1.3 TO    2.3
 7--LINE BUILDING RATE, CH/H      50.0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN

TABLE VARIABLE ? 0-3
 0=NO MORE TABLES
 1=TOTAL LENGTH OF LINE
 2=CONTAINMENT TIME
 3=FINAL FIRE SIZE
>3

===================================================================
FINAL FIRE SIZE, ACRES
===================================================================
MIDFLAME I        ELAPSED TIME TO ATTACK,  HR
  WIND   I
 (MI/H)  I      0.5    1.0    1.5    2.0    2.5    3.0
         I---------------------------------------------------------
         I
  0.     I      1.     3.     7.     12.    19.    28.
         I
  1.     I      1.     4.     9.     16.    25.    37.
         I
  2.     I      3.    11.    24.     43.    68.    97.
         I
  3.     I      8.*   32.*   71.*  127.*  198.*  286.*
         I
  4.     I     -2.*   -2.*   -2.*   -2.*   -2.*   -2.*
         I
  5.     I     -2.*   -2.*   -2.*   -2.*   -2.*   -2.*
         I

         -2 = FORWARD RATE OF SPREAD IS EITHER GREATER THAN
                OR NEARLY EQUAL TO LINE BUILDING RATE PER FLANK.  ← Note!

          * = FIRE IS TOO INTENSE FOR DIRECT ATTACK BY
                HAND CREWS.
              EQUIPMENT SUCH AS DOZERS, PUMPERS, PLOWS,
                AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

TABLE VARIABLE ? 0-3
 0=NO MORE TABLES
 1=TOTAL LENGTH OF LINE
 2=CONTAINMENT TIME
 3=FINAL FIRE SIZE
>0
```

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>CHANGE

CHANGE WHICH LINE ? 0-7
  (0 MEANS NO MORE CHANGES)
>7

(7) LINE BUILDING RATE, CH/H ? .1-200
>30,60,10

THE FOLLOWING VALUES WILL BE USED
  30.0   40.0   50.0   60.0
OK ? Y-N
>Y
```

Range input for line building rate.

```
CHANGE WHICH LINE ? 0-7
  (0 MEANS NO MORE CHANGES)
>0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST



 1---RUN OPTION                2. COMPUTE BURNED AREA
 2---MODE OF ATTACK            1. HEAD
 3--RATE OF SPREAD, CH/H       OUTPUT FROM DIRECT. RANGE=    5. TO    40.
 4---INITIAL FIRE SIZE, ACRES  OUTPUT FROM SIZE.   RANGE=    1. TO   568.
 5---LENGTH-TO-WIDTH RATIO     OUTPUT FROM SIZE.   RANGE=  1.3 TO    2.3
 7---LINE BUILDING RATE, CH/H   30.0  40.0  50.0  60.0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN

A RANGE OF VALUES IS NOT ALLOWED FOR
LINE BUILDING RATE SINCE TWO OF THE INPUT
VARIABLES FOR DIRECT OR SIZE HAVE ALREADY
BEEN ASSIGNED RANGES.
```

Midflame windspeed and elapsed time.

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH CONTAIN LINKED TO SIZE -- BACK TO SIZE
```

Go back one level in the hierarchy of keywords.

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>CHANGE

(3) ELAPSED TIME, HR. ? .1-8
>1
```

Change elapsed time from a range to a single value.

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST

 1--RATE OF SPREAD, CH/H        OUTPUT FROM DIRECT. RANGE=    5. TO   40.
 2--EFFECTIVE WIND, MI/H        OUTPUT FROM DIRECT. RANGE=   1.1 TO   5.0
 3--ELAPSED TIME, HR            1.0

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

It is necessary to rerun SIZE before you can link to CONTAIN.

```
MIDFLAME I   AREA  PERIMETER  LENGTH-   FORWARD   BACKING   MAXIMUM
  WIND   I   (AC)    (CH)    TO-WIDTH    SPREAD    SPREAD    WIDTH
 (MI/H)  I                    RATIO    DISTANCE  DISTANCE   OF FIRE
         I                               (CH)      (CH)      (CH)
         I
   0.    I    2.4     17.       1.3       5.1       1.2        4.8
         I
   1.    I    3.0     20.       1.3       6.0       1.2        5.4
         I
   2.    I    7.1     31.       1.5      10.4       1.4        7.7
         I
   3.    I   17.0     49.       1.8      17.8       1.7       11.1
         I
   4.    I   34.9     72.       2.0      27.9       2.0       14.9
         I
   5.    I   63.1    100.       2.3      40.4       2.2       18.9

IF YOU WANT TO CONTINUE WITH THE CONTAINMENT CALCULATIONS
  TYPE 'CONTAIN'

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      CONTAIN
>CONTAIN
```

Now it is OK to run CONTAIN.

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

The CONTAIN input is still there, with new values from SIZE.

```
 1--RUN OPTION                   2. COMPUTE BURNED AREA
 2--MODE OF ATTACK               1. HEAD
 3--RATE OF SPREAD, CH/H         OUTPUT FROM DIRECT. RANGE=    5. TO   40.
 4--INITIAL FIRE SIZE, ACRES     OUTPUT FROM SIZE.   RANGE=    2. TO   63.
 5--LENGTH-TO-WIDTH RATIO        OUTPUT FROM SIZE.   RANGE=   1.3 TO   2.3
 7--LINE BUILDING RATE, CH/H    30.0  40.0  50.0  60.0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

Range input for line building rate is OK now.

```
TABLE VARIABLE ? 0-3
 0=NO MORE TABLES
 1=TOTAL LENGTH OF LINE
 2=CONTAINMENT TIME
 3=FINAL FIRE SIZE
>3

=================================================================================
FINAL FIRE SIZE, ACRES
=================================================================================
MIDFLAME I        LINE BUILDING RATE, CH/H
  WIND   I
 (MI/H)  I    30.     40.     50.     60.
         I-----------------------------------------------------------------------
         I
  0.     I     4.      3.      3.      3.
         I
  1.     I     5.      4.      4.      4.
         I
  2.     I    15.     12.     11.     10.
         I
  3.     I    -2.*    40.*    32.*    28.*
         I
  4.     I    -2.*    -2.*    -2.*    -2.*
         I
  5.     I    -2.*    -2.*    -2.*    -2.*
         I

          -2 = FORWARD RATE OF SPREAD IS EITHER GREATER THAN
                 OR NEARLY EQUAL TO LINE BUILDING RATE PER FLANK.

           * = FIRE IS TOO INTENSE FOR DIRECT ATTACK BY
                  HAND CREWS.
                EQUIPMENT SUCH AS DOZERS, PUMPERS, PLOWS,
                  AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

TABLE VARIABLE ? 0-3
 0=NO MORE TABLES
 1=TOTAL LENGTH OF LINE
 2=CONTAINMENT TIME
 3=FINAL FIRE SIZE
>0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH CONTAIN LINKED TO SIZE -- BACK TO SIZE


SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH SIZE LINKED TO DIRECT -- BACK TO DIRECT
```

Refer to the Keyword hierarchy, exhibit 2, to see how we get from CONTAIN linked to SIZE and DIRECT to the DISPATCH module.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH DIRECT -- BACK TO FIRE1



FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>DISPATCH

DISPATCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,WORDY,TERSE,PAUSE,NOPAUSE
>INPUT

(1) FUEL MODEL NUMBER ? 1-99 OR QUIT
>2

(2) DEAD FUEL MOIS., % ? 1-60
>5

(3) LIVE FUEL MOIS., % ? 30-300
>100

(4) 20-FT WINDSPEED, MI/H ? 0-99
     (ASSUMED TO BE BLOWING UPHILL)
>10

(5) WIND ADJUSTMENT FACTOR ? .1-1
>.3

(6) PERCENT SLOPE ? 0-100
>15

(7) ELAPSED TIME FROM IGNITION TO ATTACK, HR ? .1-8
>1

(8) LINE BUILDING RATE, CH/H ? .1-200
>50

DISPATCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,WORDY,TERSE,PAUSE,NOPAUSE
>LIST

 1 -- FUEL MODEL --------------------     2.-- TIMBER (GRASS AND UNDERSTORY)
 2 -- DEAD FUEL MOISTURE -----------      5. %
 3 -- LIVE FUEL MOISTURE ----------- 100. %
 4 -- 20-FT WINDSPEED (UPSLOPE) -----   10. MI/H
 5 -- WIND ADJUSTMENT FACTOR -------     0.3
 6 -- SLOPE -----------------------     15. %
 7 -- ELAPSED TIME FROM IGNITION
        TO ATTACK -------------------     1.0 HR
 8 -- LINE BUILDING RATE ----------     50.0 CH/H

DISPATCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,WORDY,TERSE,PAUSE,NOPAUSE
>RUN
```

DISPATCH is essentially an automatic link from DIRECT to SIZE to CONTAIN, without some of the options.

```
    FORWARD RATE OF SPREAD ----------   17.  CH/H
    HEAT PER UNIT AREA --------------  491.  BTU/SQ.FT
    FIRELINE INTENSITY --------------  157.  BTU/FT/S
    FLAME LENGTH --------------------    4.6 FEET

    AREA AT TIME OF ATTACK ----------   16.  ACRES
    PERIMETER AT TIME OF ATTACK -----   48.  CHAINS

THESE PREDICTIONS INDICATE THAT
THE FIRE IS TOO INTENSE FOR DIRECT ATTACK
BY HAND CREWS.  EQUIPMENT SUCH AS DOZERS, PUMPERS,
AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

  HEAD ATTACK:
    TOTAL LENGTH OF LINE -----------   62.  CHAINS
      (PERIMETER OF BURNED AREA)
    ELAPSED TIME FROM ATTACK
      TO CONTAINMENT ----------------    1.2 HOURS
    FINAL FIRE SIZE -----------------   29.  ACRES

  REAR ATTACK:
    TOTAL LENGTH OF LINE ----------- 165.  CHAINS
      (PERIMETER OF BURNED AREA)
    ELAPSED TIME FROM ATTACK
      TO CONTAINMENT ----------------    3.3 HOURS
    FINAL FIRE SIZE ----------------- 132.  ACRES

DISPATCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,WORDY,TERSE,PAUSE,NOPAUSE
>QUIT

FINISH DISPATCH -- BACK TO FIRE1


FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>SITE <-------------------------------------------- Now we will try SITE.

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) MONTH OF BURN ? 1-12 OR QUIT
>4

(2) DAY OF BURN ? 1 - 31
>5

(3) DO YOU KNOW THE LATITUDE ? Y-N  }  Sometimes more than one
>Y                                  }  question is associated
                                    }  with a line number
(3) LATITUDE, DEG. ? 0-90           }
>45

SUNSET  = 1822.
SUNRISE =  537. <--------------------- Calculated
```

```
(4) BURN TIME ? 0000-2359
>1390

ILLEGAL INPUT.
THERE ARE 60 MINUTES IN AN HOUR.
TRY AGAIN.

(4) BURN TIME ? 0000-2359
>13

DID YOU MEAN 1300, RATHER THAN 0013, ? Y-N
>Y
```

This program is certainly friendly!

```
(5) DO YOU WANT TO USE THE TWO FUEL MODEL CONCEPT ? Y-N
>N

(5) FUEL MODEL ? 1-99
>1

(10) DO YOU WANT TO ENTER MAP MEASUREMENTS TO
     CALCULATE PERCENT SLOPE ? Y-N
>N

(10) PERCENT SLOPE ? 0-100
>0

(11) ELEVATION OF FIRE LOCATION, FT ? 0-12000
>1000

(12) IS THE ELEVATION DIFFERENCE BETWEEN THE LOCATION OF THE
     FIRE AND THE LOCATION OF THE TEMPERATURE AND HUMIDITY READINGS
     MORE THAN 1000 FT ? Y-N
>N

(14) CROWN CLOSURE, % ? 0-100
        (ENTER THE CLOSURE AS IF THERE WERE FOLIAGE)
>0
```

← This causes a lot of questions to be skipped.

```
(21) BURN TIME TEMPERATURE, F ? 33-120 OR QUIT
>78

(22) BURN TIME RELATIVE HUMIDITY, % ? 1-100
>34

(23) BURN TIME 20-FT WINDSPEED, MI/H ? 0-99
>0

FUELS ARE EXPOSED TO THE WIND

WIND ADJUSTMENT FACTOR = .4

(27) BURN TIME CLOUD COVER, % ? 0-100
>0

(28) BURN TIME HAZINESS ? 1-4
        1=VERY CLEAR SKY
        2=AVERAGE CLEAR FOREST ATMOSPHERE
        3=MODERATE FOREST BLUE HAZE
        4=DENSE HAZE
>1
```

1400 conditions (lines 29-33) are set equal to burn time conditions because burn time is 1300 -- between 1200 and 1600.

```
(42) MOISTURE INITIALIZATION OPTION ? 1-5

       1=FINE FUEL MOISTURE KNOWN FOR BURN DAY -1

       2=COMPLETE WEATHER DATA FOR 3 TO 7 DAYS

       3=INCOMPLETE WEATHER DATA
         RAIN THE WEEK BEFORE THE BURN

       4=INCOMPLETE WEATHER DATA
         NO RAIN THE WEEK BEFORE THE BURN
         WEATHER PATTERN HOLDING
         (NO ADDITIONAL INPUT) <---------- Note.

       5=INCOMPLETE WEATHER DATA
         WEATHER PATTERN CHANGING
>4

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST

 1--MONTH OF BURN -------------------------     4.
 2--DAY OF BURN ---------------------------     5.
 3--LATITUDE, DEG. ------------------------    45.

 4--BURN TIME -----------------------------  1300.

 5--FUEL MODEL ----------------------------     1.
                                               SHORT GRASS (1 FT)


10--SLOPE, % ------------------------------     0.
11--ELEVATION OF FIRE SITE, FT -----------   1000.
12--ELEVATION DIFFERENCE BETWEEN FIRE
      SITE AND SITE OF T/RH READINGS ------    LESS THAN 1000 FT

14--CROWN CLOSURE, % ----------------------     0.

21--BURN TIME TEMPERATURE, F --------------    78.
22--BURN TIME RELATIVE HUMIDITY, % --------    34.
23--BURN TIME 20-FT WINDSPEED, MI/H -------     0.
24--BURN TIME DIRECTION OF WIND VECTOR ----     0.
25--DIRECTION FOR SPREAD CALCULATIONS -----     0.  (DIRECTION OF MAX SPREAD)
26--EXPOSURE OF FUELS TO THE WIND ---------     1 = EXPOSED
27--BURN TIME CLOUD COVER, % --------------     0.
28--BURN TIME HAZINESS --------------------     1 = VERY CLEAR SKY

29--BURN DAY 1400 TEMPERATURE, F ----------    78.
30--BURN DAY 1400 RELATIVE HUMIDITY, % ----    34.
31--BURN DAY 1400 20-FT WINDSPEED, MI/H ---     0.
32--BURN DAY 1400 CLOUD COVER, % ----------     0.
33--BURN DAY 1400 HAZINESS ----------------     1 = VERY CLEAR SKY

42--MOISTURE INITIALIZATION OPTION --------     4 = INCOMPLETE WEATHER DATA
                                                    NO RAIN THE WEEK BEFORE BURN
                                                    WEATHER PATTERN HOLDING

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

```
INTERMEDIATE VALUES

     TIME OF SUNSET-----------------   1822.
     TIME OF SUNRISE----------------    537.
     FUEL SURFACE TEMPERATURE, F----    115.
     FUEL LEVEL RH, %---------------     10.
     PERCENT SHADE------------------      0.
     FINE DEAD FUEL MOISTURE, %-----     4.1
```

Most of the SITE input is used to calculate this.

```
BASIC INPUT

     FUEL MODEL--------------------      1-- SHORT GRASS (1 FT)
     1-HR FUEL MOISTURE, %---------      4.1
     MIDFLAME WINDSPEED, MI/H -----      0.0
     PERCENT SLOPE-----------------      0.0
     DIRECTION OF THE WIND VECTOR--      0.0
     DIRECTION OF SPREAD-----------      0.0  (DIRECTION OF MAX SPREAD)
      CALCULATIONS

OUTPUT


     RATE OF SPREAD, CH/H----------       5.
     HEAT PER UNIT AREA, BTU/SQ.FT--     95.
     FIRELINE INTENSITY, BTU/FT/S---      8.
     FLAME LENGTH, FT---------------     1.2
     REACTION INTENSITY, BTU/SQ.FT/M   870.
     EFFECTIVE WINDSPEED, MI/H------     0.0
```

The basic input and output are the same as for DIRECT.

```
IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>INPUT
```

Let's do it again for a situation that requires more input.

```
(1) MONTH OF BURN ? 1-12 OR QUIT
>6

(2) DAY OF BURN ? 1 - 31
>23

(3) DO YOU KNOW THE LATITUDE ? Y-N
>N

(3) TWO-LETTER STATE ABBREVIATION ?
>MT

(3) LATITUDE = 46. DEG

SUNSET  = 1946.
SUNRISE =  413.

(4) BURN TIME ? 0000-2359
>2200
```

Night burn.

```
(5) DO YOU WANT TO USE THE TWO FUEL MODEL CONCEPT ? Y-N
>N

(5) FUEL MODEL ? 1-99
>2

(6) DO YOU KNOW 10-HR FUEL MOISTURE ? Y-N
>N

AN ESTIMATE WILL BE BASED ON THE CALCULATED 1-HR VALUE

(6) WILL 10-HR MOIS. BE WETTER THAN 1-HR MOIS ? Y-N
>Y

(6) WHAT IS THE MOISTURE DIFFERENCE, %(MOIS.) ? 0-20
>2

(7) DO YOU KNOW 100-HR FUEL MOISTURE ? Y-N
>N

AN ESTIMATE WILL BE BASED ON THE CALCULATED 1-HR VALUE

(7) WILL 100-HR MOIS. BE WETTER THAN 1-HR MOIS ? Y-N
>Y

(7) WHAT IS THE MOISTURE DIFFERENCE, %(MOIS.) ? 0-20
>3

(8) DO YOU WANT TO SEE THE LIVE FUEL MOISTURE GUIDELINES ? Y-N
>N

(8) LIVE HERBACEOUS MOIS, % ? 30-300
>120

(10) DO YOU WANT TO ENTER MAP MEASUREMENTS TO
     CALCULATE PERCENT SLOPE ? Y-N
>N

(10) PERCENT SLOPE ? 0-100
>25

(11) ELEVATION OF FIRE LOCATION, FT ? 0-12000
>1200

(12) IS THE ELEVATION DIFFERENCE BETWEEN THE LOCATION OF THE
     FIRE AND THE LOCATION OF THE TEMPERATURE AND HUMIDITY READINGS
     MORE THAN 1000 FT ? Y-N
>Y

(12) IS THE AIR WELL MIXED BETWEEN THE TWO LOCATIONS ? Y-N
>Y

(12) IS THE FIRE SITE AT A HIGHER LOCATION ? Y-N
>1000
1 IS NOT A VALID ANSWER.
TYPE Y FOR YES  OR  N FOR NO.
>1000
1 IS NOT A VALID ANSWER.
TYPE Y FOR YES  OR  N FOR NO.
>Y
```

Always read the question!

```
(12) WHAT IS THE ELEVATION DIFFERENCE, FT ? 1000-9000
>1000
```

```
(13) ASPECT ? N,NE,E,SE,S,SW,W,NW
>NE

(14) CROWN CLOSURE, % ? 0-100
       (ENTER THE CLOSURE AS IF THERE WERE FOLIAGE)
>30

(15) IS FOLIAGE PRESENT ? Y-N
>Y

(16) ARE THE TREES IN THIS STAND SHADE TOLERANT ? Y-N
>N

(17) DOMINANT TREE TYPE ? 1-2
       1=CONIFEROUS
       2=DECIDUOUS
>1

(18) AVERAGE TREE HEIGHT, FT ? 10-300
>60

(19) RATIO OF CROWN HEIGHT TO TREE HEIGHT ? .1-1
>.6

(20) RATIO OF CROWN HEIGHT TO CROWN DIAMETER ? .2-5
>3

(21) BURN TIME TEMPERATURE, F ? 33-120 OR QUIT
>88

(22) DO YOU KNOW THE BURN TIME RELATIVE HUMIDITY ? Y-N
>N

(22) IS A FRONTAL PASSAGE OR AN INVERSION EXPECTED
     BETWEEN 1400 AND BURN TIME ? Y-N
>N
```

The RH estimate will be printed when the input is complete.

```
(23) BURN TIME 20-FT WINDSPEED, MI/H ? 0-99
>5

(24) BURN TIME DIRECTION OF WIND VECTOR ? 0-360
       (DEGREES CLOCKWISE FROM UPHILL)
>0

(25) DO YOU WANT FIRE BEHAVIOR PREDICTIONS ONLY FOR
     THE DIRECTION OF MAXIMUM SPREAD ? Y-N
>Y

(26) EXPOSURE OF FUELS TO THE WIND ? 0-4
      0=DONT KNOW
      1=EXPOSED
      2=PARTIALLY SHELTERED
      3=FULLY SHELTERED--OPEN STAND
      4=FULLY SHELTERED--DENSE STAND
>0
```

Refer to exhibit 2 to understand the logic of the questions for line 26.

```
(26) IS THE FUEL NEAR A CLEARING ? Y-N
>N

(26) IS THE FUEL HIGH ON A RIDGE WHERE TREES OFFER
     LITTLE SHELTER FROM THE WIND ? Y-N
>N
```

```
(26) IS THE FUEL MIDSLOPE OR HIGHER ON A MOUNTAIN
     WITH WIND BLOWING DIRECTLY AT THE SLOPE ? Y-N
>N

(26) IS THIS A PATCHY STAND OF TIMBER ? Y-N
>Y

FUELS ARE PARTIALLY SHELTERED FROM THE WIND

WIND ADJUSTMENT FACTOR = .3

(29) BURN DAY 1400 TEMPERATURE, F ? 33-120
>90

(30) BURN DAY 1400 RELATIVE HUMIDITY, % ? 1-100
>34

(31) BURN DAY 1400 20-FT WINDSPEED, MI/H ? 0-99
>8

(32) BURN DAY 1400 CLOUD COVER, % ? 0-100
>30

(33) BURN DAY 1400 HAZINESS ? 1-4
       1=VERY CLEAR SKY
       2=AVERAGE CLEAR FOREST ATMOSPHERE
       3=MODERATE FOREST BLUE HAZE
       4=DENSE HAZE
>3

(34) SUNSET TEMPERATURE, F ? 33-120
>70

(35) DO YOU KNOW THE SUNSET RELATIVE HUMIDITY ? Y-N
>Y

(35) SUNSET RELATIVE HUMIDITY, % ? 1-100
>45

(36) SUNSET 20-FT WINDSPEED, MI/H ? 0-99
>3

(37) SUNSET CLOUD COVER, % ? 0-100
>0

(42) MOISTURE INITIALIZATION OPTION ? 1-5

       1=FINE FUEL MOISTURE KNOWN FOR BURN DAY -1

       2=COMPLETE WEATHER DATA FOR 3 TO 7 DAYS

       3=INCOMPLETE WEATHER DATA
         RAIN THE WEEK BEFORE THE BURN

       4=INCOMPLETE WEATHER DATA
         NO RAIN THE WEEK BEFORE THE BURN
         WEATHER PATTERN HOLDING
         (NO ADDITIONAL INPUT)

       5=INCOMPLETE WEATHER DATA
         WEATHER PATTERN CHANGING
```

```
(50) NUMBER OF DAYS BEFORE THE BURN THAT RAIN OCCURRED ? 1-7
>4

(51) RAIN AMOUNT, HUNDREDTHS OF AN INCH ? 1-400     = .3 inch
>30 This is necessary because no input value can be entered
(52) 1400 TEMPERATURE ON THE DAY IT RAINED, F ? 33-120  to more
>56                                                     accuracy than
                                                          tenths.
(53) SKY CONDITION FROM THE DAY IT RAINED TILL BURN DAY ? 1-3
       1=CLEAR
       2=CLOUDY
       3=PARTLY CLOUDY
>3

(22) ESTIMATED BURN TIME RELATIVE HUMIDITY = 36.% <- Calculated

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST

 1--MONTH OF BURN ---------------------------    6.
 2--DAY OF BURN -----------------------------   23.
 3--LATITUDE, DEG. --------------------------   46.
    STATE -----------------------------------   MT

 4--BURN TIME ------------------------------- 2200.

 5--FUEL MODEL ------------------------------    2.
                                                TIMBER (GRASS AND UNDERSTORY)

 6--10-HR FUEL MOISTURE, % ------------------  10-HR = 1-HR + 2.
 7--100-HR FUEL MOISTURE, % ----------------- 100-HR = 1-HR + 3.
 8--LIVE HERBACEOUS MOIS., % ----------------  120.

10--SLOPE, % --------------------------------   25.
11--ELEVATION OF FIRE SITE, FT -------------- 1200.
12--ELEVATION DIFFERENCE BETWEEN FIRE-------- 1000. -- FIRE SITE AT
      SITE AND SITE OF T/RH READINGS, FT               HIGHER ELEVATION
13--ASPECT ----------------------------------   NE

14--CROWN CLOSURE, % ------------------------   30.
15--FOLIAGE ---------------------------------   PRESENT
16--SHADE TOLERANCE -------------------------   INTOLERANT
17--DOMINANT TREE TYPE ----------------------    1 = CONIFEROUS
18--AVERAGE TREE HEIGHT, FT -----------------   60.
19--RATIO OF CROWN HEIGHT TO
      TREE HEIGHT ---------------------------    0.6
20--RATIO OF CROWN HEIGHT TO
      CROWN DIAMETER ------------------------    3.0

21--BURN TIME TEMPERATURE, F ----------------   88.
22--BURN TIME RELATIVE HUMIDITY, % ----------   36.
23--BURN TIME 20-FT WINDSPEED, MI/H ---------    5.
24--BURN TIME DIRECTION OF WIND VECTOR ------    0.
      DEGREES CLOCKWISE FROM UPHILL
25--DIRECTION FOR SPREAD CALCULATIONS ------    0.  (DIRECTION OF MAX SPREAD)
      DEGREES CLOCKWISE FROM UPHILL
26--EXPOSURE OF FUELS TO THE WIND ----------    2 = PARTIALLY SHELTERED
```

```
29--BURN DAY 1400 TEMPERATURE, F ----------    90.
30--BURN DAY 1400 RELATIVE HUMIDITY, % ----    34.
31--BURN DAY 1400 20-FT WINDSPEED, MI/H ---     8.
32--BURN DAY 1400 CLOUD COVER, % ----------    30.
33--BURN DAY 1400 HAZINESS ----------------     3 = MODERATE FOREST BLUE HAZE

34--SUNSET TEMPERATURE, F -----------------    70.
35--SUNSET RELATIVE HUMIDITY, % -----------    45.
36--SUNSET 20-FT WINDSPEED, MI/H ----------     3.
37--SUNSET CLOUD COVER, % -----------------     0.

42--MOISTURE INITIALIZATION OPTION --------     3 = INCOMPLETE WEATHER DATA
                                                    RAIN THE WEEK BEFORE BURN
50--NUMBER OF DAYS BEFORE THE BURN
      THAT RAIN OCCURRED ------------------     4
51--RAIN AMOUNT, HUNDRETHS OF AN INCH -----    30.
52--1400 TEMPERATURE ON THE DAY
      IT RAINED, F ------------------------    56.
53--SKY CONDITION FROM THE DAY IT RAINED
      UNTIL BURN DAY ----------------------     3 = PARTLY CLOUDY

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN

INTERMEDIATE VALUES

     TIME OF SUNSET-----------------   1946.
     TIME OF SUNRISE----------------    413.
     WIND ADJUSTMENT FACTOR---------      0.3
     FUEL SURFACE TEMPERATURE, F----     85.
     FUEL LEVEL RH, %---------------     39.
     PERCENT SHADE------------------    100.
     FINE DEAD FUEL MOISTURE, %-----     10.4


BASIC INPUT

     FUEL MODEL---------------------      2-- TIMBER (GRASS AND UNDERSTORY)
     1-HR FUEL MOISTURE, %----------     10.4
     10-HR FUEL MOISTURE, %---------     12.4
     100-HR FUEL MOISTURE, %--------     13.4
     LIVE HERBACEOUS MOIS, %--------    120.0
     MIDFLAME WINDSPEED, MI/H ------      1.5
     PERCENT SLOPE------------------     25.0
     DIRECTION OF THE WIND VECTOR---      0.0
      DEGREES CLOCKWISE
       FROM UPHILL
     DIRECTION OF SPREAD------------      0.0  (DIRECTION OF MAX SPREAD)
      CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL
```

```
OUTPUT


      RATE OF SPREAD, CH/H-----------      7.
      HEAT PER UNIT AREA, BTU/SQ.FT--    404.
      FIRELINE INTENSITY, BTU/FT/S---     51.
      FLAME LENGTH, FT---------------      2.7
      REACTION INTENSITY, BTU/SQ.FT/M  2928.
      EFFECTIVE WINDSPEED, MI/H------      2.2

IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
       SIZE
>QUIT

FINISH SITE -- BACK TO FIRE1



FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
       KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>QUIT

DO YOU  REALLY  WANT TO TERMINATE THIS RUN? Y-N
>Y ←------------------------------------- Yes. I really do.

FIRE1 RUN TERMINATED.
******************************
```

APPENDIX B: INPUT/OUTPUT FORMS AND DESCRIPTIONS OF INPUT VARIABLES

An input/output form is supplied for each module of the FIRE1 program of BEHAVE. In addition, quick reference sheets describe all input variables, noting the valid range for input and whether range input is allowed. This material can be used as a quick reference while running the program.

DIRECT MODULE INPUT/OUTPUT

INPUT

1 Fuel model ________ ________ ________ ________ ________

2 1-h fuel moisture, % ________ ________ ________ ________ ________

3 * 10-h fuel moisture, % ________ ________ ________ ________ ________

4 * 100-h fuel moisture, % ________ ________ ________ ________ ________

5 * Live herbaceous moisture, % ________ ________ ________ ________ ________

6 * Live woody moisture, % ________ ________ ________ ________ ________

7 Midflame windspeed, mi/h ________ ________ ________ ________ ________

8 Slope, % ________ ________ ________ ________ ________

9 Direction of wind vector, degrees clockwise from uphill ________ ________ ________ ________ ________

10 @ Direction for spread calculations, degrees clockwise from uphill (or from the wind vector if slope is zero) ________ ________ ________ ________ ________

OUTPUT

1 Rate of spread, ch/h ________ ________ ________ ________ ________

2 Heat per unit area, Btu/ft^2 ________ ________ ________ ________ ________

3 Fireline intensity, Btu/ft/s ________ ________ ________ ________ ________

4 Flame length, ft ________ ________ ________ ________ ________

5 Reaction intensity, Btu/ft^2/min ________ ________ ________ ________ ________

6 Effective windspeed, mi/h ________ ________ ________ ________ ________

7 # Direction of maximum spread, degrees clockwise from uphill ________ ________ ________ ________ ________

* Input only for fuel models that have this component.

@ Can be input directly or the direction of maximum spread can be calculated.

\# Output only if specified in line 10 that the direction of maximum spread is to be calculated.

SIZE MODULE INPUT/OUTPUT

INPUT

1 * Rate of spread, ch/h __________ __________ __________ __________ __________

2 * Effective windspeed, mi/h __________ __________ __________ __________ __________

3 Elapsed time, h __________ __________ __________ __________ __________

OUTPUT

1 Area, acres __________ __________ __________ __________ __________

2 Perimeter, ch __________ __________ __________ __________ __________

3 Length-to-width ratio __________ __________ __________ __________ __________

4 Forward spread distance, ch __________ __________ __________ __________ __________

5 Backing spread distance, ch __________ __________ __________ __________ __________

6 Maximum width of fire, ch __________ __________ __________ __________ __________

* Input only when SIZE is used as an independent module.

CONTAIN MODULE INPUT/OUTPUT

INPUT

1 Run option (code) ________ ________ ________ ________ ________

2 Mode of attack (code) ________ ________ ________ ________ ________

3 @ Rate of spread, ch/h ________ ________ ________ ________ ________

4 @ Initial fire size, acres ________ ________ ________ ________ ________

5 @ Length-to-width ratio ________ ________ ________ ________ ________

6 * Burned area target, acres ________ ________ ________ ________ ________

7 # Line building rate, ch/h ________ ________ ________ ________ ________

OUTPUT

1 Total length of line, ch ________ ________ ________ ________ ________

2 Containment time, h ________ ________ ________ ________ ________

3 * Line-building rate, ch/h ________ ________ ________ ________ ________

3 # Final fire size, acres ________ ________ ________ ________ ________

@ Input only when CONTAIN is used as an independent module.
* Only for run option 1 (calculate line-building rate).
\# Only for run option 2 (calculate final fire size).

DIRECT-SIZE-CONTAIN LINKED INPUT

DIRECT INPUT

1 Fuel model ________ ________ ________ ________

2 1-h fuel moisture, % ________ ________ ________ ________

3 10-h fuel moisture, % ________ ________ ________ ________

4 100-h fuel moisture, % ________ ________ ________ ________

5 Live herbaceous moisture, % ________ ________ ________ ________

6 Live woody moisture, % ________ ________ ________ ________

7 Midflame windspeed, mi/h ________ ________ ________ ________

8 Slope, % ________ ________ ________ ________

9 Direction of wind vector, degrees clockwise from uphill ________ ________ ________ ________

10 Direction for spread calculations, degrees clockwise from uphill (or from the wind vector is slope is zero) ________ ________ ________ ________

SIZE INPUT

3 Elapsed time, h ________ ________ ________ ________

CONTAIN INPUT

1 Run option (code) ________ ________ ________ ________

2 Mode of attack (code) ________ ________ ________ ________

6 Burned area target, acres ________ ________ ________ ________

or

7 Line-building rate, ch/h ________ ________ ________ ________

DIRECT-SIZE-CONTAIN LINKED OUTPUT

DIRECT OUTPUT

1	Rate of spread, ch/h				
2	Heat per unit area, Btu/ft^2				
3	Fireline intensity, Btu/ft/s				
4	Flame length, ft				
5	Reaction intensity, Btu/ft^2/min				
6	Effective windspeed, mi/h				
7	Direction of maximum spread, degrees clockwise from uphill				

SIZE OUTPUT

1	Area, acres				
2	Perimeter, ch				
3	Length-to-width ratio				
4	Forward spread distance, ch				
5	Backing spread distance, ch				
6	Maximum width of fire, ch				

CONTAIN OUTPUT

1	Total length of line, ch				
2	Containment time, h				
3	Line-building rate, ch/h				
	or				
3	Final fire size, acres				

SPOT MODULE INPUT/OUTPUT

INPUT

1 Firebrand source (code) ______ ______ ______ ______ ______

2 Mean cover height, ft ______ ______ ______ ______ ______

3 20-ft windspeed, mi/h ______ ______ ______ ______ ______

4 Ridge-to-valley elevation difference, ft ______ ______ ______ ______ ______

5 Ridge-to-valley horizontal distance, mi ______ ______ ______ ______ ______

6 Spotting source location (code) ______ ______ ______ ______ ______

7 * Tree species (code) ______ ______ ______ ______ ______

8 * Torching tree d.b.h., inches ______ ______ ______ ______ ______

9 * Torching tree height, ft ______ ______ ______ ______ ______

10 * Number of trees torching together ______ ______ ______ ______ ______

11 # Continuous flame height, ft ______ ______ ______ ______ ______

OUTPUT

Maximum spotting distance, mi ______ ______ ______ ______ ______

* Input only for firebrand source = 1 (torching tree option).
# Input only for firebrand source = 2 (pile burning option).

DISPATCH MODULE INPUT/OUTPUT

INPUT						
1	Fuel model					
2	Dead fuel moisture, %					
3	Live fuel moisture, %					
4	20-ft windspeed, mi/h (upslope)					
5	Wind adjustment factor					
6	Slope, %					
7	Elapsed time from ignition to attack, h					
8	Line-building rate, ch/h					
OUTPUT						
	Forward rate of spread, ch/h					
	Heat per unit area, Btu/ft^2					
	Fireline intensity, Btu/ft/s					
	Flame length, ft					
	Area at time of attack, acres					
	Perimeter at time of attack, ch					
Head attack:						
	Total length of line, ch (perimeter of burned area)					
	Elapsed time from attack to containment, h					
	Final fire size, acres					
Rear attack:						
	Total length of line, ch (perimeter of burned area)					
	Elapsed time from attack to containment, h					
	Final fire size, acres					

SITE MODULE INPUT/OUTPUT

TIME AND LOCATION

1	Month of burn	________	1	
2	Day of burn	________	2	
3	Latitude, degrees	________	3	IF latitude is known or
	State	________		IF latitude is not known
4	Burn time (2400 hour)	________	4	

FUEL MODEL

5	Fuel model	________	5	
	Percent cover	________		IF two-fuel-model concept
	Other fuel model	________		

FUEL MOISTURE

6	10-h fuel moisture, %	________	6	IF 10-h fuel in model
7	100-h fuel moisture, %	________	7	IF 100-h fuel in model
8	Live herbaceous moisture, %	________	8	IF herbaceous fuel in model
9	Live woody moisture, %	________	9	IF woody fuel in model

SLOPE, ELEVATION, ASPECT

10	Slope, %	________	10	IF slope is known or
	Map scale (code or representative fraction or inches/mi)	________		
	Contour interval, ft	________		
	Map distance, inches	________		IF slope is not known
	Number of contour intervals	________		
11	Elevation of fire location, ft	________	11	
12	Elevation difference between fire location and T/RH readings, ft	________	12	
13	Aspect	________	13	IF slope> 0

TIMBER OVERSTORY DESCRIPTION

14	Crown closure, %	________	14	
15	Foliage present or absent	________	15	
16	Shade tolerant or intolerant	________	16	
17	Dominant tree type (code)	________	17	IF crown closure > 0
18	Average tree height, ft	________	18	
19	Ratio of crown height to tree height	________	19	
20	Ratio of crown height to crown diameter	________	20	

SITE MODULE INPUT/OUTPUT (CON.)

BURN TIME WEATHER

21 Burn time temperature, °F ____________ 21

22 Burn time relative humidity, % ____________ 22

23 Burn time 20-ft windspeed, mi/h ____________ 23

24 Burn time direction of wind vector, degrees clockwise from uphill ____________ 24

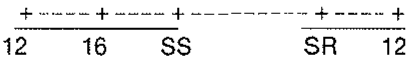
25 Direction for spread calculations, degrees clockwise from uphill or from wind vector if slope = 0 (direction of maximum spread can be calculated) ____________ 25

IF wind > 0

26 Exposure of fuels to the wind (code) ____________ 26

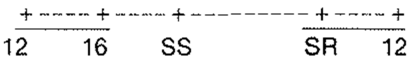
27 Burn time cloud cover, % ____________ 27

IF daytime burn



28 Burn time haziness (code) ____________ 28

IF burn time before 1600
or after sunrise



EARLY AFTERNOON WEATHER

29 Burn day 1400 temperature, °F ____________ 29

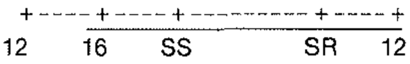
30 Burn day 1400 relative humidity, % ____________ 30

31 Burn day 1400 20-ft windspeed, mi/h ____________ 31

32 Burn day 1400 cloud cover, % ____________ 32

33 Burn day 1400 haziness (code) ____________ 33

IF burn time **not**
between 1200 and 1600



SUNSET WEATHER

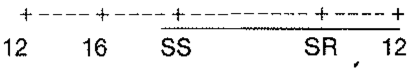
34 Sunset temperature, °F ____________ 34

35 Sunset relative humidity, % ____________ 35

36 Sunset 20-ft windspeed, mi/h ____________ 36

37 Sunset cloud cover, % ____________ 37

IF burn time after sunset
and before 1200



SUNRISE WEATHER

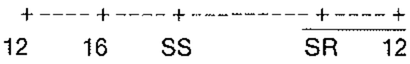
38 Sunrise temperature, °F ____________ 38

39 Sunrise relative humidity, % ____________ 39

40 Sunrise 20-ft windspeed, mi/h ____________ 40

41 Sunrise cloud cover, % ____________ 41

IF burn time after sunrise
and before 1200



MOISTURE INITIALIZATION OPTION

42 Moisture initialization option (code) ____________ 42

FINE FUEL MOISTURE KNOWN FOR THE DAY BEFORE THE BURN

43 Burn day −1 fine fuel moisture, % ____________ 43

IF moisture initialization option = 1

COMPLETE WEATHER AVAILABLE FOR 3 TO 7 DAYS PRIOR TO THE BURN

44 Number of days of weather ____________ 44

		−1	−2	−3	−4	−5	−6	−7	
45	Burn day −x 1400 temperature, °F								45
46	Burn day −x 1400 relative humidity, %								46
47	Burn day −x 1400 20-ft windspeed, mi/h								47
48	Burn day −x 1400 cloud cover, %								48
49	Burn day −x rain amount, hundredths of an inch								49

IF moisture initialization option = 2

INCOMPLETE WEATHER DATA; RAIN THE WEEK BEFORE THE BURN

50 Number of days before the burn that rain occurred ____________ 50

51 Rain amount, hundredths of an inch ____________ 51

52 1400 temperature on the day it rained, °F ____________ 52

53 Sky condition from the day it rained until burn day (code) ____________ 53

IF moisture initialization option = 3

INCOMPLETE WEATHER DATA; NO RAIN THE WEEK BEFORE THE BURN; WEATHER PATTERN HOLDING

No additional input

IF moisture initialization option = 4

INCOMPLETE WEATHER DATA; WEATHER PATTERN CHANGING

54 Burn day −1 1400 temperature, °F ____________ 54

55 Burn day −1 1400 relative humidity, % ____________ 55

56 Burn day −1 1400 20-ft windspeed, mi/h ____________ 56

57 Burn day −1 1400 cloud cover, % ____________ 57

58 Weather condition prior to burn day −1 (code) ____________ 58

IF moisture initialization option = 5

SITE MODULE INPUT/OUTPUT (CON.)

INTERMEDIATE VALUES

Time of sunset __________

Time of sunrise __________

Wind adjustment factor __________

Fuel surface temperature, °F __________

Fuel level relative humidity, % __________

Percent shade __________

Fine dead fuel moisture, % __________

BASIC INPUT

Fuel model __________

1-h fuel moisture, % __________

10-h fuel moisture, % __________

100-h fuel moisture, % __________

Live herbaceous fuel moisture, % __________

Live woody fuel moisture, % __________

Midflame windspeed, mi/h __________

Slope, % __________

Direction of wind vector, degrees clockwise from uphill (or from the wind vector if slope is zero) __________

Direction for spread calculations, degrees clockwise from uphill (or from the wind vector if slope is zero) __________

OUTPUT

Rate of spread, ch/h __________

Heat per unit area, Btu/ft^2 __________

Fireline intensity, Btu/ft/s __________

Flame length, ft __________

Reaction intensity, Btu/ft^2/min __________

Effective windspeed, mi/h __________

Direction of maximum spread, degrees clockwise from uphill __________

DIRECT INPUT VARIABLES

Line No.	Value	Legal values	Range OK?	Comments
1	Fuel model	1-99 QUIT	n	1-13 for standard NFFL models. 14-99 for custom models from file. 0 indicates that you want to use the two-fuel-model concept. You will be asked for DOMINANT FUEL MODEL PERCENT COVER OTHER FUEL MODEL. Can type QUIT to terminate DIRECT input.
2	1-h fuel moisture, %	1-60	y	Required input. All fuel models have 1-h fuels.
3	10-h fuel moisture, %	1-60	y	Input only for fuel models that have 10-h fuels.
4	100-h fuel moisture, %	1-60	y	Input only for fuel models that have 100-h fuels.
5	Live herbaceous moisture, %	30-300	y	Input only for fuel models that have live herbaceous fuels. The input value is used to determine the amount of fuel load that is transferred from the live herbaceous class to the 1-h dead class for **dynamic** custom fuel models.
6	Live woody moisture, %	30-300	y	Input only for fuel models that have live woody fuel.
7	Midflame windspeed, mi/h	0-99	y	
8	Slope, %	0-100	y	
9	Direction of the wind vector, degrees	0-360	y	Wind direction is specified as degrees clockwise from upslope. This is the direction that the wind is blowing **to,** the direction that the wind is pushing the fire. Enter 0 if the wind is blowing directly upslope. If slope = 0 or windspeed = 0, the question is not asked, and wind direction is set to 0.
10	Direction for the spread calculations, degrees	0-360	y	You will be asked if you want predictions only for the direction of maximum spread. If you answer **yes**, spread direction is not requested. If windspeed, slope, and wind direction are all nonzero values, the direction of maximum spread will be calculated. Otherwise, the direction of maximum spread is 0. If you answer **no**, spread direction is requested. Spread direction is specified as degrees clockwise from upslope unless there is no slope; then it is specified as degrees clockwise from the wind vector.

SIZE INPUT VARIABLES

Line No.	Value	Legal values	Range OK?	Comments
1	Rate of spread, ch/h	0.1-500 QUIT	y	Forward rate of spread. This is a user input if SIZE is used as an independent module. If SIZE is linked to DIRECT or SITE, then the calculated rate of spread is used. Can type QUIT to terminate SIZE input.
2	Effective windspeed, mi/h	0-99	y	Effective windspeed accounts for the combined effects of slope and midflame windspeed. This is a user input if SIZE is used as an independent module. If SIZE is linked to DIRECT or SITE, then the calculated effective windspeed is used.
3	Elapsed time, h	0.5-8	y	This is the elapsed time from ignition. During this time period, conditions are assumed to be uniform.

CONTAIN INPUT VARIABLES

Line No.	Value	Legal values	Range OK?	Comments
1	Run option	1-2 QUIT	n	Code input: 1 = compute line construction rate 2 = compute burned area Can type QUIT to terminate CONTAIN input.
2	Mode of attack	1-2	n	Code input: 1 = head 2 = rear
3	Rate of spread, ch/h	0.1-500	y	Forward rate of spread. If CONTAIN is used as an independent module, this is a direct input. If CONTAIN is linked to DIRECT or SITE and SIZE, then the calculated rate of spread is used as input to CONTAIN.
4	Initial fire size, acres	0.1-100	y	The fire shape at this time should be roughly elliptical. If CONTAIN is used as an independent module, then this is a direct input. If CONTAIN is linked to DIRECT or SITE and SIZE, the calculated area is used as input to CONTAIN.
5	Length-to-width ratio	1-7	y	This describes the shape of the elliptical fire. If CONTAIN is used as an independent module, then this is a direct input. If CONTAIN is linked to DIRECT or SITE and SIZE, then the calculated length-to-width ratio is used as input to CONTAIN.
6	Burned area target, acres	0.1-2000	y	Input only for run option 1. The target area at containment. The required line-building rate is calculated.
7	Line-building rate, ch/h	0.1-200	y	Input only for run option 2. Use total line-building rate for fire. The final fire size is calculated.

SPOT INPUT VARIABLES

Line No.	Value	Legal values	Range OK?	Comments
1	Firebrand source	1-2 QUIT	n	Code input: 1 = torching tree 2 = burning pile 3 = wind-driven surface fire (not yet in the program) 4 = running crown fire (We can't do this. This is in the list to emphasize that a running crown fire differs from torching trees.) Can type QUIT to terminate SPOT input.
2	Mean cover height, ft	0-300	y	For open cover, divide average tree height by 2. Enter 0 for short grass, bare ground, or water.
3	20-ft windspeed, mi/h	0-99	y	20 ft above the treetops.
4	Ridge/valley elevation difference, ft	0-4000	y	Used as multiples of 1000 in the calculations.
5	Ridge/valley horizontal distance, mi	0-4	y	Map distance.
6	Spotting source location	0-3	n	Code input: 0 = midslope, windward side 1 = valley bottom 2 = midslope, leeward side 3 = ridgetop
7	Tree species	1-6	n	Input only for torching tree option. Code input: 1 = Engelmann spruce 2 = Douglas-fir, subalpine fir 3 = hemlock 4 = ponderosa pine, lodgepole pine 5 = white pine 6 = balsam fir, grand fir
8	Torching tree d.b.h., inches	5-40	y	Input only for torching tree option.
9	Torching tree height, ft	10-300	y	Input only for torching tree option.
10	Number of trees torching	1-30	y	Input only for torching tree option.
11	Continuous flame height, ft	1-100	y	Input only for pile burning option.

DISPATCH INPUT VARIABLES*

Line No.	Value	Legal values	Comments
1	Fuel model	1-99 QUIT	1-13 for standard fuel models. 14-99 for custom fuel models. Two-fuel-model concept not allowed. Can type QUIT to terminate DISPATCH input.
2	Dead fuel moisture, %	1-60	1-h, 10-h, and 100-h fuels are all assigned the same fuel moisture.
3	Live fuel moisture, %	30-300	Live herbaceous and live woody fuel are assigned the same fuel moisture. This input is always requested, whether or not there are live fuels in the fuel model being used.
4	20-ft windspeed, mi/h	0-99	Windspeeds are generally forecast for the 20-ft level. Wind is assumed to be blowing uphill.
5	Wind adjustment factor	0.1-1	This value can be looked up on a table. Exposure to the wind depends on canopy cover, topography, and possibly fuel model.
6	Percent slope	0-100	
7	Elapsed time from ignition to attack, hours	0.1-8	The fire should be spreading steadily during this time. This does not include the time that an ignition smolders before it "takes off."
8	Line-building rate, ch/h	0.1-200	Use total line-building rate for the fire. The final fire size is calculated for both head and rear attack.

*Ranges are not allowed for any input value.

SITE INPUT VARIABLES*

<table>
<tr><th>Line No.</th><th>Value</th><th>Legal values</th><th>Comments</th></tr>
<tr><td>1</td><td>Month of year</td><td>1-12
QUIT</td><td>Can type QUIT to terminate SITE input.</td></tr>
<tr><td>2</td><td>Day of burn</td><td>1-31</td><td>No error checking for the maximum number of days in each month.</td></tr>
<tr><td>3</td><td>Latitude, degrees
State</td><td>0-90</td><td>You will be asked if you know the latitude. If Y, input value. If N, enter 2-letter State abbreviation and average latitude for State will be assigned.</td></tr>
<tr><td>4</td><td>Burn time (2400-hour)</td><td>0-2359</td><td>This is solar time.</td></tr>
<tr><td>5</td><td>Fuel model</td><td>1-99</td><td>1-13 for standard NFFL models.
14-99 for custom models from file.
0 indicates that you want to use the two-fuel-model concept. You will be asked for
DOMINANT FUEL MODEL
PERCENT COVER
OTHER FUEL MODEL.</td></tr>
<tr><td>6</td><td>10-h fuel moisture, %</td><td>1-60</td><td>Input only for fuel models that have 10-h fuels.
If value is not known, it will be estimated for you. You must tell whether it will be wetter or drier than the 1-h moisture and by what percentage.</td></tr>
<tr><td>7</td><td>100-h fuel moisture, %</td><td>1-60</td><td>Input only for fuel models that have 100-h fuels.
If value is not known, it will be estimated for you. You must tell whether it will be wetter or drier than the 1-h moisture and by what percentage.</td></tr>
<tr><td>8</td><td>Live herbaceous moisture, %</td><td>30-300</td><td>Input only for fuel models that have live herbaceous fuels. The input value is used to determine the amount of fuel load that is transferred from the live herbaceous class to the 1-h dead class for dynamic custom fuel models.</td></tr>
<tr><td>9</td><td>Live woody moisture, %</td><td>30-300</td><td>Input only for fuel models that have live woody fuel.</td></tr>
<tr><td>10</td><td>Slope, %</td><td>0-100</td><td>Input value if slope is known.</td></tr>
<tr><td></td><td>Map scale</td><td>0-8</td><td>Slope not known, code input for map scale:
<table>
<tr><th>Representative fraction</th><th>Inches/mi</th></tr>
<tr><td>0 = direct entry</td><td></td></tr>
<tr><td>1 = 1:253,440</td><td>1/4</td></tr>
<tr><td>2 = 1:126,720</td><td>1/2</td></tr>
<tr><td>3 = 1:63,360</td><td>1</td></tr>
<tr><td>4 = 1:31,680</td><td>2</td></tr>
<tr><td>5 = 1:24,000</td><td>2.64</td></tr>
<tr><td>6 = 1:21,120</td><td>3</td></tr>
<tr><td>7 = 1:15,840</td><td>4</td></tr>
<tr><td>8 = 1:7,920</td><td>8</td></tr>
</table>
If direct entry, choose representative fraction or inches per mile as method of entry and input value.</td></tr>
<tr><td></td><td>Contour interval, ft</td><td>10-500</td><td>Vertical distance between contour intervals on a contour map.</td></tr>
<tr><td></td><td>Map distance, inches</td><td>0.1-10</td><td>Horizontal measurement between the two designated points where slope is to be calculated.</td></tr>
<tr><td></td><td>Number of contour intervals</td><td>1-100</td><td>Number of contour intervals between the two designated points where slope is to be calculated.</td></tr>
</table>

---

*Ranges are not allowed for any input variable.

SITE INPUT VARIABLES (CON.)

Line No.	Value	Legal values	Comments
11	Elevation of fire location, ft	0-12000	
12	Elevation difference between fire and T/RH readings more than 1,000 ft?	Y-N	Used to adjust T/RH readings from elevation of reading to elevation of fire. Adjustment can be made only if air is well-mixed between the two locations (no inversions).
	Elevation difference, ft	1000-9000	You must tell if the fire site is at higher location and how much difference there is.
13	Aspect	N,NE,E,SE, S,SW,W,NW,	Input only if slope is greater than zero.
14	Crown closure, %	0-100	Enter as if there were foliage. Lines 15 through 20 are input only if crown closure is greater than zero.
15	Foliage present?	Y-N	
16	Shade tolerant?	Y-N	Are the trees in the overstory shade tolerant or not?
17	Dominant tree type	1-2	Code input: 1 = Coniferous 2 = Deciduous
18	Average tree height, ft	10-300	
19	Ratio of crown height to tree height	0.1-1	
20	Ratio of crown height to crown diameter	0.2-5	
21	Burn time air temperature, °F	33-120 QUIT	Can type QUIT to terminate SITE input.
22	Burn time relative humidity, %	1-100	If you don't know the value and burn time is before 1200 or after 1600, relative humidity can be estimated for you. An estimate can be made only if no frontal passage or inversion is expected between 1400 and burn time. If burn time is between 1200 and 1600, a value must be entered.
23	Burn time 20-ft wind, mi/h	0-99	
24	Burn time direction of wind vector, degrees	0-360	Wind direction is specified as degrees clockwise from upslope. This is the direction that the wind is blowing **to**, the direction that the wind is pushing the fire. Enter 0 if the wind is blowing directly upslope. If slope = 0 or windspeed = 0, the question is not asked.
25	Direction for spread calculations, degrees	0-360	You will be asked if you want predictions only for the direction of maximum spread. If you answer **yes**, spread direction is not requested. If windspeed, slope, and wind direction are all nonzero values, the direction of maximum spread will be calculated. Otherwise, the direction of maximum spread is 0. If you answer **no**, spread direction is requested. Spread direction is specified as degrees clockwise from upslope unless there is no slope; then it is specified as degrees clockwise from the wind vector.

SITE INPUT VARIABLES (CON.)

Line No.	Value	Legal values	Comments
26	Exposure of fuels to wind	0-4	Code input: 0 = don't know 1 = exposed 2 = partially sheltered 3 = fully sheltered—open stand 4 = fully sheltered—closed stand If you answer 0, you will be asked a series of questions to help determine exposure. The wind adjustment factor is printed with the intermediate variables.
27	Burn time cloud cover, %	0-100	Required input for daytime burns.
28	Burn time haziness	1-4	Required if burn time before 1600 or after sunrise. Code input: 1 = very clear sky 2 = average clear forest atmosphere 3 = moderate forest blue haze 4 = dense haze or light to moderate smoke Dense smoke should be treated as 100% **cloud cover.**
			Early Afternoon Weather
			Questions 29-33 are required if burn time is **not** 1200-1600. If burn time is between 1200 and 1600, 1400 conditions are assumed to be the same as burn time conditions.
29	Burn day 1400 temperature, °F	33-120	
30	Burn day 1400 relative humidity, %	1-100	Cannot be estimated.
31	Burn day 1400 20-ft windspeed, mi/h	0-99	
32	Burn day 1400 cloud cover, %	0-100	
33	Burn day 1400 haziness	1-4	Code input: 1 = very clear sky 2 = average clear forest atmosphere 3 = moderate forest blue haze 4 = dense haze or light to moderate smoke Dense smoke should be treated as 100% cloud cover.
			Sunset Weather
			Questions 34-37 are required if burn time is between sunset and 1200 noon.
34	Sunset temperature, °F	33-120	
35	Sunset relative humidity, %	1-100	Can be estimated if no frontal passage or inversion is expected between 1400 and sunset.
36	Sunset 20-ft windspeed, mi/h	0-99	
37	Sunset cloud cover, %	0-100	
			Sunrise Weather
			Questions 38-41 are required if burn time is between sunrise and 1200 noon.
38	Sunrise temperature, °F	33-120	
39	Sunrise relative humidity, %	1-100	Can be estimated if no frontal passage or inversion is expected between 1400 and sunrise.
40	Sunrise 20-ft windspeed, mi/h	0-99	
41	Sunrise cloud cover, %	0-100	

SITE INPUT VARIABLES (CON.)

Line No.	Value	Legal values	Comments
42	Moisture initialization option	1-5	Code input: 1 = fine fuel moisture known the day before the burn. 2 = complete weather available for 3 to 7 days prior to the burn. 3 = incomplete weather data and it rained the week before the burn. 4 = incomplete weather data, no rain the week before the burn, and weather pattern is stable (no additional input). 5 = incomplete weather data; weather pattern changing.
	Fine Fuel Moisture Known for the Day Before the Burn		
43	Burn day −1 fine fuel moisture, %	1-100	Required for initialization **option 1.**
	Complete Weather Available for 3 to 7 Days Prior to the Burn		
			Questions 44-49 required for initialization **option 2.**
44	No. days of weather data	3-7	
45	Burn day −x 1400 temperature, °F	33-120	Lines 45 through 49 are input for the number of days specified in line 44. x indicates the number of days prior to burn day.
46	Burn day −x 1400 relative humidity, %	1-100	
47	Burn day −x 1400 20-ft windspeed, mi/h	0-99	
48	Burn day −x 1400 cloud cover, %	0-100	
49	Burn day −x rain amount, hundredths of an inch	0-400	
	Incomplete Weather Data; Rain the Week Before the Burn		
			Questions 50-53 required for initialization **option 3**
50	No. days before burn that rain occurred	1-7	
51	Rain amount, hundredths of an inch	0-400	
52	1400 temperature on the day it rained, °F	33-120	
53	Sky condition from the day it rained until burn day	1-3	Code input: 1 = clear 2 = cloudy 3 = partly cloudy
	Incomplete Weather Data; No Rain the Week Before the Burn; Weather Pattern Holding		
			No additional input is required for initialization **option 4.**

Incomplete Weather Data; Weather Pattern Changing

Questions 54-58 required for initialization **option 5**.

Line No.	Value	Legal values	Comments
54	Burn day −1 1400 temperature, °F	33-120	
55	Burn day −1 1400 relative humidity, %	1-100	
56	Burn day −1 1400 20-ft windspeed, mi/h	0-99	
57	Burn day −1 1400 cloud cover, %	0-100	
58	Weather condition prior to burn day −1	1-3	Code input: 1 = hot and dry 2 = cool and wet 3 = between 1 and 2

SITE INTERMEDIATE VARIABLES

Value	Legal values	Comments
Time of sunset	Calculated	Local sun time. Program won't run unless sunset is after 1600.
Time of sunrise	Calculated	Local sun time.
Wind adjustment factor	Calculated	Based on exposure to the wind (line 26).
Fuel surface temperature, °F	Calculated	Burn time temperature and relative humidity are adjusted for solar radiation and converted to fuel level.
Fuel level relative humidity, %	Calculated	
Percent shade	Calculated	From cloud cover and canopy cover (not haze).
Fine dead fuel moisture, %	Calculated	1-h fuel moisture. Most of the SITE input variables are used to calculate this value.

APPENDIX C: FUEL MODEL FILES

The only aspect of BEHAVE that requires specific understanding of how a computer works is that of fuel model files. This appendix describes the fuel model file and how it is used. This appendix also explains the terminology associated with fuel model files: file name, file description, password, fuel model name, fuel model parameters.

The link among the BEHAVE programs is the fuel model file as illustrated in figure 2. The file is an area in the computer where custom fuel models are stored. A number of fuel models will be stored in a single file. Each user can have one or more personal files, or a file can be accessed by many users. The "Fuel Model File Record" and "Fuel Model Parameter Record" sheets in exhibits 23 and 24 are designed to help you record information about your fuel model files. Refer to the examples in exhibits 25 and 26 for the following discussion.

You assign the file name (for example, ANDREWS.DAT) at the time the file is created by either the NEWMDL or TSTMDL program. The computer uses this name to define a location in its memory. You must specify the name of the file before you use a custom fuel model or add another fuel model to the file.

The name that you assign to your fuel model file depends on the computer that you are using. A file name that is valid on one computer may not be on another. For example, ANDREWS.DAT is valid on the Intermountain Fire Sciences Laboratory's minicomputer, but will cause an unrecoverable fatal error on the Fort Collins Computer Center (FCCC) computer. The BEHAVE programs allow up to 12 characters for a file name and do not check for validity. It is up to you to name your files properly. Check with your computer specialist for clarification. As an example, exhibit 27 illustrates conventions for (naming files for) the FCCC Univac 1100.

You can use up to 72 characters for the **file description** (for example, EXAMPLE FOR APPENDIX C). This is for reference and means nothing to the computer. You type in the description when you create a file. The description is printed when you use the file. The file description helps you keep track of which file you are using. You also assign a four-character **password** (for example, LOOK) at the time the file is created. The password must be typed in when the file is changed. Telling other BEHAVE users your file name, but not the password, allows them to use your custom fuel models without being able to change the file. The password has no meaning to FIRE1 because files can never be changed by that program.

The numbers that define a fuel model are the **fuel model parameters** as seen in exhibit 26 (1 HR LOAD = 2.00 T/A, DEPTH = 1.0 FT, etc.). These values are stored in the file along with a user-assigned fuel model number and name. Wind adjustment factor is included with the fuel model parameters because it is a constant that is fuel model-dependent.

The **fuel model number** can be anything from 14 to 99. The numbers 1 through 13 are reserved for the standard NFFL fuel models. Because you must specify the name of the file before you use a custom fuel model, there is no problem if many users have a fuel model 14, for example.

You assign a 32-character **fuel model name** for your own reference (for example, the name of fuel model 1 is SHORT GRASS; the name of your fuel model 27 might be STRAWBERRY RIDGE).

FUEL MODEL FILE RECORD

FILE NAME ______________________________ PASSWORD ________________

(FCCC qualifier) ______________________________

FILE DESCRIPTION ____

FUEL MODELS:

NUMBER	NAME

Exhibit 23.—Fuel model file form for duplication.

FUEL MODEL PARAMETER RECORD

FILE NAME ______________________________

FUEL MODEL NUMBER __________ NAME ______________________________

STATIC _____
DYNAMIC _____

LOAD (T/AC)		S/V RATIOS		OTHER	
1 HR	______	1 HR	______	DEPTH (FT)	______
10 HR	______	LIVE HERB	______	HEAT CONTENT (BTU/LB)	______
100 HR	______	LIVE WOODY	______		
LIVE HERB	______	S/V = (SQFT/CUFT)		EXT MOISTURE (%)	______
LIVE WOODY	______				

WIND ADJUSTMENT FACTOR FOR FULLY EXPOSED FUELS ______

FUEL MODEL NUMBER __________ NAME ______________________________

STATIC _____
DYNAMIC _____

LOAD (T/AC)		S/V RATIOS		OTHER	
1 HR	______	1 HR	______	DEPTH (FT)	______
10 HR	______	LIVE HERB	______	HEAT CONTENT (BTU/LB)	______
100 HR	______	LIVE WOODY	______		
LIVE HERB	______	S/V = (SQFT/CUFT)		EXT MOISTURE (%)	______
LIVE WOODY	______				

WIND ADJUSTMENT FACTOR FOR FULLY EXPOSED FUELS ______

Exhibit 24.—Fuel model parameter form for duplication.

FUEL MODEL FILE RECORD

FILE NAME ANDREWS.DAT PASSWORD LOOK

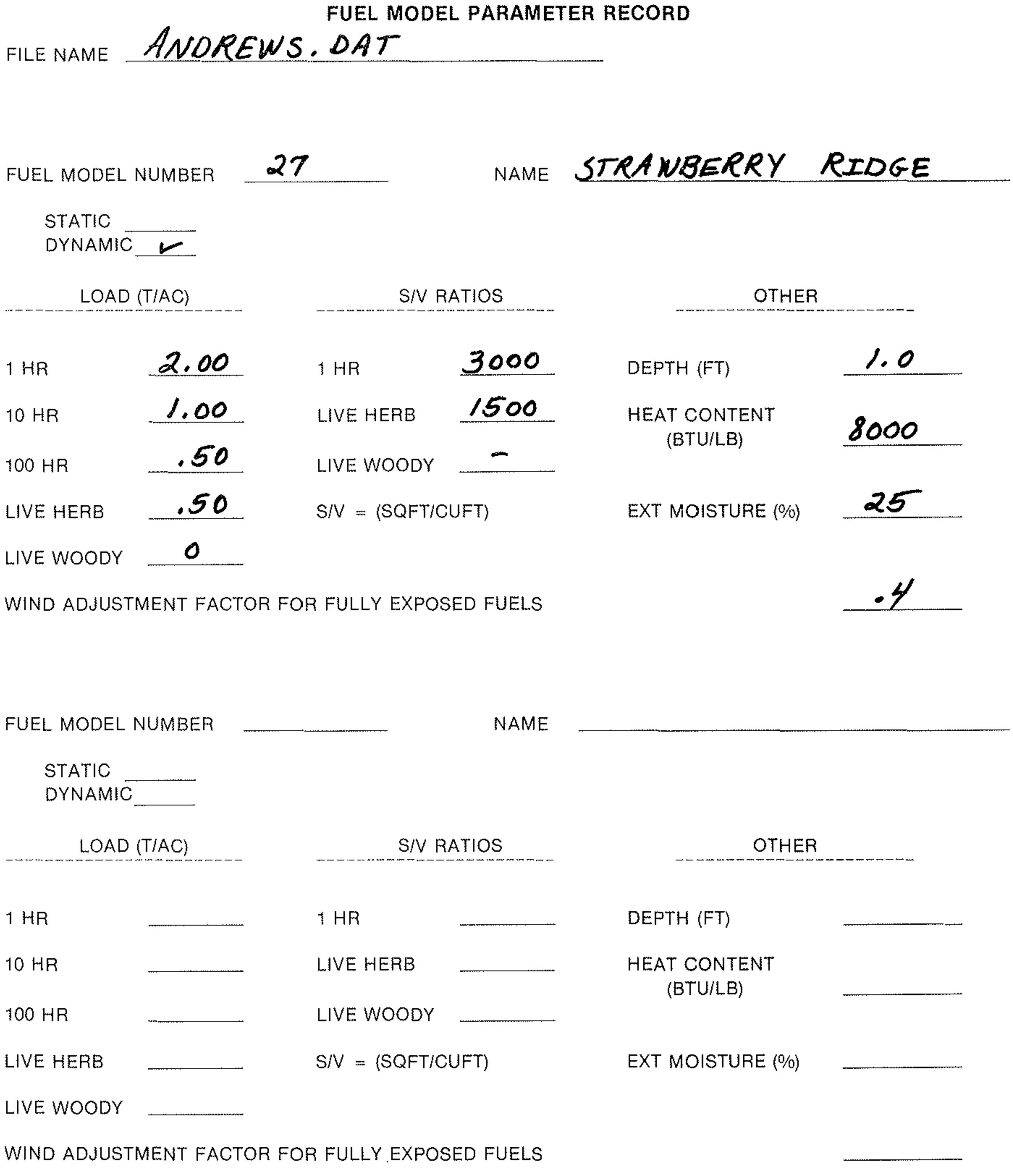
(FCCC qualifier) –

FILE DESCRIPTION EXAMPLE FOR APPENDIX C

FUEL MODELS:

NUMBER	NAME
14	SHORT GRASS / LITTER
89	2-YR SLASH/BRUSH
27	STRAWBERRY RIDGE

Exhibit 25.—Example, fuel model file record.



FUEL MODEL PARAMETER RECORD

FILE NAME ANDREWS.DAT

FUEL MODEL NUMBER 27 NAME STRAWBERRY RIDGE

STATIC
DYNAMIC ✓

LOAD (T/AC)

1 HR 2.00
10 HR 1.00
100 HR .50
LIVE HERB .50
LIVE WOODY 0

S/V RATIOS

1 HR 3000
LIVE HERB 1500
LIVE WOODY –
S/V = (SQFT/CUFT)

OTHER

DEPTH (FT) 1.0
HEAT CONTENT (BTU/LB) 8000
EXT MOISTURE (%) 25

WIND ADJUSTMENT FACTOR FOR FULLY EXPOSED FUELS .4

FUEL MODEL NUMBER NAME

STATIC
DYNAMIC

LOAD (T/AC)

1 HR
10 HR
100 HR
LIVE HERB
LIVE WOODY

S/V RATIOS

1 HR
LIVE HERB
LIVE WOODY
S/V = (SQFT/CUFT)

OTHER

DEPTH (FT)
HEAT CONTENT (BTU/LB)
EXT MOISTURE (%)

WIND ADJUSTMENT FACTOR FOR FULLY EXPOSED FUELS

Exhibit 26.—Example, fuel model (parameter) record.

You can enter a file name up to 12 characters, but don't use the special characters "." or "". The qualifier, which is part of the RUN command (@RUN run-name,account-number,qualifier), is automatically used as part of the file name (qualifier*file-name). But* ***don't*** *type the qualifier when the program asks for the file name.*

Since the files that you create will be public (accessible to anyone), we suggest that you use a qualifier other than BEHAVE to lessen the chance for duplicate file names. If you do pick a name that someone else is already using, you will not be able to alter their file without knowing the password. Just pick another file name.

If you use a different qualifier when you want to use a file than you did when you created the file, you will get a "FILE DOES NOT EXIST" or a "THIS IS A NEW FILE" message even if you typed the file name the same both times. You should decide on a qualifier and stick to it.

Exhibit 27.—Comments on fuel model file naming conventions for the Fort Collins Computer Center (FCCC) Univac 1100.

The format of the fuel model file is given in exhibit 28. The letter "A" is written in the file to indicate that the format is for the 1984 version of BEHAVE. If the format is changed for future updates of the system, the letter will change. It is possible that prediction models added to BEHAVE will require constants to be stored for each fuel model.

"Header" Record

Column(s)	Read format	Data recorded
1 - 4	A4	Password
5 - 6	2X	Blank
7 - 78	18A4	File description
79	1X	Blank
80	A1	A = format indicator

Fuel Model Records

Column(s)	Read format	Data recorded
1 - 2	I2	Fuel model number
3	F1.1	Wind reduction factor
4 - 35	8A4	Fuel model name
36 - 39	F4.2	1-h load
40 - 43	F4.2	10-h load
44 - 47	F4.2	100-h load
48 - 51	F4.2	Live herbaceous load
52 - 55	F4.2	Live woody load
56 - 59	F4.2	Fuel bed depth
60 - 64	F5.0	Heat content
65 - 66	F2.0	Extinction moisture
67 - 70	F4.0	1-h S/V ratio
71 - 74	F4.0	Live herbaceous S/V ratio
75 - 78	F4.0	Live woody S/V ratio
79	A1	A = format indicator
80	I1	0 = static 1 = dynamic

Exhibit 28.—Fuel model file structure.

Fuel model files are created using the NEWMDL and TSTMDL programs of the FUEL subsystem of BEHAVE (Burgan and Rothermel 1984). Fuel models can be added to, deleted from, or replaced in a file using the NEWMDL and TSTMDL programs. Fuel models can be drawn from a file using the TSTMDL and FIRE1 programs. It is important to note that the only interaction that the FIRE1 program has with a file is getting a fuel model from the file.

The FIRE1 keyword CUSTOM allows you to specify the name of the file that you want to access. You can then list the numbers and names of the fuel models in the file or look at the parameters for a specific model. Once a fuel model file is attached to a FIRE1 run using CUSTOM, you can reference its models by number just like the standard 13. You cannot change the file (add, delete, or replace models) or change the parameters of a fuel model using the FIRE1 program.

Fuel models are "built" using the programs NEWMDL and TSTMDL. The keyword MODEL in NEWMDL and FUEL followed by LIST in TSTMDL allow you to see the current parameters for the fuel model that you are working on. These parameters are in "working" memory and will "go away" when you terminate the run unless you use the keyword FILE to save your fuel model in the fuel model file.

When a fuel model is loaded from a file by TSTMDL, it is still in the file and the parameters are **also** in working memory where they can be changed. You can then use the keyword FILE to replace the original fuel model in the file with the revised model. Or you can RENUMBER the fuel model and then add it to the file as a new fuel model.

TSTMDL also allows you to load an NFFL fuel model into working memory as a custom model. You can change the parameters and FILE it for later use as a custom model.

Only one fuel model can be in working memory at a time. A replacement is made, either by using the keyword FUEL followed by NEW or NFFL or by using the keyword FILE to load a fuel model from the file. When a fuel model is loaded, the one that was previously in the working area is lost unless you saved it in a file.

APPENDIX D: BEHAVE AND THE NATIONAL FIRE-DANGER RATING SYSTEM

Special attention is given to the National Fire-Danger Rating System (NFDRS) (Deeming and others 1977) because it is a widely used national system and because the relative application of NFDRS and BEHAVE is sometimes confused. NFDRS and BEHAVE are both used to evaluate fire potential, but in different ways. They are complementary systems, each with its own niche in fire management applications. NFDRS utilizes standardized weather observations to produce indexes of seasonal fire danger. BEHAVE is for making site-specific fire behavior predictions, with the resolution of the input based on the application. Both BEHAVE and NFDRS are flexible, and can be adapted to a wide range of fire management needs. Proper application depends on the user understanding some of the basic principles of the two systems.

NFDRS became a national system in 1972 and was revised in 1978. Although nomograms for fire behavior calculations were made available in 1976, there were no guidelines for determining input and interpreting output. The nomograms alone are not a fire behavior prediction "system." A manual system for predicting fire behavior evolved through the FBO course and is now published as "How to Predict the Spread and Intensity of Forest and Range Fires" (Rothermel 1983) 11 years after the NFDRS was adopted. Because NFDRS was available before a formal fire behavior prediction system existed, fire danger indexes were sometimes used as specific estimators of fire behavior. This misuse of the NFDRS is understandable, but it has led to confusion regarding the difference between fire danger rating and fire behavior prediction. The availability of BEHAVE as a national fire behavior prediction system should eliminate the problem.

In order to describe the difference between NFDRS and BEHAVE, I will discuss the resolution of the input values, differences in the equations used in the calculations, and interpretation of the output. This is followed by a discussion of fuel models.

Input

Although both NFDRS and BEHAVE ultimately need a fuel model, fuel moisture, windspeed, and slope to estimate fire behavior, the way this input is obtained is quite different. NFDRS requires that standard weather observations be taken once each day. Calculation of daily fire danger indexes is based on this weather, calculated values from previous days, and fixed descriptors of the fire danger area. Often, only a single fuel model and slope class are used to describe a large area. Fuel moistures are calculated from the measured weather. This seasonal calculation of fuel moisture is one of the prime features of NFDRS, allowing it to be an indicator of fire danger.

On the other hand, determination of input values to BEHAVE can vary with the information that is available. For example, you can select one of the 13 NFFL models, a custom model, or the two-fuel-model concept. And fine dead fuel moisture can be entered directly based on a guess or on a measurement in the field, or it can be calculated from the moisture model in SITE. The burden is on the user to make the decision, matching the resolution of BEHAVE input to the application.

Calculations

Both BEHAVE and NFDRS are based on the same mathematical model (Rothermel 1972). Nevertheless, the equations were significantly modified as they are used in the NFDRS (Andrews and Morris in preparation). The adjustments were intended to make the NFDRS indexes better reflect the seasonal trend. The original model, with modifications by Albini (1976b), is used in BEHAVE and other fire behavior processors. This mathematical model, with additional minor modifications, is also used to calculate Spread Component (SC) in NFDRS. The equations used for Energy Release Component (ERC) are similar to those used in BEHAVE for heat per unit area. However, there is a major difference. To focus more attention on heavy fuels and thus seasonal drying and wetting trends, the weighting is done by loading rather than surface-area-to-volume ratio. Therefore, although ERC and heat per unit area are related, there is a significant difference in their calculation.

In BEHAVE, flame length is calculated from rate of spread and heat per unit area. Correspondingly in NFDRS, Burning Index (BI) is calculated from SC and ERC. Therefore BI is related to flame length, but because of the differences in the calculations they are not the same. It has been said that Burning Index is equal to 10 times the flame length because the 20 NFDRS fuel models were designed to make it so, not because the equations for BI are the same as those used to calculate flame length in BEHAVE. There is a relationship, not an equality. The NFDRS Burning Index is an **index** that rates fire danger (**related to** potential flame length). BEHAVE produces flame length predictions.

Output

NFDRS indexes and components are relative measures of fire potential. Therefore to be meaningful they have to be related to something, usually values from earlier in the season or from previous seasons. This is why proper use of NFDRS depends so heavily on archived weather data. The fire danger class is the bottom line for most applications of NFDRS. These values are based on an analysis of indexes calculated using historical weather.

If there are changes in the NFDRS, all historical calculations must be redone. The impact on users, in both time and money, means that changes are made to NFDRS only when the improvements make the tradeoff worthwhile. Consistency is of primary concern. On the other hand, BEHAVE can more easily be updated as new research becomes available.

The systems are designed quite differently because of their level of application. NFDRS has rigid rules on collecting and entering weather data to make daily calculations. BEHAVE is more flexible and can be used in a variety of ways. Interpretation of results is vital to both NFDRS and BEHAVE.

Application of NFDRS and BEHAVE

NFDRS finds its niche in fire management in broad area planning where seasonal trends and year-to-year comparisons are necessary. NFDRS is well suited for **planned** fire management actions: presuppression, suppression, detection, and prevention. BEHAVE is used for site-specific fire behavior predictions where estimates of actual fire behavior are needed. For example, NFDRS indexes might be used in deciding whether a newly reported fire will be declared a wildfire or a prescribed fire. And for a wildfire, a confine, contain, or control decision might be based on either NFDRS or fire behavior predictions. Fire behavior predictions, however, should be used for projecting the growth of the fire.

Fuel Models

NFDRS utilizes a set of 20 standard fuel models; BEHAVE has a different set of 13 standard (NFFL) fuel models. This situation occurred because the equations that use the fuel models are different for NFDRS and BEHAVE.

A fuel model is a **model**. It is a list of numbers that represent the fuel for a set of equations. Therefore, designing a fuel model involves much more than doing a fuel inventory. It is an iterative process that requires using a fuel model with the equations to obtain fire behavior predictions, comparing predictions to observed or expected fire behavior, adjusting the fuel model parameters, and so on. If the equations are different (as are those for NFDRS and BEHAVE), then the final fuel model will necessarily be different. Therefore a fuel model is a direct function of the equations that use it. Fuel models for both BEHAVE and NFDRS are designed using the same process. The 20 NFDRS fuel models were designed as part of a research project. Half of the BEHAVE system is devoted to helping users design their own fire behavior fuel models (Burgan and Rothermel 1984). The question is not "which is the 'right' **fuel model**?" but rather "which **system** is best suited to the job at hand?"

Anderson (1982) presented a "Physical Description Similarity Chart of NFDRS and FBO Fuel Models." He gives a correspondence between the 20 NFDRS fuel models and the 13 NFFL fire behavior fuel models (fig. 21). The correlation is primarily based on physical description of the fuel, as indicated by the title of the chart. The two sets of fuel models were correlated by rankings of rate of spread and intensity. The actual calculated values differed. In addition, the correlations were based on severe burning conditions. The correspondence at less severe levels would likely be quite different.

Do not substitute a similar NFFL fuel model for a familiar NFDRS fuel model or use NFDRS fuel models in BEHAVE. To disabuse you of this idea, I will show what happens when one uses NFDRS fuel models in fire behavior calculations (BEHAVE). I will also compare "similar" NFDRS and NFFL fuel models.

To make these comparisons, we must convert Spread Component (SC) to rate of spread, Energy Release Component (ERC) to heat per unit area, and Burning Index (BI) to flame length. Because SC is in ft/min, it is divided by 1.1 to get rate of spread in ch/h. ERC is multiplied by 25 to get heat per unit area (Btu/ft^2). BI is divided by 10 to get flame length (ft) (Deeming and others, 1977, p. 1). This conversion is done only for purposes of illustration. As stated earlier, the basic equations in NFDRS and BEHAVE are different.

PHYSICAL DESCRIPTION SIMILARITY CHART OF NFDRS AND FBO FUEL MODELS

NFDRS MODELS REALINED TO FUELS CONTROLLING SPREAD UNDER SEVERE BURNING CONDITIONS

NFDRS FUEL MODELS	FIRE BEHAVIOR FUEL MODELS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
A W. ANNUALS	X													GRASS
L W. PERENNIAL	X													
S TUNDRA	X					3rd			2nd					
C OPEN PINE W/GRASS		X							2nd					
T SAGEBRUSH W/GRASS		X			3rd	2nd								
N SAWGRASS			X											
B MATURE BRUSH (6FT)				X										SHRUB
O HIGH POCOSIN				X										
F INTER. BRUSH					2nd	X								
Q ALASKA BLACK SPRUCE						X	2nd							
D SOUTHERN ROUGH						2nd	X							
H SRT- NDL CLSD. NORMAL DEAD								X						TIMBER
R HRWD. LITTER (SUMMER)								X						
U W. LONG- NDL PINE									X					
P SOUTH, LONG- NDL PINE									X					
E HRWD. LITTER (FALL)									X					
G SRT- NDL CLSD. HEAVY DEAD										X				
K LIGHT SLASH											X			SLASH
J MED. SLASH												X		
I HEAVY SLASH													X	
	GRASS			SHRUB				TIMBER			SLASH			

Figure 21.—Similarity chart to align physical descriptions of fire-danger rating fuel models with fire behavior fuel models (from Anderson 1982).

Having made the conversion, table 4 shows rate of spread, heat per unit area, and flame length for three NFDRS fuel models and their "similar" NFFL fuel models. These points are plotted on the fire characteristics chart in figure 22. All calculations use the same environmental conditions: dead fuel moisture, 5 percent; live fuel moisture, 30.3 percent (that is, live herbaceous fuels 99.7 percent cured as used by Anderson, 1982, p. 17); midflame windspeed, 5 mi/h; slope, 33 percent (slope class 2). The NFDRS calculations were done using the direct moisture input option of the NFDRS program on the TI-59 CROM (Burgan 1979a). In order to use the NFDRS fuel models in the fire behavior calculations, the TSTMDL program of the FUEL subsystem was used to enter NFDRS fuel model parameters, with the specification that the custom fuel models are dynamic. The FIRE1 program of BEHAVE was used to do the calculations for both the "custom" NFDRS fuel models and the NFFL fuel models.

Table 4.—Calculated rate of spread, heat per unit area, and flame length for three NFDRS fuel models and their "similar" (see fig. 21) NFFL fuel models

Fuel model	Calculations by	Rate of spread	Heat per unit area	Flame length
		Ch/h	*Btu/ft²*	*Ft*
B	NFDRS	90	2,875	22
B	BEHAVE	92	6,385	32
4	BEHAVE	193	3,202	33
G	NFDRS	19	2,250	9.6
G	BEHAVE	19	994	6.6
10	BEHAVE	19	1,488	8.1
A	NFDRS	81	50	3.5
A	BEHAVE	82	69	3.8
1	BEHAVE	119	92	5.2

Rate of spread is essentially the same whether NFDRS or BEHAVE is used to do the calculations. The spread equations in the two systems are nearly the same. But, unless there are only fine fuels as in the case with fuel model A, the calculated heat per unit area (H/A) and flame length (FL) will be different. Notice that H/A and FL are higher when fuel model B is used in BEHAVE than they are with the NFDRS calculations. The opposite is true for fuel model G; the BEHAVE predictions are lower.

Now note the relationship between the NFDRS fuel model calculations using the NFDRS equations and the similar NFFL fuel model calculations using BEHAVE. There is a similarity between fuel models A and 1, B and 4, and G and 10. But the actual calculated values can be very different. Specifically, fuel model 1 has significantly higher rates of spread than fuel model A. When the windspeed is increased to 10 mi/h, the difference is even more pronounced. The rate of spread for fuel model 1 is 345 ch/h as compared to 129 ch/h for fuel model A.

Generalizations should not be made based on these examples. Under other environmental conditions, relationships could reverse. Conclusion: A custom fuel model should not be used in BEHAVE unless it is thoroughly tested using the program TSTMDL.

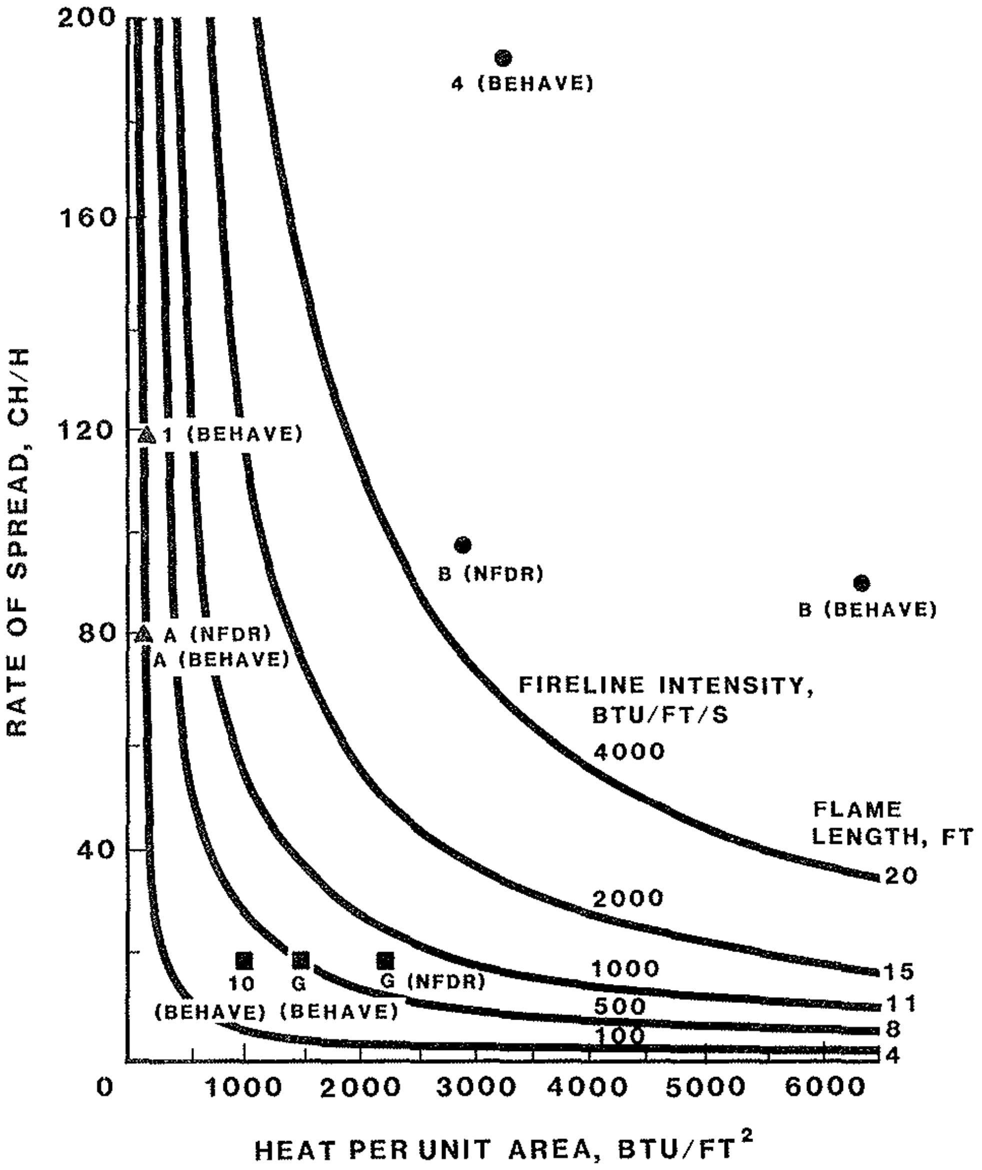


Figure 22.—The values shown in table 4 plotted on a fire characteristics chart.

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Andrews, Patricia L. BEHAVE: fire behavior prediction and fuel modeling system—BURN Subsystem, part 1. General Technical Report INT-194. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1986. 130 p.

Describes BURN Subsystem, Part 1, the operational fire behavior prediction subsystem of the BEHAVE fire behavior prediction and fuel modeling system. The manual covers operation of the computer program, assumptions of the mathematical models used in the calculations, and application of the predictions.

KEYWORDS: fire, fire behavior prediction, fire spread, fire intensity