How to Predict the Spread and Intensity of Forest and Range Fires

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INTRODUCTION

Can wildland fire behavior really be predicted? That depends on how accurate you expect the answer to be. The minute-by-minute movement of a fire will probably never be predictable--certainly not from weather conditions forecasted many hours before the fire. Nevertheless, practice and experienced judgment in assessing the fire environment, coupled with a systematic method of calculating fire behavior, yields surprisingly good results. This manual documents the procedures for estimating the rate of forward spread, intensity, flame length, and size of fires burning in forests and rangelands. The procedures are complete and can be applied by individuals working in the field. It does not address the problems of large fuel burnout or duff consumption and duration of burning. The methods pertain to the fine fuels that carry the fire and produce the flames at the fire front. Although there are several tables and condensed procedures that can be extracted for a field reference, most of the procedures must be learned and practiced diligently to produce proficiency and useful results.

The material is extensive for good reason. Fire behavior, fuels, and meteorology are extremely complicated subjects that can bear limited condensation before losing sensitivity. Consequently, no apologies are given for the length. If you have not seen these methods before, some perspective is needed to avoid overenthusiasm or undue skepticism. It should be clear to anyone who has observed wildland fires that there is considerable variability in the fuels, the windspeed, and other influences that rule out the ability to make absolute predictions. It should also be clear that a few easily identified variables can cause drastic differences in the way fires burn and spread. Fuel compactness is a good example. Sparse dead grass and tightly packed pine needles have completely different burning characteristics even though individual pieces of each are physically similar. Similarly, fuel moisture, wind, and slope can all produce dramatic differences in spread rate and intensity. The effect of changes in these major variables upon fire behavior is accounted for by the fire model within the system. The difficulty in use arises in the estimation of the most appropriate inputs for situations that appear very diverse. Prediction accuracy is dependent upon the skill and knowledge of the user and the degree of uniformity or lack of uniformity of the fuels and environmental conditions.

This manual is no substitute for experience, but rather by coupling experience with a systematic prediction method, the professionalism needed for implementing new concepts in fire management is emerging. Large fires where fire behavior can be carefully studied are considerably fewer than earlier in this cen tury. Ironically, this comes at a time when fire management policy brings greater demands for quantitative assessment of fires. This manual is intended to help fill this need.

The manual is a compilation of material developed for the National Wildfire Coordinating Group's S-590 Fire Behavior Officer Course[1] and from a 3-day course in predicting fire behavior using the TI-59 calculator equipped with a preprogrammed chip. New research material has been added in an evolutionary process since the methods were first developed and tried in the field in 1976.

Until now, access to these methods was available only through the 2-week S-590 course. This manual cannot replace that training, but can serve as a text providing the material to those who cannot attend the course, and as a reference for those who do. It may also be used to supplement the material in the revised S-390 fire behavior course.[2]

As the citations will show, many persons have been involved in the development of the material. Much of the material has not previously been published, however, making it difficult to cite. It is important to document the work and give proper credit before the origin is lost.

The material has been tried and refined considerably since first taught in the FBO class in 1976. In fact, the material has been greatly strengthened by former students who have helped refine the techniques and test them operationally.

I have eliminated extraneous material that is useful only to fire behavior officers, such as the instructions for preparing briefings and forecasts. However, examples of how the prediction methods are integrated into the fire planning strategy and material that a fire behavior officer might prepare for them are given in appendix G. I have not attempted to condense it for quick reference in the field, but rather depend on the user to apply only those sections needed for a particular situation. The style is narrative and cites examples, rather than a step-by-step procedure. The manual must be thoroughly learned so that the appropriate section can be recalled immediately when needed. Approximately 200 fire behavior officers have been trained and tested in these procedures. Responses regarding its usefulness have been very encouraging. As you become proficient in the use of the material, I believe you will achieve a new level of professionalism in fire management.

The literature citations provide a good record of the background material used to develop this manual. There are a few publications that should be cited as being especially helpful for application of this material:

Weather: Schroeder and Buck (1970)
Fuels: Anderson (1982)
Calculations: Albini (1976) and Burgan (1979)
Spot fire distance: Chase (1981)
Interpretation: Andrews and Rothermel (1982)
Verification: Rothermel and Rinehart (1983)

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[1]This 2-week course is taught at the National Advanced Resource Technology Center at Marana Air Park, AZ.

[2]National Wildfire Coordinating Group's S-390 Fire Behavior Course. Produced by Boise Interagency Fire Center, Joe Duft and Jerry Wifams, co-chairmen of course development.

CHAPTER I

PREDICTING FIRE BEHAVIOR

The procedures for predicting fire behavior include three primary sections:

I . A means of evaluating the inputs describing the fuels, fuel moisture, windspeed, and slope.

2. A means of calculating the two basic fire descriptors -- rate of spread and intensity.

3. Methods for interpreting the rate of spread and intensity to get spread distance, perimeter, area, flame length, and to identify conditions that lead to spotting and crowning. An important feature is the display of probable fire growth by time period on maps.

A diagram of how information flows through the systems is shown in figure 1-1.

The primary method of interpreting the inputs is a fire model (Rothermel 1972) that has been adapted for calculation on nomograms (Albini 1976), or with a handheld TI-59 calculator and a preprogramed microchip developed by Burgan (1979).[1]

Fire spread may be thought of as a series of ignitions wherein heat from the fire raises successive strips of fuel to the ignition temperature. This principle has been explained by several authors; Thomas (1963), Anderson (1969), and Frandsen (1971).

The fire model evaluates the energy generated by the fire, the heat transfer from the fire to the fuel ahead of it, and the energy absorbed by that fuel. Because fine fuels carry the fire, the model is weighted toward such fuels-primarily material less than one-fourth inch in diameter. Both live and dead fuels are considered. Fuel moisture affects both the energy generated and the energy absorbed. Effects of wind and slope on heat transfer are included. Fuel particle size and fuel load and com pactness or bulk density have a strong influence on fire behavior. The heat content, mineral content, and fuel particle density are treated as constants in this manual although they are variable within the model. Andrews (1980) offers a compilation of some of the validation studies on the fire model. Results of these studies are shown in figure 1-2. Methods for verifying the procedures given in this manual in various fuel and environmental situations are offered by Rothermel and Rinehart (1983).

[1]These same procedures will work with a computer program under development tentatively named BEHAVE, as well as the tabular method of calculation being developed for the revised S-390 fire behavior course and the revised fireline handbook.

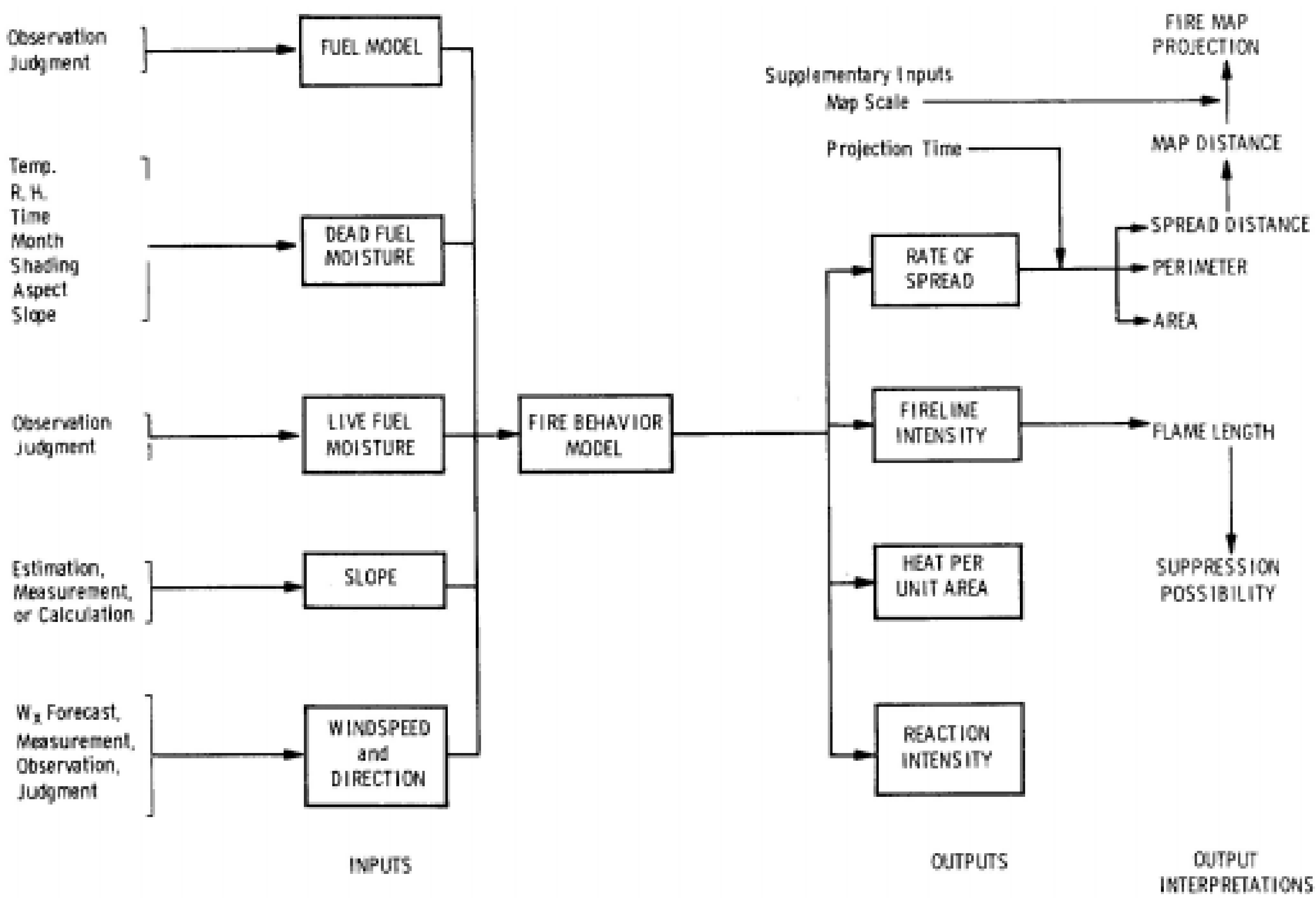

Figure I-1.—Fire behavior prediction system information flow.

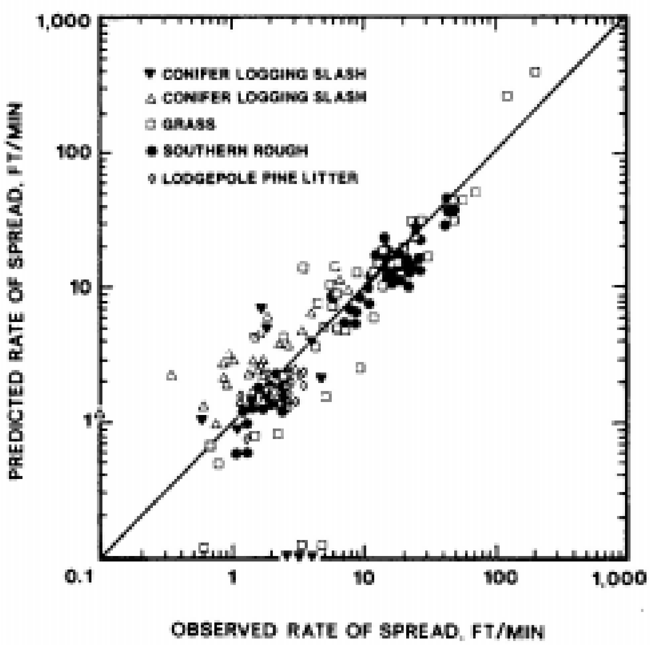

Figure I-2.-Field verification of the linear trend between predicted and observed spread rates for a wide range of fuels. The logarithmic scales dampen scatter at high spread rate while increasing it at low values. Data obtained from these sources: conifer logging slash (solid triangles), Bevins (18T6k conifer logging stash (open triangles), Brown (1972r grass, Sneeuw~ jagt and Frandsen (1966}; southern rough, Hough and Albini (197815 lodgepole pine litter, Lawson (1972).

Limitations

The fire model is primarily intended to describe a flame front advancing steadily in surface fuels within 6 feet of, and contiguous to, the ground. Typical of such fuels are dead grasses, needle litter, leaf litter, shrubs, dead and down limbwood, and logging slash. These are the fuels in which fires start and make their initial runs and in which direct attack is usually made.

The methods and model in this manual do not apply to smoldering combustion such as occurs in tightly packed litter, duff, or rotten wood.

Severe fire behavior such as crowning, spotting, and fire whirls is not predicted by the fire model. The onset of severe fire behavior, however, can often be predicted from surface fire intensity as will be explained.

Short-range firebrands may be blown ahead of the fire where they ignite fuels and increase the rate of fire spread. This mechanism is not accounted for, but the deficiency does not appear to affect the prediction of fire behavior. Short-range firebrands must ignite the fuel and start a new fire front before the fire overruns that position or the spotting will not be significant in increasing spread rate. In many cases the main fire does overrun the potential spot foes. Further, the model assumes fuels are uniform and continuous. Short-range spotting can actually compensate for the discontinuous nature of some fuels, giving extended usefulness of the model.

Although the original model was developed for uniform continuous fuels, subsequent research on nonuniform fuels (Frandsen and Andrews 1979) and the introduction of the two-fuel-model concept (Rothermel 1978)' permit some nonuniformity to be considered.

The methods in this manual describe the behavior at the head of the fire where the fine fuels are assumed to carry the fire. Backing fires can also be described in some cases. The burnout of fuels, usually large fuels and tightly packed litter, behind the fire front is not described.

Only the foliage and fine stems of living plants are considered fuels. When moisture content is high, such plants can dampen fire spread. When moisture content drops below a critical level, however, living plants can increase the rate of fire spread. This is accounted for by the fire model.

It is assumed that the fire has spread far enough so that it is no longer affected by the source of ignition. The system is therefore of limited usefulness in predicting behavior of prescribed fires, where the pattern of ignition is often used to control fire behavior. Nevertheless, the model is often used to plan prescribed fires by assessing the fire potential both inside and outside of the proposed burn area.

Applications

This material was drawn from a course for training fire behavior officers; therefore predictions are expressed in "real time." Predictions are keyed to a specific site, using observed weather or weather forecasts and observed fuels and topography. The material is not limited to this application, and has been adapted for other purposes, as explained in the following section.

PREDICTING FIRE BEHAVIOR

Assessing behavior of a running fire or planning strategy on a fire that has escaped initial attack is the primary use. Procedures are described in the section titled "The Fire Prediction Process." An example is given in appendix G.

DISPATCHING

When the decision has been made to suppress a newly discovered fire, the initial attack forces do not spend much time predicting fire behavior upon reaching the fire because of the urgency to direct all of their attention to suppression. Actually, it would be more useful to predict fire behavior at the dispatching office before initial attack forces are sent. Such decisions would require data on fuels, topography, and weather comparable to those needed for on-site predictions. Methods similar to those in this manual are being streamlined for such a purpose.

PLANNING

The fire prediction methods described are being used for fire management planning in many parts of the world. Although cumbersome for long-range planning, they can be effectively used for short-range and operational planning.

[1]A concept for appraising fire in nonuniform fuels. Presented at 1978 meeting on fuel and smoke management, Mt. Hood National Forest.

PRESCRIBED BURNING

Fire prediction methods can be useful when planning prescribed fires, including their containment or control, and for assessing fuel and weather conditions as burn time approaches. The methods can be used to estimate the behavior of fire that escapes the lines. Care must be used in estimating fire behavior within the burn area. The system was designed to describe the behavior of a line of fire free of influences from the drafts of other fires. Many prescribed fires are ignited in patterns intended to influence behavior: ring firing, center firing, mass firing, or strip head fires. Fires conducted for vegetation manipulation or site treatment may require burning prescriptions based on factors other than the system can provide. Experience and calibration in the fuel type can overcome some obstacles. The verification and calibration procedures given by Rothermel and Rinehart (1983) may be helpful,

MONITORING FIRES

The system is especially well suited for monitoring and predicting the behavior of fires resulting from unplanned ignitions that meet an approved prescription and, therefore, do not require immediate suppression action. Experience on the Independence Fire in Idaho in 1979 demonstrated the usefulness of anticipating the movement of a large fire burning under prescription conditions for several weeks in rugged mountain country.[1] The Forest Service categorizes these fires in planned areas as a prescribed fire from an unplanned ignition. Most agencies permit such fires to burn provided all fire behavior variables remain within the prescription developed in an approved plan. Prescribed fires in this category come closest to matching a wildfire situation. Control activities, if any, are usually confined to protecting boundaries or improvements. Additional ignitions are usually not made. Because these fires can exist through several burning periods, they offer excellent opportunities for both predicting fire behavior and verifying the prediction methods.

The Fire Prediction Process

When a fire escapes initial attack, the reinforcement forces include an overhead suppression team who will carefully assess the overall fire situation. The purpose of the prediction process, therefore, is to enable this team to estimate what a fire will do under the expected weather and existing topographic conditions. These procedures actually form a short-term planning system that uses observations of fire behavior, fuels, topography, and weather forecasts to give advance notice of the kind of fire that can be expected. Typical steps taken in this process would be as follows:

ASSESS THE PAST AND PRESENT FIRE SITUATIONS

What has the fire done before you were able to observe it and what is it doing now? In both cases, try to determine what type of fuels the fire has been burning in, and what fuel stratum has been carrying the fire? What has the weather been? How has the fire responded to the weather in terms of intensity, rate of spread, and direction? What time of day has the fire been making runs? Has there been crowning and spotting?

DETERMINE CRITICAL AREAS

Critical areas can comprise threatened resources, cultural or natural, or fuels that can burn with high intensity or fast spread rates. Obtain and study carefully the escaped fire situation analysis (EFSA) -- in some cases you may be asked to help prepare an EFSA. The EFSA will identify critical areas and thereby help identify where fire prediction estimates are needed.

WHAT INFORMATION IS NEEDED AND WHEN

Fire behavior is often predicted in response to a request from a fire officer responsible for suppression strategy or tactical plans. The prediction must be timely and presented in a form that is readily understood. Timeliness is extremely important. When an immediate estimate is requested, an elaborate answer is not expected. Estimates can be made in an amazingly short time when the procedures are understood well enough to recognize the simplifying assumptions that can be made while still retaining the significant factors. When more time is available, more elaborate predictions can be made, using maps and charts for interpretation. Remember, there is nothing as useless in the plans tent as a late fire behavior forecast.

ESTIMATE INPUTS

The greatest challenge to your professional skills on a fire will be appraising the fuels, weather, and topography. The procedures presented herein are designed to show you how to use weather information that is either received from the weather service or measured on-site. The procedures are not designed to forecast weather. Where will you get your weather information? Is there a mobile weather unit on-site or ordered? Are your weather interpreting skills as sharp as they should be? Have you been following the danger rating indexes for this area? What degree of curing have the fuels experienced? Did you get a weather forecast before coming to the fire, and is there a weather change predicted? There are a number of problems to consider, and if you are not experienced in the type of fire situation in which you find yourself, try to find an experienced local person who has time to brief you on the general behavior of fires in the area, including spotting and crowning potential, fuel types and fuel maps, topography, and predictable diurnal weather conditions. The input sections elaborate on specific data needed.

CALCULATE FIRE BEHAVIOR

Either the nomograms, the TI-59 with a fire behavior CROM,[1] or the tables in the revised S-390 fire behavior course can be used to calculate rate of spread, flame length, and fireline intensity.

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[1]Keown, Larry D. Fire management in the Selway-Bitterroot Wilderness, Nezperce National Forest, a report of the 1979 fire season and Independence Fire. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; May 1980.

[1]Custom Read Only Memory chip designed for predicting fire behavior that can be placed in a TI-59 calculator. Two thousand CROM's were built and distributed to fire suppression forces throughout the United States.

INTERPRET THE OUTPUTS

For new fire starts or spot fires, fire growth as an elliptical pattern on the ground can be estimated in terms of perimeter and area by time periods. If on a slope, the procedures used for predicting area and perimeter assume the wind is blowing directly upslope. The length-to-width ratio of the ellipse is governed by the windspeed and steepness of the slope.

The growth of fire from a line of fire is estimated from a series of projection points selected at strategic points along the fireline. Methods are shown for dealing with any combination of wind and slope, including fire burning upslope or backing downslope and with wind blowing either up, down, or crossslope. The fire growth for a specified time period is then projected on a map.

Fireline intensity or flame length is used to interpret the possibility of torching, spotting, or crown fires. This, of course, must be supplemented with information about the overall fuels or timber stand condition.

FURTHER FIRE ASSESSMENT

Expected growth is extremely important in the early stages of a fire or if a weather change is forecast before firelines are secure. As control of the fire is gradually gained, the question of the general movement of the fire is replaced with a concern for unexpected events such as spotting across control lines, fire whirls, or flareup of hot spots that may cause torching or a run through the tree crowns or unburned islands. Weather changes are often the key to this behavior. Attention is also directed to burnout and backfiring and for securing firelines. You can expect to be asked for assistance in these operations. Therefore, in the latter stages of a fire, direct your attention to the weather forecasts and the probability of these events, rather than the routine prediction of fire growth.