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ESTIMATING WILDFIRE BEHAVIOR AND EFFECTS

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ABSTRACT

This paper presents a brief survey of the research literature on wildfire behavior and effects and assembles formulae and graphical computation aids based on selected theoretical and empirical models. The uses of mathematical fire behavior models are discussed, and the general capabilities and limitations of currently available models are outlined.

Rothermel's fire spread model is used to develop nomographs for estimating rate of spread, reaction intensity, and flame length for a variety of "typical" fuel complexes, under widely variable conditions. Factors affecting spread rate and overall shape of a fire are quantified, as well as some fire effects such as crown scorching and duff removal.

Appendices give more details of the formulations presented graphically in the text, including the definitions of terms used to quantify fire behavior and effects and tables of numerical factors for converting values to different units of measurement.

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INTRODUCTION

This document is an outgrowth of a short course in fire behavior estimation.¹ It is not intended to be an exhaustive survey or even a thorough introduction to the material, but a starting point from which the interested reader may venture into the literature of fire behavior modeling. Some theoretical and empirical relationships are presented, along with computation aids that may prove to be useful to those concerned with wildland fire behavior and effects.

Although fire behavior prediction is by no means a new field, the use of complex mathematical models for this purpose has only recently begun. The availability of computers has made the use of very complicated models a routine procedure in research, and allows complex calculations to be done by machines instead of people. The result is that more powerful models are now easy to use.

The purpose of this report is to introduce fire behavior specialists to some tools being developed in research which may be useful for predicting fire behavior. Through the process of constructive "feedback," research efforts can be tailored better to fit the needs of those who use research results. The continuation of such a dialogue about fire behavior modeling is actively being sought here.

USES OF FIRE BEHAVIOR MODELS

Potential uses of fire behavior models span the spectrum of fire-related decision-making. From land use planning to prescribed fire design, models are used to aid decisionmakers. The nature of the decisions being made, and the consequences of errors, determine the types of predictions and the degree of accuracy required of the model output. Here we review some model uses and indicate the type of output needed and the general level of accuracy each requires.

Fire-Danger Rating

Fire-danger rating is a management tool used to establish the degree of fire hazard and the risk of fire outbreak. On the basis of such assessments, decisions are made concerning land use and fire control readiness. The National Fire-Danger Rating System (NFDRS) (Deeming and others 1974) is a multiple-index scheme designed to provide fire control and land management personnel with a systematic means of assessing various aspects of fire danger on a day-to-day basis.

¹Albini, Frank A. Advanced Fire Management Training Course, National Fire Training Center, Marana Air Park, Marana, Arizona, November 11-22, 1974.

Although easy to use because of its tables of indices, the system is based on complicated models of fire behavior. The multiple-index concept allows the assessment of different aspects of fire behavior (Deeming and others 1974; USDA Forest Service 1962). For example, in the National Fire-Danger Rating System, the spread component is calculated from predicted forward rate of spread, the energy release component from a rate of heat release per unit area, and the burning index from an estimate of flame length.

Model outputs need not be highly accurate for this use. It is important that the system of models (fire behavior models and fuel models) properly rank the fire behavior variables estimated and that they respond to changes in weather consistently and with sufficient sensitivity to permit decision boundaries to be established. For these purposes, stylized fuel models are entirely adequate, and indices of *relative* severity of fire behavior are sufficient.

Fire Control Planning

Fire control planning is a complex job of resource allocation. When, where, and to what level to man stations; the rules for initial attack dispatching; and the material to include in a fireline handbook may sound like unrelated questions, but to be answered they have a common need for data--estimation of fire behavior.

Although the estimation of wildfire behavior is a significant ingredient in the planning of fire control activities and the allocation of fire control resources, it is by no means the only (and frequently not even the principal) ingredient. Considerations such as resource value threatened, relative risk of ignition, transportation, communications, equipment capabilities, etc., often dominate the problem of manning stations and initial attack dispatching. The experienced fireman on the scene of a fire must be the source of predictions of potential fire behavior. The potential fire behavior entries in handbooks and training aids are only for purposes of quick, preliminary assessment.

Models that predict fire behavior can be useful in manning and dispatching planning if they are no more precise than the stylized models of the NFDRS; indeed, danger-rating indices themselves are used for these purposes. So the accuracy requirements for fire behavior estimation for these planning efforts are no more stringent than for fire-danger rating. This same general level of precision is probably adequate for fireline handbooks and similar training aids as well, but instead of indices, the models should provide actual estimates of forward rate of spread, perimeter growth, intensity, flame length, etc.

These same kinds of estimates, except with slightly better accuracy (say, "factor-of-two" accuracy?), might be useful to fire behavior officers. For quantitative estimation, if the models are easy enough to use under field conditions, and if they offer at least enough resolution between fuel types to exhibit significant differences, models may be useful additions to the tools of the fire behavior officer's trade.

A set of working charts for estimating forward rate of spread, intensity, flame length, and crown scorch height are included in this document. This is done in hopes that those concerned will try them and communicate to the author their assessments of the utility and accuracy of the charts. They are also intended for use as training aids and may be useful in some dispatching activities. Comments on these kinds of applications are also solicited.

Prescribed Fire Planning

Prescribed fires are used in many areas and for many purposes (Peet 1965; USDA Forest Service 1971; Fahnestock 1973; USDA Forest Service, n.d.). Hazard reduction (Pagni and others 1971; Green 1970; Schimke and Green 1970), species control (Pechanec and Blaisdell 1954), habitat improvement (Cushwa and others 1969; Leege 1968), silviculture (Roe and others 1971; Beaufait 1966), reduction of air pollution from wildfire smoke (Hall 1972; Mobley and others 1973; USDA Forest Service, n.d.), etc., are objectives of prescribed burning.

To plan prescribed fires to achieve stated objectives, to minimize cost of control and mopup, and to reduce the risk of escape or undesirable behavior, a firm basis of fire behavior estimation must be established. This basis should include not only the gross behavior of the fire but its effects on the surrounding environment. So, predictive models that allow the estimation of spread rate, intensity, flame length, etc., should be useful in prescription formulation but may not suffice to prejudge relevant fire effects such as fuel reduction, smoke generation, soil conditioning, and others.

Because specific effects are sought and specific sites are burned under preselected conditions to achieve them, in many cases prescribed burning poses the most stringent requirements for fire behavior prediction models. The use of preestablished fuel bed descriptions (such as the fuel models of the NFDRS) may be inappropriate for accurate prediction as the specific site being burned may differ substantially from the assumed fuel bed. But such "stylized" or "typical" models may be useful in establishing roughly what the fire behavior will be before the first burn, or for estimating what the sense and magnitude of *changes* in fire behavior will be as the burning conditions vary. The computation aids presented later in this document are offered with these intended applications in mind. There is no substitute for experience, but these tools may be useful aids in extrapolating from known to slightly different conditions when coupled with experience and careful observation.

CAPABILITIES AND LIMITATIONS OF SOME AVAILABLE MODELS

There are many mathematical models of varying scope and complexity that deal with many of the elements mentioned above. Most of these models reside in the literature, but some have been put into a form useful to nonresearch personnel. We will concentrate on a few models and mention others only in passing. The purpose of this cursory review is to introduce the reader not active in fire research to the literature of this field and to indicate roughly the present state-of-the-art of fire behavior modeling.

Scope of Predictions Possible

Mathematical models exist that relate physical and chemical properties of fuel arrays to specific fire behavior, such as forward rate of spread, fire intensity, flame length, burning time, and others. The environmental variables of windspeed and slope are also required to operate the models, as well as fuel moisture content.

Rates of fire spread and growth.--Using mathematical models published by the authors listed below, it is possible to calculate forward rates of spread for various fuel complexes.

Author(s)	Publication date	Type of fuel array considered
Fons	1946	Light forest fuels
Fons, Clements & George	1963	Laboratory wood cribs
Thomas & Simms	1963	Forest fuels (grass, brush)
Hottel, Williams & Steward	1965	Arrays of paper sheets
Albini	1967	Brush
Anderson	1969	Uniform porous bed
Fang & Steward	1969	Randomly packed fine particles
Thomas	1971	Cribs, gorse, and heather
Steward	1971	Mathematically describable bed
Frandsen	1971	Uniform porous bed
Rothermel	1972	General (uniform) wildland fuels
Pagni & Peterson	1973	Uniform porous bed

Of the models listed above, Rothermel's wildland fuel spread model (1972) is the most comprehensive and robust to date. It has been subjected to some direct verification tests in logging slash assembled fuel beds (Brown 1972) and both prescribed and wild grass fires (Sneeuwjagt 1974). Stevenson and others (1975) were also able to match observations and after-the-fact predictions of spread rate in mixed chaparral-like fuels using the Rothermel model in conjunction with an area-growth computer algorithm (Kourtz and O'Regan 1971). We will focus on this model at length in this paper.

The forward rate of spread of a wildland fire is only one descriptor of growth.² The growth rate of the perimeter of a large fire, as well as its area and the shape of the perimeter, are also useful quantities to predict.

A computer-based model of great mathematical elegance, but with a voracious appetite for data, has been developed by Kourtz and O'Regan (1971) and will be used in the FIRESCOPE computer-assisted Multi-Agency Coordination Center (Hanna and others 1974) to assess fire growth potential. The data that this model uses include the rate of spread from point-to-point; these quantities are generated by Rothermel's model in the application cited.

A much simpler model assembled by Anderson³ from data taken by Fons⁴ allows one to estimate roughly the shape, size, rate of perimeter increase, and rate of area growth of a wind-driven wildland fire using only the forward rate of spread and windspeed as

²Both George Fahnestock and Clive Countryman have pointed out to the author (private communications, 1975) that the term "rate of spread" has often been used to connote "rate of perimeter growth." The term "forward rate of spread" should be used to indicate head fire linear rate of advance. Current usage seems to favor the shorter phrase "rate of spread" for head fire rate of advance, but this unfortunate confusion of terms will no doubt persist for some time. Here we shall be explicit when referring to perimeter (or area) growth and use the phrase "rate of spread" for head fire rate of advance.

³Anderson, Hal E. Memorandum to R. C. Rothermel and W. C. Fischer on file at the Northern Forest Fire Laboratory, Missoula, Montana, August 10, 1973.

⁴Fons, Wallace L. Unpublished data on rate of growth and fire shape. On file at Pacific Southwest For. and Range Exp. Stn., For. Fire Lab., Riverside, Calif. [n.d.].

inputs. Van Wagner (1969) proposed a very similar method that predicts the same quantities; this method uses three rates of advance of the fire front--heading, flanking, and backing.

Fire intensity and related effects.--Byram (1959) defined a rather basic measure of fire intensity which has been proven very useful. Byram's fireline intensity has been used in describing the difficulty of controlling a fire because of the heat it produces (Hodgson 1968) and to predict or correlate flame length (Byram 1959), the height of scorching of conifer crowns (Van Wagner 1973), and the occurrence of spotting (Hodgson 1968). These relationships make this measure of intensity very valuable in fire behavior prediction. This intensity is defined as the rate of heat release per unit length of fire edge, and so is proportional to the rate of advance perpendicular to the edge.

Using a simple relationship between fuel particle size and burning time (Anderson 1969), or flame residence time, Rothermel's model can be used to predict Byram's intensity and the related aspects of fire intensity correlated to it.

Rothermel (1972) and Anderson (1969) make use of a different measure of intensity--the rate of heat release per unit area burning. This quantity appears directly in Rothermel's spread model and can be used in Thomas' (1963) equations correlating flame length and height with fire mass release rate. Thomas' equations are somewhat difficult to use in describing wildland fire flame behavior but usually predict a flame length approximately equal to that given by the equation given by Byram if one uses the flame width predicted by Anderson's relation as the characteristic dimension D in Thomas' equations.

Limitations on Accuracy of Predictions

The mathematical models cited above permit one to calculate various features of fire behavior. Some are easy to use, some very complicated, but all will be found to produce results which do not always agree with observed fire behavior. In some instances, the disagreement can be quite significant (Brown 1972; Lawson 1972).

There are three principal reasons for such disagreement, no matter which models are used:

1. The model may not be applicable to the situation.
2. The model's inherent accuracy may be at fault.
3. The data used in the model may be inaccurate.

Model *applicability*.--If one applies a model in a situation for which the model was not intended to be used, the "error" in the model's prediction can be very large. All the models discussed and cited above have the following limitations and should not be expected to predict what they do not pretend to represent:

1. The fuel bed modeled is continuous, uniform, and homogeneous. The more the real fuel situation departs from this ideal, the more erratic the predictions will be when compared to real fire behavior.

2. The fuel bed is a single layer and is contiguous to the ground, not an aerial layer, such as the crowns of coniferous trees. Although brush fires may technically be considered "crown fires" and have been treated by some of the above-mentioned models, a large-scale conifer crown fire is not specifically modeled and would probably be poorly predicted.

3. Fire spread by spotting (flying embers or firebrands) is not modeled by any of the models mentioned above, so fire spread rate in those situations where spotting is important will likely be poorly estimated.

4. Fire whirlwinds and similar extreme, fire-induced atmospheric disturbances are not modeled. Countryman (1971) provides guidance as to when such phenomena are to be expected, but actual predictions are not yet within the state-of-the-modelers¹-art.

→ Accuracy of *model* relationships.--Wildland fires, being infrequent, unpredicted, and often occurring in inconvenient locations, are not ideal candidates for instrumentation and measurement. As a consequence, data to test theoretical or empirical formulae for wildfire behavior accumulate slowly. Model testing probably will continue to rely mostly on laboratory experiments and prescribed fire data, with occasional "windfall" wildfire observations.

The relationships between variables in all of the models must be viewed as weakly tested, semiempirical, and subject to exception. Where tests have been possible with sufficient rigor to test model relationship accuracy, they have usually shown the prediction errors to be within a few tens of percent on the average. Fire behavior varies over many orders of magnitude, and model builders consider models successful if the relationships predict fire behavior within a factor of two or three over a range of two or three decades. This can be taken as roughly representative of the current state-of-the-art in fire behavior model accuracy, including both the effects of applicability and internal accuracy. So until the limitations of model applicability outlined above are relaxed by further research, improvements in model relationship accuracy beyond the current level are unlikely to increase the overall accuracy of predictions.

The most important source of error in any particular prediction may be difficult to pin down to model applicability, model accuracy, or data accuracy. But the *internal* consistency of a well-disciplined mathematical model allows one to use it to assess the impact of changes in important variables for specific situations, even if the model overpredicts or underpredicts systematically, whether due to model inapplicability, model inaccuracy, or data errors.

For example, the effect of a 5 mi/h windspeed increase on the rate of spread in a grass-type fuel can be predicted to within a few tens of percent using Rothermel's (1972) model, but a specific prediction of spread rate at one windspeed in the same fuel type may be a factor of two high or low (Sneeuwjagt 1974).

Accuracy of data.--Fire behavior models should be sensitive to those parameters known to affect fire behavior, such as variations in fuel moisture, windspeed, slope, fuel bed depth, and others. If these data are not known accurately enough, model output may be significantly in error. It is easy to recognize the nature of and the effects of errors in data such as the windspeed, the slope, or the fuel moisture content. More subtle, yet equally important descriptors, such as fuel particle surface/volume ratios, the loading of fuel components in each size class, and the proportions of live and dead components, must also be specified accurately in order to predict fire behavior realistically. Rothermel's (1972) figures 24 and 25 illustrate dramatically the importance of these fuel bed descriptors in determining predicted fire intensity and forward rate of spread.

Because models of phenomena as complex as wildfire are, generally, quite nonlinear, the output may be highly sensitive to a particular parameter over one range of values and nearly insensitive to the same parameter in a different value range. For this reason, it is difficult to make a valid quantitative statement about the relationship between input data accuracy and output accuracy. The model in question must be used to establish its requirements for data accuracy, considering the range of values of the variables used for input.

If any general rule is valid, however, it is that most likely data accuracy will not be the factor which limits the validity of behavior model predictions. The usually dominating error source is that the fuel complex is not uniform, continuous, homogeneous, and consolidated into a single layer. Nor is the windspeed constant, the slope everywhere the same, nor the fuel moisture content the same from place to place. After model applicability, probably the next most important error source is inherent model accuracy. If standard fuel inventory techniques are followed (Brown 1971, 1974; Van Wagner 1968b; USDA Forest Service 1959), it is unlikely that data accuracy would be the dominant error source. If no measurements are made, however, but estimates from observations are used, the accuracy of the estimates may cause errors as large as the first two sources, or even larger.

SOME FIRE BEHAVIOR COMPUTATION AIDS

In this section, some graphical results from the physical and mathematical relationships that make up some specific fire behavior prediction models are presented, and the reader is referred to some others. The presentation here will be brief by necessity. The interested reader is urged to consult the original documentation for a better understanding of the various models.

To apply models predicting fire behavior, it is necessary to have in hand specific definitions of the terms used to describe the phenomena. Appendix I discusses phenomena and defines their descriptive terms, and gives some tables showing conversion factors between various common units of measurement.

Appendix II presents and discusses the various models used in calculating the results given here. The discussions are brief, but the equations are given for the interested reader.

Rothermel's Spread Rate Model

Frandsen (1973a) programed a Hewlett-Packard Model 9820 minicomputer to calculate intensity and rate of spread from Rothermel's model. Recently, this program has been revised and extended by Ms. Patricia Andrews of the Northern Forest Fire Laboratory. In its current version, the program will not only solve a single problem, but will produce graphs of spread rate versus windspeed and/or reaction intensity versus fuel moisture. Written instructions on the operation of the new program can be obtained by writing to Ms. Andrews.

The Northern Forest Fire Laboratory maintains a computer-based library of fire behavior models at the Lawrence Berkeley Laboratories computer facility on the campus of the University of California at Berkeley. A Users' Manual (Albini 1976) is in preparation; draft copies are available from the author. Listing and card images of the FORTRAN IV source code are also available.

Nomographs for Stylized Fuel Models

By using Rothermel's equations (appendix II) and some stylized fuel models similar to those employed in the NFDRS (Deeming and others 1974), a set of graphs has been drawn that together can be used to estimate fire behavior in a wide variety of situations. A set of graphs has been constructed and organized for easy use. The fuel models used are described in detail in table 7, appendix III.

These sets of graphs, or working charts, are technically called nomographs, meaning graphical aids for the computation of numbers. The nomographs are collected at the end of this section.

The mathematical basis for the nomographs is the rate of spread model (Rothermel 1972) with minor modifications, as discussed in appendix III. Thus, the fire behavior described by the nomographs pertain to the leading edge of a spreading surface fire. *It does not include* spread by spotting (firebrands or embers), crown fire (spread through coniferous tree crowns), or the long-term residual fire intensity.

How to Use the Nomographs

1. Determine the best fuel model to use. The 13 fuel models contained in the set of nomographs are grouped into four general fuel community groups:

Grass and Grass-Dominated Fuel Complexes
Chaparral and Shrubfields
Timber Litter
Logging Slash

Although identified by an explicit, short name, the model usually will apply to more than one fuel situation. For example, fuel model 2, labeled "Timber (Grass and Understory)," also can be used for fire behavior assessment of southern pine clearcut slash. And fuel model 4, labeled "Chaparral (6 ft)," can also be used for heavy fresh "red" conifer logging slash.

Each of the fuel models in each general group has a set of brief descriptions of applicable "best-fits" fuel types and "can-also-be-used-for" fuel types. The reader is urged to skim over the four pages separating the groups of fuel models to become familiar with the variety of models available and fuel communities to which they are intended to apply.

2. Determine the "variable" factors: windspeed, terrain slope, and fuel moistures. A working chart in the lower left-hand quadrant of each fuel model allows one to combine the measured 20-ft windspeed and the slope tangent to obtain an "effective windspeed." The procedure is explained in the text accompanying the chart on each figure.

For fires not driven by the prevailing wind (e.g., backing or flanking fire), use zero windspeed.

Fuel moisture for the dead fuel components can be taken from fire-danger rating assessments, fuel stick measurements on site, or from any other appropriate source. For models 1-5 and 8-10, use the 1-hour timelag fuel moisture. For models 6 and 7, if the data are available, combine the three moisture contents as follows:

$$\begin{aligned} \text{"Dead Fuel Moisture"} &= 0.89 \times (\text{1-hour timelag moisture}) \\ &+ 0.09 \times (\text{10-hour timelag moisture}) \\ &+ 0.02 \times (\text{100-hour timelag moisture}). \end{aligned}$$

For the logging slash models, 11-13, combine the three moisture contents as follows:

$$\begin{aligned} \text{"Dead Fuel Moisture"} &= 0.76 \times (\text{1-hour timelag moisture}) \\ &+ 0.18 \times (\text{10-hour timelag moisture}) \\ &+ 0.06 \times (\text{100-hour timelag moisture}). \end{aligned}$$

Live fuel moisture (foliage moisture) is required for models 2, 4, 5, 7, and 10. If data are unavailable for estimating such moisture, the following rough estimates based on the stage of the dominant cover species in its annual cycle can be used:

300 percent--Fresh foliage, annuals developing, early in growth cycle.

200 percent--Maturing foliage, still developing, with full turgor.

100 percent--Mature foliage, new growth complete and comparable to older perennial foliage.

50 percent--Entering dormancy, coloration starting, some may have dropped from stems.

3. Proceed to calculate fire behavior using the nomograph with the appropriate effective windspeed range. For each fuel model, there are two nomographs--one for low and one for high windspeeds.

A. Enter the nomograph, via the upper right-hand scale, at the appropriate "Dead Fuel Moisture." Draw a horizontal line across the page at that point.

If only dead fuel is present in the fuel model, determine the point of intersection of this horizontal line with the S-shaped curve in the upper right-hand quadrant. From this point of intersection, draw a vertical line down through the lower right-hand quadrant. Call this "line A." Go on to step B, skipping the following steps.

If both live and dead fuels are present in the fuel model, determine the point of intersection of the horizontal line with the curve in the upper right-hand quadrant, which corresponds to the live fuel (foliage) moisture. Interpolate if necessary. These curves are labeled and also distinguished by different dot-and-dash patterns. From this point of intersection, draw a vertical line down through the lower right-hand quadrant. Call this "line A." *Continue the horizontal line* through the upper left-hand quadrant, connecting it to the "Dead Fuel Moisture" scale on the upper left-hand scale at the same value used to enter the nomograph on the upper right-hand scale.

The curves in the upper left-hand quadrant are labeled with the various live fuel moistures and are drawn with the same dot-and-dash patterns as their corresponding curves in the upper right-hand quadrant. *If the horizontal line intersects* the curve in the upper left-hand quadrant for the live fuel moisture being used, *then draw a straight line* through this point of intersection to the lower right-hand corner of this quadrant. Call this "line K." You will use this constructed line later, in step D. *If the horizontal line does not intersect* the curve of live fuel moisture being used, *you will not need to use a constructed line* in step D.

B. Line A, constructed in step A, extends vertically into the lower right-hand quadrant, crossing the lines labeled "Effective Windspeed" in that quadrant. You should already have determined the value of the effective windspeed using the small graph inset in the lower left-hand quadrant. If not, do so before proceeding; the

instructions are printed below the graph on each page. Determine the point of intersection of the vertical line with the line labeled with the value of the effective windspeed, interpolating if necessary. From this point of intersection, draw a horizontal line across the bottom of the nomograph, extending through the lower left-hand quadrant.

C. Determine the point of intersection of the horizontal line constructed in step B with the diagonal line in the lower left-hand quadrant. From this point of intersection, draw a vertical line into the upper left-hand quadrant, passing through the lines drawn in that quadrant.

D. *If only dead fuel is present in the fuel model*, then determine the point of intersection of the vertical line constructed in step C with the line labeled with the appropriate 1-hour timelag fuel moisture, interpolating if necessary. From this point of intersection, draw a horizontal line back through the upper right-hand quadrant. Call this "line D." Go on to step E and read results.

If both live and dead fuels are present in the fuel model, then the next step depends upon whether or not you constructed line K in step A. *If line K was constructed*, determine its intersection with the vertical line constructed in step C. From this point of intersection, draw a horizontal line back through the upper right-hand quadrant. Call this "line D." Go on to step E and read results. *If you did not have to construct line K* in step A, then locate the curve labeled with the value of live fuel moisture used in step A, interpolating if necessary. From where this curve intersects the vertical line constructed in step C, draw a horizontal line to the right, through the upper right-hand quadrant. Call this "line D."

E. Read results at three places:

(1) Line A crosses the horizontal axis separating the two right-hand quadrants. Read the scale at that point to determine the reaction intensity (see appendixes I and II) of the fire.

(2) Line D crosses the vertical axis separating the two upper quadrants. Read the scale at that point to determine the forward rate of spread of the fire.

(3) Line A (extended upward if necessary) and line D intersect in the upper right-hand quadrant. The flame length at the front of the fire can be determined from this intersection point. Interpolate between the hyperbolic curves (those that run from upper left to lower right in a rounded L shape), which are labeled with the values of flame length.

Examples

Two examples are worked out step-by-step on the following pages, one step per page. Each page is marked with the letter of the step in the instruction sequence just above. To follow the steps in the construction of the solution to each example, match the letter of the instruction steps (A-E) with the page. On each page, the lines constructed in that step are shown dashed, previously completed lines solid. The data for the two examples are given below:

Example I (fig. I).--Estimate the fire intensity, forward rate of spread, and the flame length of a fire in cured broomsedge, given a fuel moisture content of 5 percent and a windspeed (at 20-ft height) of 8 mi/h, on level ground.

Solution 1.--Verify that the appropriate fuel model is number 3--Tall Grass (2.5 ft). The chart to use is the "low windspeed" member of the pair. The results of the construction illustrated on the following pages are: fire intensity, 3,000 Btu/min/ft²; rate of spread, 97 chains per hour; flame length, 12.5 ft.