Methods for Predicting Fire Behavior— You Do Have a Choice

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Predictions of wildland fire behavior are used in various aspects of fire management: prescribed fire planning, presuppression planning, real-time fire suppression activities. Methods for calculating fire behavior covered here represent continued improvement of the packaging of mathematical prediction models for use by fire managers. Such improvement resulted from expanding user needs, additional research results, and new technology. Options available to managers range from manual methods (such as tables and nomograms), to handheld calculators, to computers. These methods mainly differ in prediction capabilities and ease of use. It is important to understand that although the methods may differ, all produce valid results.

In this article I will discuss the manual methods described by Rothermel in "How To Predict the Spread and Intensity of Forest and Range Fires" *(15)*, the TI-59 calculator with a CROM (Custom Read Only Memory) *(8)*, the HP-71B calculator with a CROM *(18)*, and the BEHAVE fire behavior prediction and fuel modeling system *(6, 7)* (fig. 1).

Computer programs not nationally available to all agencies and private firms, such as FIREMOD *(1)* and FIRECAST *(12)*, will not be discussed here. In addition, I have included only those methods that predict site-specific fire behavior. This discussion, therefore, does not include systems designed for other purposes, the National Fire Danger Rating System, for example. I will not cover the role and importance of experience, except to emphasize that it is vital to any method of predicting fire behavior.

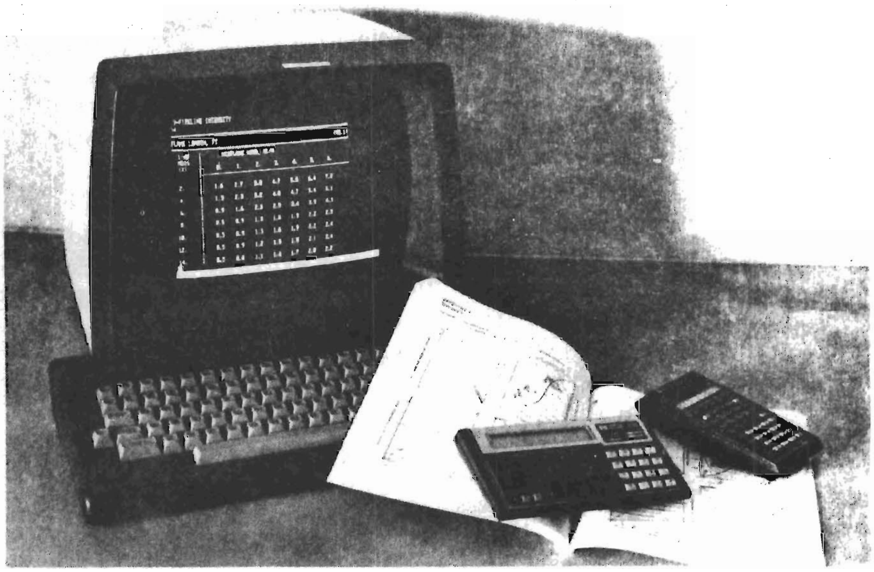

Figure 1—*Fire behavior predictions can be made using manual methods (such as nomograms or tables), the TI-59 and HP-71B calculators, or the BEHAVE fire behavior prediction and fuel modeling system.*

Manual Methods

Manual methods for calculating fire behavior include tables, graphs, and nomograms. Albini's nomograms for spread rate and intensity *(2)* were the first step in providing prediction models to the field. As Dick Rothermel stated in the preface to "How To Predict the Spread and Intensity of Forest and Range Fires," Frank Albini "let the genie out of the bottle with publication of his book of nomograms in 1976." Although that was 10 years ago, the nomograms remain useful in this age of computers. Nomograms graphically depict potential fire behavior, showing relationships that cannot as easily be seen in tables. Nomograms allow quick estimation of spread rate, flame length, and intensity, based on a minimum of information.

Rothermel *(15)* describes the nomograms and other manual methods for calculating fire behavior that have been developed through the S-590 Fire Behavior Analyst (FBA) course. Even with the availability of calculators and BEHAVE, S-590 continues to include the manual methods. An FBA should be proficient in all methods of calculating fire behavior (manual, calculator, BEHAVE, and, of course, experience), so as to be prepared to cope with contingencies such as battery failure or lack of electric power.

The S-390 Intermediate Fire Behavior course *(13)* also covers manual methods. So many students take S-390 that it would be impractical to require all of them to use a computer or calculator. In addition, the S-390 Field Reference can be readily used in the field. The reference has been nicknamed the "two-bit TI," meaning that it can do what the TI does, at less cost.

TI-59 Calculator

Developing a spread and intensity CROM for the TI-59 handheld calculator gave users a quick, easy, and handy means for calculating fire behavior predictions in the field as well as in the office. The automation was a major step beyond manual methods.

Additional fire behavior prediction programs for the TI-59 are available on cards *(4, 11)*. This calculator can process calculations too complex for manual methods. For example, the nomograms for maximum spotting distance are limited to spotting from a single torching tree on flat ground. The TI program allows for mountainous terrain and for spotting from a group of torching trees, burning piles, and wind-driven surface fires.

BEHAVE System

The next improvement after the development of the calculator was the BEHAVE fire behavior prediction and fuel modeling system *(6, 9, 16)*. BEHAVE is currently being expanded to allow additional prediction capabilities *(7)*. Anyone who has progressed from nomograms to the TI and then to BEHAVE can attest to the extent of the advancement. BEHAVE is not only the most comprehensive of the methods for calculating fire behavior, but it is also the easiest to use.

Many of the prediction models in BEHAVE were already available in the form of manual methods or TI-59 programs. BEHAVE also includes models not previously available. One of the major features of BEHAVE is the capability to design custom fuel models.

BEHAVE gathers the prediction models into one easy-to-use package. Tables of predictions can be generated quickly. For example, in a few minutes one can tabulate the effect of various windspeeds on rate of spread, whereas it takes days to build tables using the TI-59. In the office, BEHAVE is the logical choice for fire behavior calculations.

However, despite improved capability to access computers from remote sites, handheld calculators are still needed for predicting fire behavior in the field.

HP–71B Calculator

The HP–71B calculator is replacing the TI–59 calculator for fire behavior calculations *(10, 18)*. The TI-59's are breaking down and are no longer manufactured. Handheld calculator technology has advanced significantly since the adoption of the TI-59 and its CROM. So the HP is much more than a replacement. Its capabilities go far beyond those of the TI and are almost the same as BEHAVE.

The HP fire behavior program is patterned after the BURN subsystem of BEHAVE (the FIRE 1 and FIRE 2 programs). The design, keywords, and worksheets are similar insofar as is practical. I anticipate that people will frequently switch between BEHAVE and the HP. For example, in fire camp an FBA may have access to BEHAVE, but on the fireline will use the HP.

Calculation Comparison

Table 1 shows aspects of fire behavior that can be calculated, and alternative methods for doing so. For example, forward rate of spread, if upslope with the wind, can be calculated using tables, nomograms, BEHAVE, and the TI-59 and HP-71B calculators. Only BEHAVE and the HP-71B, however, can calculate rate of spread for any specified direction. Containment by indirect attack can be calculated only by BEHAVE; this is the only calculation that can be done by BEHAVE and not by the HP-71B. The table also indicates that BEHAVE provides the only means for designing custom fuel models; the

Table 1—*Major elements of fire behavior that can be predicted and various methods of calculation [Numbers in parentheses refer to publications in the literature cited section.]*

Fire behavior element	Manual methods	TI-59	HP-71B	BEHAVE
Rate of spread; flame length; fireline intensity:				
Upslope with the wind	Tables *(13)*, nomograms *(15)*	CROM *(8)*	CROM *(18)*	*(6)*
In the direction of maximum spread	vectoring *(15)*	—	CROM *(18)*	*(6)*
In any specified direction	—	—	CROM *(18)*	*(6)*
Heat per unit area	Nomograms *(15)*	CROM *(8)*	CROM *(18)*	*(6)*
Reaction intensity	Nomograms *(2)*	CROM *(8)*	CROM *(18)*	*(6)*
Area; perimeter:				
With upslope wind	Tables *(13, 15)*	CROM *(8)*	CROM *(18)*	*(6)*
With cross-slope wind	—	—	CROM *(18)*	*(6)*
Length-to-width ratio	Diagrams *(13, 15)*	—	CROM *(18)*	*(6)*
Forward spread distance	Multiplication *(15)*	CROM *(8)*	CROM *(18)*	*(6)*
Backing spread distance; maximum width of fire	—	—	CROM *(18)*	*(6)*
Maximum spotting distance:				
From torching trees	Nomograms *(15, 3)*	Card *(11)*	CROM *(18)*	*(6)*
From burning piles	—	Card *(11)*	CROM *(18)*	*(6)*
From wind-driven surface fires	—	Card *(11)*	CROM *(18)*	*(7)*
Containment (final fire size, line building rate, containment time):				
Direct attack	—	Card *(4)*	CROM *(18)*	*(6)*
Indirect attact	—	—	—	*(7)*
Scorch height	Graph *(2)*	—	CROM *(18)*	*(7)*
Probability of ignition	Tables *(13, 15)*	—	CROM *(18)*	*(7)*
Ignition component	—	CROM *(8)*	—	—
Fine dead fuel moisture	Tables *(13, 15)*	CROM *(8)*	CROM *(18)*	*(6, 7)*
Custom fuel models				
Develop	—	—	—	*(9)*
Use	—	Card *(9)*	CROM *(18)*	*(6)*

fuel models can then be used on the TI and HP.

Some factors related to individual predictions deserve further discussion. All methods for predicting fire behavior are based on Rothermel's spread model *(14)*. Therefore, given the same input, the predicted rate of spread will be the same whether the calculations are done using a nomogram, table, calculator, or computer.

Table 1 indicates that fine dead fuel moisture can be calculated using tables, the TI-59 CROM, the HP-71B

CROM, and BEHAVE. Nevertheless, there are major differences in the methods. The TI-59 estimates fine dead fuel moisture based on temperature, relative humidity, and shade. It should be used only as a last resort. The S-590 tables allow adjustment for other factors: aspect, slope, position on the slope, and time of day. The S-390 tables are a modification of, and produce results similar to, the S-590 tables. The prediction model implemented on the HP-71B and in BEHAVE is a highly sophisticated site-specific model *(17)*. The different input required for each of the models should tell the user that the models are indeed different.

The models used to predict factors other than fuel moisture are not dramatically different. Answers may be slightly different, but not significantly so, when one considers the application and the resultant decisions. In most cases input and output are the same. The differences lie in the internal workings of the mathematical model.

The vectoring method for predicting spread under cross-slope wind conditions includes some simplifying assumptions that permit the use of manual methods. More sophisticated calculations are done in BEHAVE and on the HP.

The area and perimeter calculations for the tables and the TI are based on a double-ellipse formula *(5)*, whereas BEHAVE and the HP use a simple elipse. The results are slightly different. This modification made it possible to link size calculations to containment calculations and to predict fire behavior in a cross-slope wind.

The containment calculations for the TI, HP, and BEHAVE are all slightly different. The TI model had limitations and discontinuities that were overcome for the BEHAVE version. The HP requires a tabular version of the model in BEHAVE because of the number of calculations involved.

Probability of ignition is the same for the tables, the HP, and BEHAVE. (The S-390 table is a condensation of the S-590 table.) Through oversight, ignition component rather than probability of ignition was put on the fire behavior part of the TI CROM. Ignition component was developed for use in the National Fire Danger Rating System; probability of ignition is used for fire behavior prediction.

Summary

Methods for estimating fire behavior vary from manual calculations to computer programs. Manually calculated predictions are subject to many limitations, and one must be highly trained to use them. Nevertheless, manual calculations will always remain useful, especially for a fire behavior analyst on a wildfire suppression overhead team. Those who need fire behavior predictions at a specified time will not accept the excuse of equipment failure. And when tailgate predictions of fire behavior are called for, a quick look at a nomogram should suffice.

Even with the availability of manual methods and BEHAVE, there has been overwhelming demand to replace the TI-59. Because of advances in technology, the HP-71B CROM has capabilities far beyond those of the TI-59 CROM. The HP-71B is very similar to BEHAVE, including a user-friendly interface. However, the availability of the HP-71B does not mean that each TI-59 should be replaced with an HP. Although the TI is capable of only about 10 percent of what the HP can do, if that 10 percent meets your needs and your TI is still working, there is no urgent need to immediately switch to the HP. The predictions from the TI are as valid as ever.

BEHAVE is at the automated end of the methods scale. It has the most capabilities and is the most user-friendly alternative. In most cases BEHAVE is the preferred choice; however, access to a computer is not always possible. Although predictive capabilities increase in the progression from manual methods to calculators to BEHAVE, each method for calculating fire behavior has its own niche in fire management activities. You are now fortunate enough to have a wide choice in the method that you use to calculate fire behavior. ■

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