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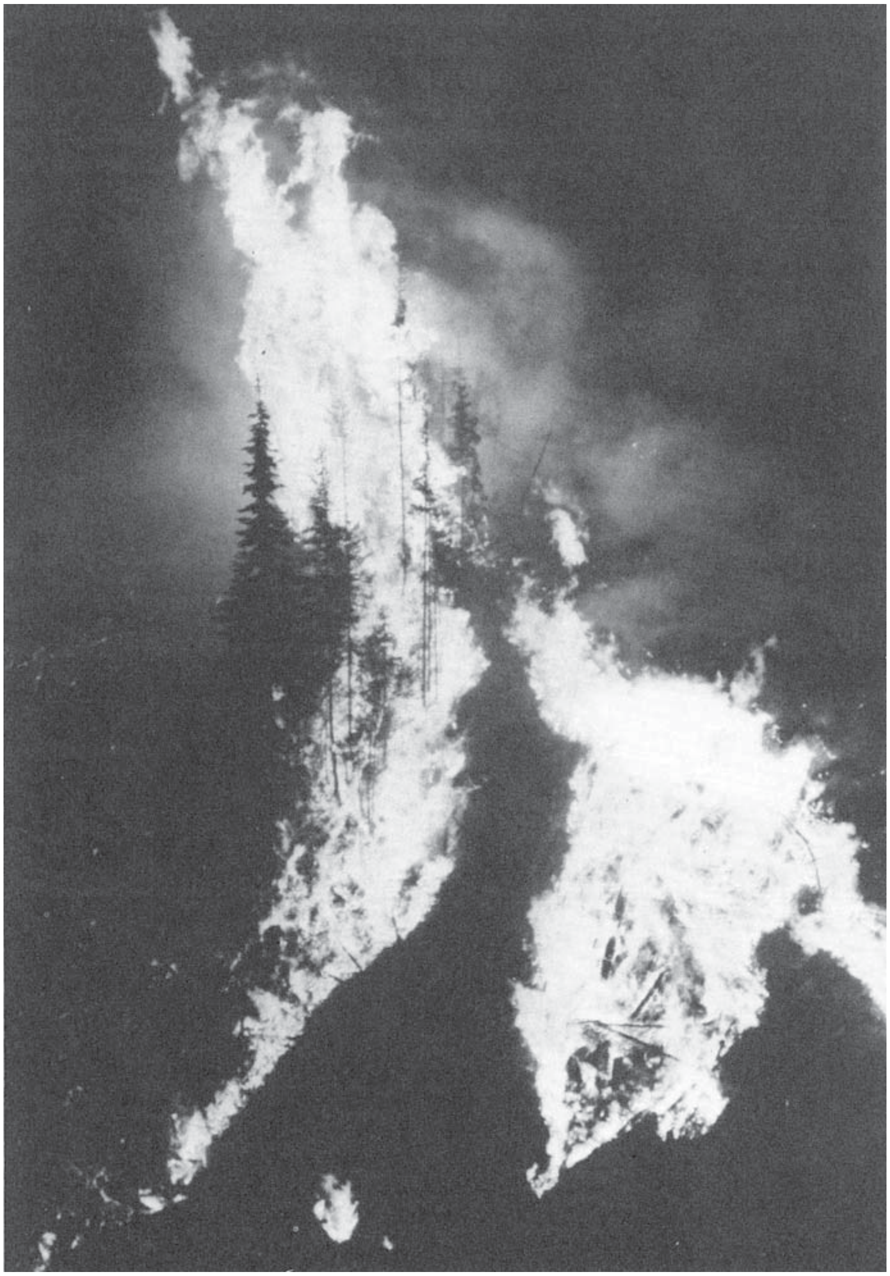
How to Predict the Spread and Intensity of Forest and Range Fires

Richard C. Rothermel



THE AUTHOR

RICHARD C. ROTHERMEL is a research engineer stationed at the Northern Forest Fire Laboratory in Missoula, Mont. Rothermel received his B.S. degree in aeronautical engineering at the University of Washington in 1953. He served in the U.S. Air Force as a special weapons aircraft development officer from 1953 to 1955. Upon his discharge he was employed at Douglas Aircraft Co. as a designer and trouble shooter in the armament group. From 1957 to 1961 Rothermel was employed by the General Electric Co. in the aircraft nuclear propulsion department at the National Reactor Testing Station in Idaho. In 1961 Rothermel joined the Northern Forest Fire Laboratory, where he has been engaged in research on the mechanisms of fire spread. He received his master's degree in mechanical engineering at the University of Colorado, Fort Collins, in 1971. He was project leader of the Fire Fundamentals Research Work Unit from 1966 until 1979 and is currently project leader of the Fire Behavior Research Work Unit at the fire laboratory.

RESEARCH SUMMARY

This manual documents the procedures for estimating the rate of forward spread, intensity, flame length, and size of fires burning in forests and rangelands. It contains instructions for obtaining fuel and weather data, calculating fire behavior, and interpreting the results for application to actual fire problems. Potential uses include fire prediction, fire planning, dispatching, prescribed fires, and monitoring managed fires.

Included are sections that deal with fuel model selection, fuel moisture, wind, slope, calculations with nomograms, TI-59 calculations, point source, line fire, interpretations of outputs, and growth predictions.

PREFACE

When Hal Anderson and I came to the Northern Forest Fire Laboratory in 1961, it was not yet a year old and there was a feeling that surely this lab was going to contribute. Just what would be accomplished was not entirely clear, but things were going to happen. There was also a sense of being overwhelmed, not only by all the unknowns of wildfire behavior, but also by how to use this brand new facility. There were at least two schools of thought in regard to the wind tunnels: (1) bring in box-car loads of fuel from all over the country for burning in the wind tunnels, and (2) weld the doors shut until a logical plan for use of the facilities was developed.

We did not weld the doors and we did not ship in fuel by the box-car load, but we did work hard at understanding fire spread and adapting concepts of modeling and systems to the problems of forest fire prediction. During the first 10 years a fire behavior model was produced. It took 10 more years to learn how to obtain the inputs and interpret the outputs for use by the "man on the ground," which culminated in the writing of this manual. Specialized versions of the prediction methods have been available for some time in automated forms, such as the National Fire Danger Rating System and the slash hazard appraisal system.

No manual of this size, covering the diverse material needed to analyze fire conditions, can be a solo production. It could not have been done without the man who crusaded for the laboratory facilities and who was the first lab chief, Jack Barrows. His paper (Barrows 1951) showed us "industry types" how fire could be examined, but more importantly his continual optimism and confidence gave us the inspiration so necessary for a project that was to take 20 years to pull together.

Many outstanding people have worked on this problem, as shown by the publications cited. I must single out a few for special acknowledgment, mostly members of Research Work Unit 2103 at one time or another.

No one could ask for a steadier and more reliable partner in a 20-year endeavor than Hal Anderson, who started work at the lab with me in 1961. He and Jim Brown, who came a couple of years later, are recognized leaders in fuel research. Bill Frandsen joined the project in 1967 and the scientific staff at that time consisted of just Bill and me. Bill established the basis for the fire spread model with his analysis of the conservation of energy on a spreading fire. Charlie Philpot came to the lab while he was earning his Ph.D. under Dr. Shafizadeh at the University of Montana and gave great assistance in the area of fuel chemistry. We were exceedingly fortunate to have excellent technicians during this time, including Merlin Brown, who ran the wind tunnels, Bob Schuette, who constructed innumerable fuel beds, Walt Wallace, who handled the chemical analysis, and Bobbie Hartford, an invaluable assistant in the field and in the lab.

In the late 60's the idea of fire management generated a whole new list of problems for research that were spelled out in a paper by Chandler and Roberts (1973). Fortunately, about this time we hired Frank Albini, an outstanding analyst who straightened out our modeling and let the genie out of the bottle with publication of his book of nomographs in 1976. That same year the first fire behavior officers' (FBO's) course was organized at Marana, Ariz. Ernie Anderson, director of the training center at Marana, insisted that we put together a fire prediction system that a man could use on the line or in a plans tent and teach it in 2 weeks. I am not sure how to describe the early sessions, but students who have taken the course hail each other as graduates or survivors of the class of '76 or '77, etc. The course was successful; however, some of the early material was so weak that the students should have chased all of us instructors off the base. Instead, their support encouraged us to improve the course and eventually to write this manual. Students who successfully complete the course can now receive 2 hours of credit at the University of Arizona.

Ernie Anderson also predicted that we would have computers on the fireline. Three years later a project initiated by John Deeming, Jack Cohen, and Bob Burgan, and finished by Bob Burgan, resulted in just that—a microchip for the TI-59 calculator. During the transition from nomograms to calculator, Pat Andrews from our project has superseded me as an instructor at Marana; her interest in applying research results has resulted in outstanding contributions to fire management.

Instructors from many places have participated since the first class. Steve Sackett took on the difficult task of bringing realism to fuel moisture assessment and the tough job of providing fuel beds for burning each year. The meteorologists, Clyde O'Dell, Frank Gift, and Dave Goens, have made that difficult subject understandable.

The instruction for FBO's at Marana has now been largely taken over by experienced field personnel who were former students. Some have made outstanding contributions to fire technology; these include Dave Aldrich, Rod Norum, Jim Elms, and John Chapman from the class of '76; George Rinehart, John Shepherd, Gordie Schmidt, and Bill Williams, class of '77; Larry Keown, Ed Mathews, Ron Prichard, Jan Van Wagtendonk, and Mike Templeton, class of '78; and Randy Doman and Steve Holscher from the class of '79.

Of course the hardest workers on this text, with its endless tables, figures, exhibits, exercises, and examples, as well as revisions, have been Lucille Davis and Gladys Look, our clerks, and Carolyn Chase, a mathematician who has organized all of the material for publication.

This is not a complete list of contributors; others are mentioned in the text, and considerable support came from the directors at Marana, Ernie Anderson, Jerry Mauk, and Dick Henry, and course leaders Joe Duft, Larry Mahaffey, Bonnie Turner, Hank LaSala, and Don Willis. The staff of the Intermountain Research Station must be recognized for its accomplishments in technology transfer and for allowing so much time and effort to be devoted to an area normally shunned by research. I appreciate their support.

To everyone I express a heartfelt thank you.

CONTENTS

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

Richard C. Rothermel

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 century. 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 preprogramed 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, Ariz.

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

CHAPTER I

PREDICTING FIRE BEHAVIOR

The procedures for predicting fire behavior include three primary sections:

1. 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 I-1.

The primary method of interpreting the inputs is a fire model (Rothermel 1972) that has been adapted for calculation on graphs or 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 compactness 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 I-2. Methods for verifying the procedures given in this manual in various fuel and environmental situations are offered by Rothermel and Rinehart (1983).

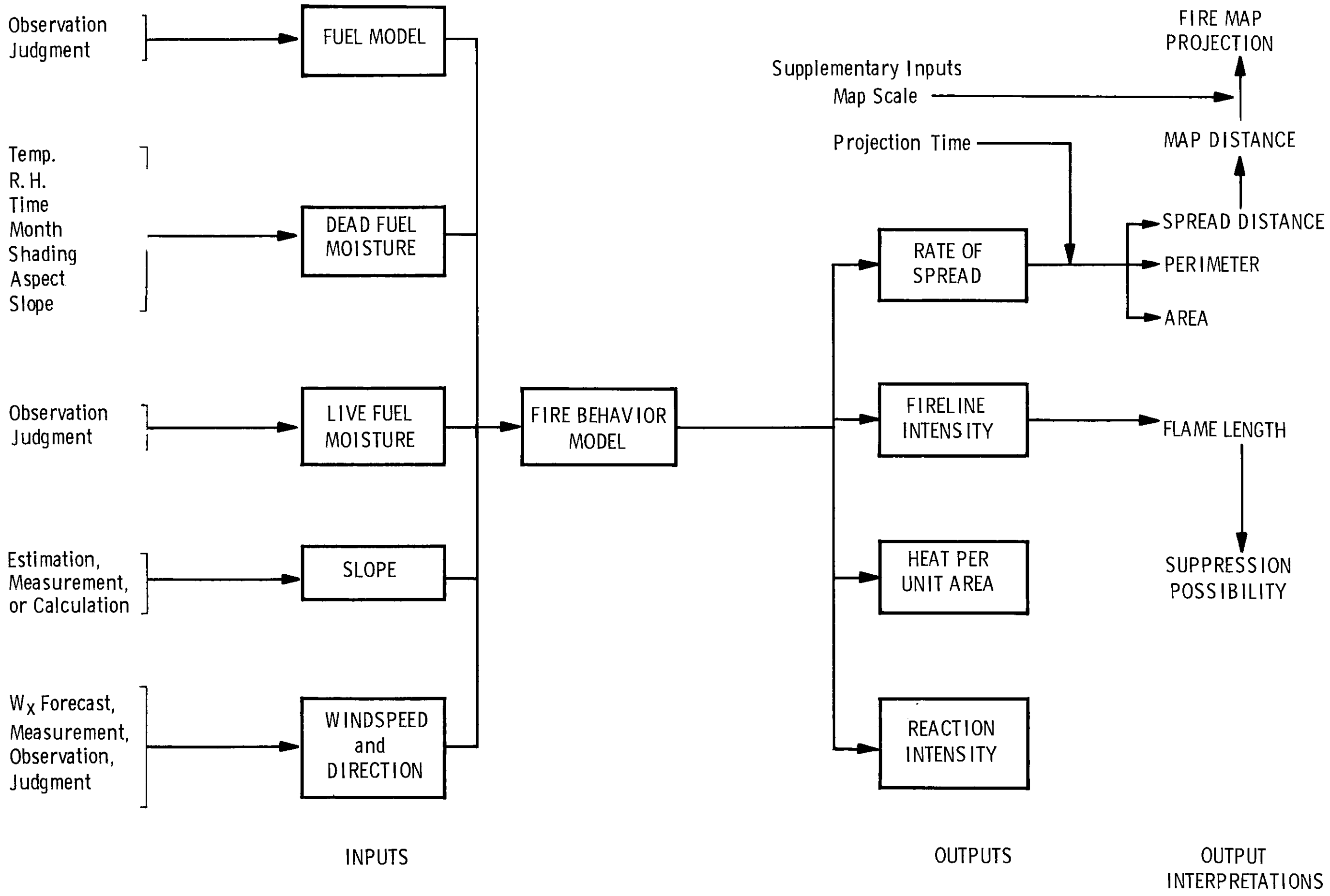

Figure I-1.—Fire behavior prediction system information flow.

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[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.

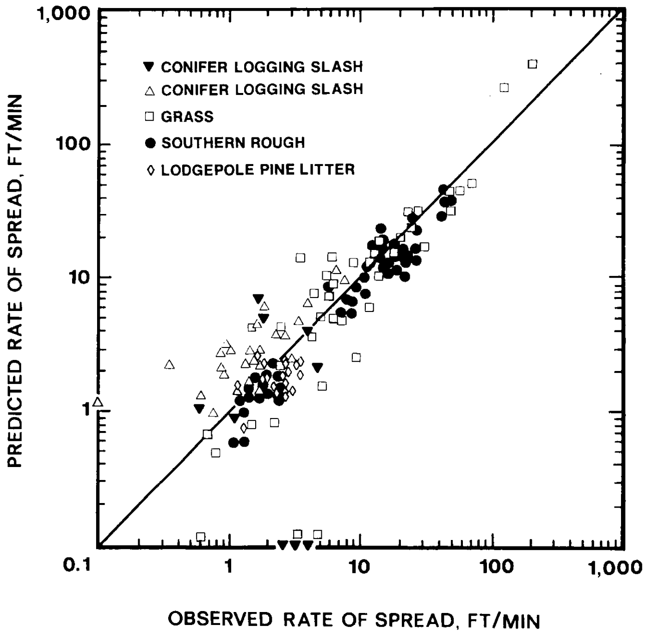

Figure I-2.—Field verification of the linear trend between predicted and observed spread rates for a wide range of fuels. The logarithmic scales dampen scatter at high spread rate while increasing it at low values. Data obtained from these sources: conifer logging slash (solid triangles), Bevins (1976); conifer logging slash (open triangles), Brown (1972); grass, Sneeuwjagt and Frandsen (1966); southern rough, Hough and Albini (1978); 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 fires. 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)[2] 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.

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[2] 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.[3] 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 advanced 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,[4] 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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[3] 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.

[4] 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 cross-slope. 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 fire lines 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.

CHAPTER II

OBTAINING INPUTS

Many factors influence fire behavior in wildland fuels. The primary factors are fuels, weather, and topography. The influence of weather on fire behavior is expressed through fuel moisture and wind. Thus the four primary inputs to the fire model are fuels, fuel moisture, wind, and slope. Second-order variables such as temperature, humidity, shading, and sheltering operate through one of the four primary groups. These are discussed in separate sections.

To predict fire behavior by means of the fire model, descriptors of all the influencing factors must be expressed in numerical form. These inputs determine the final outputs. To avoid confusion and to maintain a record, a fire behavior worksheet is provided for recording the inputs and for calculating the results, or outputs. The worksheet, exhibit II-1, is usable with nomograms or the TI-59 calculator. Data for each calculation are recorded in one column. As the inputs are developed, they are recorded on the appropriate line described in the text. The back of the fire behavior worksheet provides a form to aid in estimating dead fuel moisture. Chapter II is devoted to describing how to assess the input values needed on the worksheet. Details on the use of the fire behavior worksheet are provided in chapter III.

Exhibit II-1.—Fire behavior worksheet.

Sheet _____ of _____

NAME OF FIRE ______________________________ FIRE BEHAVIOR OFFICER ________________

DATE ______________________________ TIME ______________________________

PROJ. PERIOD DATE ______________________________ PROJ. TIME FROM __________ to __________

INPUT DATA							TI-59 Reg. No.
1	Projection point		_____	_____	_____	_____	
2	Fuel model proportion, %		_____	_____	_____	_____	
3	Fuel model		_____	_____	_____	_____	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	_____	_____	_____	_____	60
5	Dry bulb temperature, °F	DB	_____	_____	_____	_____	61
6	Relative humidity, %	RH	_____	_____	_____	_____	62
7	1 H TL FM, %	1H	_____	_____	_____	_____	28
8	10 H TL FM, %	10H	_____	_____	_____	_____	63
9	100 H TL FM, %	100H	_____	_____	_____	_____	30
10	Live fuel moisture, %	LIVE	_____	_____	_____	_____	33
11	20-foot windspeed, mi/h		(_____)	(_____)	(_____)	(_____)	
12	Wind adjustment factor		(_____)	(_____)	(_____)	(_____)	
13	Midflame windspeed, mi/h	M WS	_____	_____	_____	_____	79
14	Maximum slope, %	PCT S	_____	_____	_____	_____	80
15	Projection time, h	PT	_____	_____	_____	_____	81
16	Map scale, in/mi	MS	_____	_____	_____	_____	82
17	Map conversion factor, in/ch		_____	_____	_____	_____	
18	Effective windspeed, mi/h		_____	_____	_____	_____	

OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	_____	_____	_____	_____	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	_____	_____	_____	_____	90
21	Fireline intensity, Btu/ft/s	[B]	INT	_____	_____	_____	_____	53
22	Flame length, ft	[R/S]	FL	_____	_____	_____	_____	54
23	Spread distance, ch	[C]	SD	_____	_____	_____	_____	42
24	Map distance, in	[R/S]	MD	_____	_____	_____	_____	43
25	Perimeter, ch	[D]	PER	_____	_____	_____	_____	40
26	Area, acres	[R/S]	AREA	_____	_____	_____	_____	89
27	Ignition component, %	[E]	IC	_____	_____	_____	_____	44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	_____	_____	_____	_____	52

Exhibit II-1.— (con.) Fine dead fuel moisture calculations.

a. Projection point				
b. Day or night (D/N)	D/N	D/N	D/N	D/N

DAY TIME CALCULATIONS

c. Dry bulb temperature, °F				
d. Relative humidity, %				
e. Reference fuel moisture, % (from table A)				
f. Month				
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time				
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect				
k. Slope				
l. Fuel moisture correction, % (from table B, C, or D)				
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)				

NIGHT TIME CALCULATIONS

n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				

Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.

q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location(from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

Fuels

HOW FUELS ARE DESCRIBED

This section presents methods for characterizing fuels for input to the fire model. The fire model requires specific fuel information described in numerical terms. These include:

- Fuel loading - the mass of fuel per unit area, live and dead, grouped by particle size classes.
- Surface area to volume ratio of each size group.
- Fuel depth - ft
- Fuel particle density - lb/ft^3
- Heat content of fuel - Btu/lb
- Moisture of extinction - the upper limit of fuel moisture content beyond which the fire will no longer spread with a uniform front.[1]

Measuring these fuel properties is too slow for wildfire predictions. An alternative method that utilizes predescribed fuel arrangements called fuel models is provided. Fuel models have been developed that represent most surface fuels you are likely to encounter. Each fuel model contains all of the numerical values (listed above) needed by the fire spread model. The task then is to choose the most appropriate fuel model (or in the case of some nonuniform fuels, two fuel models), representing the area where fire spread is to be predicted.

SELECTING FUEL MODELS

The fuel models for calculating fire behavior are those used by Albini (1976) to develop the nomograms published in his paper, "Estimating Wildfire Behavior Effects." There are 13 models, including 11 developed by Anderson and Brown and published by Rothermel (1972), a model for dead brush developed at the suggestion of Von Johnson,[2] and a model for southern rough developed by Albini. These are called the "NFFL fuel models"; or "fire behavior models." The models are described in table II-1. They are tuned to the fine fuels that carry the fire and thus describe the conditions at the head of the fire. They were developed for the time of year when fires burn well. There is no provision for changing the proportions of living and dead fuel.

Anderson (1982) describes and provides typical photographs of each of the 13 fuel models. The written descriptions are reproduced here in the section, "Fuel Model Descriptions." Anderson also provides a similarity chart for cross referencing the 13 NFFL fuel models to the 20 fuel models used in the National Fire Danger Rating System.

A key is provided to help select the model. It leads to a suggested model, which may be confirmed with Anderson's description. If the fuels are not uniform enough to describe with a single model, the two-fuel-model concept may be appropriate.

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[1] Moisture of extinction is dependent upon compactness of the fuel, its depth, particle size, windspeed, and slope. When conditions are favorable for burning, its effect on fire spread and intensity is low, but when conditions for burning are poor, it can cause significant changes in predicted behavior.

[2] Fire research scientist, then at East Lansing, Mich., who recognized the need for fuel model 6 for much of the area for which he was responsible.

Table II-1.—Description of NFFL fuel models used in fire behavior[1]

Fuel model	Typical fuel complex	Fuel loading				Fuel bed depth	Moisture of extinction dead fuels
		1 h	10 h	100 h	Live		
	Grass and Grass-Dominated	*tons/acre*				*Feet*	*Percent*
1	Short grass (1 ft)	0.74	--	--	--	1.0	12
2	Timber (grass and understory)	2.0	1.0	0.50	0.50	1.0	15
3	Tall grass (2.5 ft)	3.0	--	--	--	2.5	25
	Chaparral and Shrub Fields						
4	Chaparral (6 ft)	5.0	4.0	2.0	5.0	6.0	20
5	Brush (2 ft)	1.0	.50	--	2.0	2.0	20
6	Dormant brush, hardwood slash	1.5	2.5	2.0	--	2.5	25
7	Southern rough	1.1	1.9	1.5	.37	2.5	40
	Timber Litter						
8	Closed timber litter	1.5	1.0	2.5	--	.2	30
9	Hardwood litter	2.9	.41	.15	--	.2	25
10	Timber (litter and understory)	3.0	2.0	5.0	2.0	1.0	25
	Slash						
11	Light logging slash	1.5	4.5	5.5	--	1.0	15
12	Medium logging slash	4.0	14.0	16.5	--	2.3	20
13	Heavy logging slash	7.0	23.0	28.0	--	3.0	25

[1] Documented by Albini (1976) and Rothermel (1972).

The availability of only 13 fuel models to describe all the fuels in the United States may seem very limiting. The two-fuel-model concept, however, expands this number considerably. The two-fuel-model concept depends upon the proportional coverage of an area by two fuels. (The method is fully described in this section.)

Fire behavior estimates will be simpler if a single fuel model can be found to describe the fuels. In fact, as experience is gained from observing fires and estimating behavior, it is possible to select a fuel model, not only from a description of the physical properties of the vegetation, but also by the fire behavior characteristics it is known to produce. Experienced fire behavior officers, working in one or two fuel types, have learned to calibrate or tune the answers to more closely match fire behavior (Norum 1982). Methods for calibrating a fuel to match the behavior in a specific fuel type are provided by Rothermel and Rinehart (1983).

Considerations in Selecting a Fuel Model

1. Determine the general vegetation type, i.e., grass, brush, timber litter, or slash.
2. Estimate which stratum of surface fuel is most likely to carry the spreading fire. For instance, the fire may be in a timbered area, but the timber is relatively open and dead grass, not needle litter, is the stratum carrying the fire. In this case, fuel model 2, which is not listed as a timber model, should be considered. In the same area if the grass is sparse and there is no wind or slope, the needle litter would be the stratum carrying the fire and fuel model 9 would be a better choice.
3. Note the general depth and compactness of the fuel. This information will be needed when using the fuel model key. These are very important considerations when matching fuels, particularly in the grass and timber types.
4. Determine which fuel classes are present and estimate their influence on fire behavior. For instance, green fuel may be present, but will it play a significant role in fire behavior? Large fuels may be present, but are they sound or decaying and breaking up? Do they have limbs and twigs attached or are they bare cylinders? You must look for the fine fuels and choose a model that represents their depth, compactness, and to some extent, the amount of live fuel and its contribution to fire. Do not be restricted by what the model name is or what its original application was intended to be.
5. Using these observations, proceed through the fuel model key and the descriptions provided by Anderson (1982) to select a fuel model.
6. Record the selected fuel model on line 3 of the fire behavior worksheet.

NFFL Fuel Model Key[3]

I. PRIMARY CARRIER OF THE FIRE IS GRASS. Expected rate of spread is moderate-to-high, with low-to-moderate fireline intensity (flame length).

A. Grass is fine structured, generally below knee level, and cured or primarily dead. Grass is essentially continuous.
SEE THE DESCRIPTION OF MODEL 1.

B. Grass is coarse structured, above knee level (averaging about 3 ft) and is difficult to walk through.
SEE THE DESCRIPTION OF MODEL 3.

C. Grass is **usually** under an open timber, or brush, overstory. Litter from the overstory is involved, but grass carries the fire. Expected spread rate is slower than fuel model 1 and intensity is less than fuel model 3.
SEE THE DESCRIPTION OF MODEL 2.

II. PRIMARY CARRIER OF THE FIRE IS BRUSH OR LITTER BENEATH BRUSH. Expected rates of spread and fireline intensities (flame length) are moderate-to-high.

A. Vegetative type is southern rough or low pocosin. Brush is generally 2 to 4 ft high.
SEE THE DESCRIPTION OF MODEL 7.

B. Live fuels are absent or sparse. Brush averages 2 to 4 ft in height. Brush requires moderate winds to carry fire.
SEE THE DESCRIPTION OF MODEL 6.

C. Live fuel moisture **can** have a significant effect on fire behavior.

1. Brush is about 2 ft high, with light loading of brush litter underneath. Litter may carry the fire, especially at low windspeeds.
SEE THE DESCRIPTION OF MODEL 5.

2. Brush is head-high (6 ft), with heavy loadings of dead (woody) fuel. Very intense fire with high spread rates expected.
SEE THE DESCRIPTION OF MODEL 4.

3. Vegetative type is high pocosin.
SEE THE DESCRIPTION OF MODEL 4.

III. PRIMARY CARRIER OF THE FIRE IS LITTER BENEATH A TIMBER STAND. Spread rates are low-to-moderate; fireline intensity (flame length) may be low-to-high.

A. Surface fuels are mostly foliage litter. Large fuels are scattered and lie on the foliage litter; that is, large fuels are not supported above the litter by their branches. Green fuels are scattered enough to be insignificant to fire behavior.

1. Dead foliage is **tightly compacted**, short needle (2 inches or less) conifer litter or hardwood litter.
SEE THE DESCRIPTION OF MODEL 8.

2. Dead foliage litter is **loosely compacted** long needle pine or hardwoods.
SEE THE DESCRIPTION OF MODEL 9.

B. There is a significant amount of larger fuel. Larger fuel has attached branches and twigs, or has rotted enough that it is splintered and broken. The larger fuels are fairly well distributed over the area. Some green fuel may be present. The overall depth of the fuel is probably below the knees, but some fuel may be higher.
SEE THE DESCRIPTION OF MODEL 10.

C. Fuels are nonuniform, the area is mostly covered with litter interspersed with accumulations of dead and downed material (jackpots).
SEE THE TWO-FUEL-MODEL CONCEPT.

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[3] Gordie Schmidt (of R-6 and the PNW Station) has been especially helpful in reviewing and suggesting changes in the fuel model key.

IV. PRIMARY CARRIER OF THE FIRE IS LOGGING SLASH. Spread rates are low-to-high, fireline intensities (flame lengths) are low-to-very high.

A. Slash is aged and overgrown.

1. Slash is from hardwood trees. Leaves have fallen and cured. Considerable vegetation (tall weeds) has grown in amid the slash and has cured or dried out.
SEE THE DESCRIPTION OF MODEL 6.

2. Slash is from conifers. Needles have fallen and considerable vegetation (tall weeds and some shrubs) has overgrown the slash.
SEE THE DESCRIPTION OF MODEL 10.

B. Slash is fresh (0–3 years or so) and not overly compacted.

1. Slash is not continuous. Needle litter or small amounts of grass or shrubs must be present to help carry the fire, but primary carrier is still slash. Live fuels are absent or do not play a significant role in fire behavior. The slash depth is about 1 ft.
SEE THE DESCRIPTION OF MODEL 11.

2. Slash generally covers the ground (heavier loadings than Model 11), though there may be some bare spots or areas of light coverage. Average slash depth is about 2 ft. Slash is not excessively compacted. Approximately one-half of the needles may still be on the branches but are not red. Live fuels are absent, or are not expected to affect fire behavior.
SEE THE DESCRIPTION OF MODEL 12.

3. Slash is continuous or nearly so (heavier loadings than Model 12). Slash is not excessively compacted and has an average depth of 3 ft. Approximately one-half of the needles are still on the branches and are red, OR all the needles are on the branches but they are green. Live fuels are not expected to influence fire behavior.
SEE THE DESCRIPTION OF MODEL 13.

4. Same as 3, EXCEPT all the needles are attached and are red.
SEE THE DESCRIPTION OF MODEL 4.

NFFL Fuel Model Descriptions

These descriptions are taken from Anderson's book (1982) and should be used in conjunction with the fuel model key.

Grass Group

Fire behavior fuel model 1.—Fire spread is governed by the fine herbaceous fuels that have cured or are nearly cured. Fires move rapidly through cured grass and associated material. Very little shrub or timber is present, generally less than one-third of the area.

Grasslands and savanna are represented along with stubble, grass tundra, and grass-shrub combinations that meet the above area constraint. Annual and perennial grasses are included in this fuel model.

Fire behavior fuel model 2.—Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, besides litter and dead-down stemwood from the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands and pine stands or scrub oak stands that cover one-third or two-thirds of the area may generally fit this model, but may include clumps of fuels that generate higher intensities and may produce firebrands. Some pinyon-juniper may be in this model.

Fire behavior fuel model 3.—Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. The fire may be driven into the upper heights of the grass stand by the wind and cross standing water. Stands are tall, averaging about 3 ft, but may vary considerably. Approximately one-third or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses.

Shrub Group

Fire behavior fuel model 4.—Fire intensity and fast-spreading fires involve the foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory. Stands of mature shrub, 6 or more feet tall, such as California mixed chaparral, the high pocosins along the east coast, the pine barren of New Jersey, or the closed jack pine stands of the North Central States are typical candidates. Besides flammable foliage, there is dead woody material in the stand that significantly contributes to the fire intensity. Height of stands qualifying for this model depends on local conditions. There may be also a deep litter layer that confounds suppression efforts.

Fire behavior fuel model 5.—Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs, and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. Shrubs are generally not tall, but have nearly total coverage of the area. Young, green stands such as laurel,[4] vine maple, alder, or even chaparral, manzanita, or chamise with no deadwood would qualify.

Fire behavior fuel model 6.—Fire carries through the shrub layer where the foliage is more flammable than fuel model 5, but requires moderate winds, greater than 8 mi/h at midflame height. Fire will drop to the ground at low windspeeds or openings in the stand. The shrubs are older, but not as tall as shrub types of model 4, nor do they contain as much fuel as model 4. A broad range of shrub conditions is covered by this model. Fuel situations to consider include intermediate-aged stands of chamise, chaparral, oak brush, and low pocosin. Even hardwood slash that has cured out can be considered. Pinyon-juniper shrublands may be represented, but the rate of spread may be overpredicted at windspeeds less than 20 mi/h.

Fire behavior fuel model 7.—Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammable nature of live foliage and other live material. Stands of shrubs are generally between 2 and 6 ft high. Palmetto-gallberry understory within pine overstory sites are typical and low pocosins may be represented. Black spruce-shrub combinations in Alaska may also be represented.

Timber Group

Fire behavior fuel model 8.—Slow-burning ground fires with low flame heights are the rule, although the fire may encounter an occasional "jackpot" or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose

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[4] Recent information indicates that laurel may be more flammable than model 5 indicates.

fire hazards. Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and some twigs since little undergrowth is present in the stand. Representative conifer types are white pines, lodgepole pine, spruce, fir, and larch.

Fire behavior fuel model 9.—Fires run through the surface litter faster than model 8 and have higher flame height. Both long-needle conifer and hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are representative, but high winds will actually cause higher rates of spread than predicted. This is due to spotting caused by rolling and blowing leaves. Closed stands of long-needled pine like ponderosa, Jeffrey, and red pines or southern pine plantations are grouped in this model. Concentrations of dead-down woody material will contribute to possible torching out of trees, spotting, and crowning.

Fire behavior fuel model 10.—The fires burn in the surface and ground fuels with greater fire intensity than the other timber litter models. Dead down fuels include greater quantities of 3-inch or larger limbwood resulting from overmaturity or natural events that create a large load of dead material on the forest floor. Crowning out, spotting, and torching of individual trees is more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; for example, insect- or disease-ridden stands, wind-thrown stands, overmature stands with deadfall, and aged slash from light thinning or partial cutting.

Logging Slash Group

Fire behavior fuel model 11.—Fires are fairly active in the slash and herbaceous material intermixed with the slash. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered. Clearcut operations generally produce more slash than represented here. The less-than-3-inch material load is less than 12 tons per acre. The greater-than-3-inch material is represented by not more than 10 pieces, 4 inches in diameter, along a 50-ft transect.

Fire behavior fuel model 12.—Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression is dominated by slash, much of it less than 3 inches in diameter. These fuels total less than 35 tons per acre and seem well distributed. Heavily thinned conifer stands, clearcuts, and medium or heavy partial cuts are represented. The greater-than-3-inch material is represented by encountering 11 pieces, 6 inches in diameter, along a 50-ft transect.

Fire behavior fuel model 13.—Fire is generally carried across the area by a continuous layer of slash. Large quantities of greater-than-3-inch material are present. Fires spread quickly through the fine fuels and intensity builds up more slowly as the large fuels start burning. Active flaming is sustained for long periods and firebrands of various sizes may be generated. These contribute to spotting problems as the weather conditions become more severe. Clearcuts and heavy partial cuts in mature and overmature stands are depicted where the slash load is dominated by the greater-than-3-inch material. The total load may exceed 200 tons per acre, but the less-than-3-inch fuel is generally only 10 percent of the total load. Situations where the slash still has "red" needles attached but the total load is lighter, more like model 12, can be represented because of the earlier high intensity and quicker area involvement.

The Two-Fuel-Model Concept

If nonuniformity of the fuel makes it impossible to select a fuel model from part I, then the two-fuel-model concept may be useful.

The two-fuel-model concept is designed to account for changes in fuels in the horizontal direction, i.e., as the fire spreads, it will encounter significantly different fuels. The concept depends upon the size of the fire being large with respect to the size of the fuel arrangements causing the discontinuity. By this it is meant that the length of the fireline is long enough so that at any one time the fireline extends through both fuel types in several locations and that as the fire spreads it will encounter both fuel types repeatedly during the length of the prediction period. If this is not the case, it is likely that you will have two distinct burning conditions and the averaging process used for estimating spread rate will be meaningless. The larger the fire and the farther it travels, the larger the fuel patches can be when applying this concept.

Another consideration is that if one fuel does not make up at least 20 percent of the area, fire spread will be dominated by the other fuel and it is not worth attempting to apportion the spread rate between two fuels.

The concept assumes that horizontally nonuniform fuels can be described by two fuel models in which one represents the dominant vegetative cover over the area, and the second represents fuel concentrations that interrupt the first. For example, in a forest stand the dominant fuel strata over most of the area may be short-needle litter (fuel model 8), with concentrations of dead and down limbwood and treetops. Depending on the nature of these jackpots, they could be described by model 10 or one of the slash models, 12 or 13. An important feature of the concept is that it is not necessary to try to integrate the effect of both the needle litter and limbwood accumulation into one model. Two distinct choices can be made.

The two-fuel-model concept may also be applied to rangeland, where grass may dominate the area, along with patches of brush. Of course, the system will work vice versa, where brush is dominant, with occasional patches of grass.

The process is begun with four steps:

1. Select a fuel model from the key that represents the dominant cover—50 percent or more of the area.
2. From the key, select a fuel model that represents fuel concentrations within the area that interrupt the dominant cover.
3. Estimate the percentage of cover for the two fuels. The sum of the two should equal 100 percent.
4. Record the selected fuel models on line 3 of the fire behavior worksheet in two separate columns. Record the estimated proportional coverage of each model on line 2. This completes the information needed as inputs to the two-fuel-model concept. Calculating spread rate and interpreting intensity are explained in chapter III.

Fuel Moisture

BACKGROUND

The amount of moisture contained in wildland fuels is extremely important in determining fire behavior. The fire model utilizes fuel moisture in the determination of both fire intensity and the heat required to bring the fuel ahead of a spreading fire up to ignition temperature. The objective of this section is to provide methods for estimating fuel moisture from on-site weather measurements, or a weather forecast, or both. The moisture condition of the fine fuels is of primary importance in spreading fires. Some fuel models contain both living and dead fuels; consequently the moisture of each must be considered. In the case of live fuels, foliage moisture is of primary importance. Table II-1 and the nomograms indicate which fuel models contain live fuels.

Estimates of fuel moisture from **on-site measurements** of temperature, humidity, and shade can be made with the TI-59 CROM as described by Burgan (1979). The tabular method described here is preferred because its versatility allows estimates to be made at sites with different slope, aspect, season, and time of day, as well as from weather forecasts for locations where on-site measurements can't be made.

CAUTION: Both the tabular and TI-59 procedures for estimating fuel moisture from temperature and humidity assume that there has not been recent precipitation. If there has been precipitation, several hours of good drying are necessary before the fine fuel moisture estimates can be relied upon to be reasonable. Blackmarr (1971) has found that fine fuels that have been saturated with moisture and are drying (desorption) can be 3 to 5 percent higher in fuel moisture than fine fuels that have been dry and are gaining moisture (adsorption). If you are concerned with fuels that have been wetted recently by precipitation or dew, a correction of 3 to 5 percent may be added to the fuel moisture obtained from the procedures in this section.

Fuel moisture is simply an expression of the amount of water in a fuel component. It is standard practice to express fuel moisture as a percentage of the ovendry weight, and this is the form used to calculate fire behavior. Fuel moisture is the result of past and present weather events. Values can range as low as 1 to 2 percent in extreme drought conditions in the Southwest to more than 200 percent for live fuels. Weather affects live fuels quite differently than dead fuels; therefore methods for estimating their values are different. Live fuel moisture can range as low as 40 percent in some Southwest chaparral and the plants will still recover; however, most plants that become that dry will die. Dead fuel moistures are usually less than 30 percent. Some dead fuels in the Southeast can carry fire at 40 percent moisture, but it is unusual for fires to spread when the dead fuel moisture is that high.

Live fuel moisture values are a result of physiological changes in the plant. These are due mainly to the time of the season, precipitation events, the temperature trend, and the species. Dead fuels respond to day-to-day and hourly changes in the microclimate surrounding the fuel particle.

LIVE FUEL MOISTURE ESTIMATION

Live moisture may be evaluated in three ways:

1. Sampling and measurement.
2. From a current record of a nearby National Fire Danger Rating station.
3. Estimation from observation and a table of indicators and values.

Drying and weighing fuels is impractical for wildfire application. Moisture values in the National Fire Danger Rating System must be used with care, especially in mountainous terrain where elevation and aspect will result in moisture values far different from those taken at a valley weather station.

The favored method for quickly determining live fuel moisture at remote locations is through estimation of the stage of plant development, and the interpretations provided by table II-2. Record the value of the live fuel moisture on line 10 of the fire behavior worksheet. Note that the moisture values are spaced by large increments in the high range. This is because at high moisture values, where the live fuel will not support combustion by itself, the fire model is not as sensitive to the moisture level as it is at lower values. Above 200 percent, estimate to the nearest 100 percent; between 100 and 200 percent estimate by 50 percent; below 100 percent try to achieve 25 percent or better. Check publications that describe green fuel moisture and how it changes with the season for vegetation in your area. Many of the fuel models do not contain live fuels and it is not necessary to estimate the live fuel moisture for them.

Table II-2.— Guidelines for estimating live fuel (foliage) moisture content. Live fuel moisture is required for fuel models 2, 4, 5, 7, and 10. If data are unavailable for estimating live fuel moisture, the following rough estimates can be used

Stage of vegetative development	Moisture content
	Percent
Fresh foliage, annuals developing, early in growing cycle	300
Maturing foliage, still developing with full turgor	200
Mature foliage, new growth complete and comparable to older perennial foliage	100
Entering dormancy, coloration starting, some leaves may have dropped from stem	50
Completely cured	Less than 30, treat as a dead fuel

Example: Suppose you are in a brush area with considerable living foliage and you have chosen fuel model 5. It is early fall, the leaves are just beginning to change color, none of them have dropped, and some foliage seems in summer condition. According to table II-2, the foliage would be between 50 and 100 percent moisture content. So estimate a value of 75 percent and enter it on line 10 of the fire behavior worksheet.

Grass Fuels—Cured or Not?

The grass fuel models are preset for the time of year when burning conditions are rather severe. The grass fuels are assumed to be completely cured—that is, less than 30 percent fuel moisture. Even fuel model 2, which has a small amount of live fuel, acts as a cured grass model. The three grass models work well for cured conditions, but do not represent other times of the year when the grass is green.

DEAD FUEL MOISTURE

A unique system for classifying dead fuels uses the length of time required for a fuel particle to change moisture by a specified amount when subjected to a change in its environment. It was developed by Fosberg (1971). Dead fuels are classified on the basis of 1-, 10-, 100-, and 1,000-hour classes or response times. Fine fuels, dead foliage, and twigs, or other items usually one-fourth inch or less in diameter or thickness comprise the 1-hour time class. These fuels commonly govern the rate of spread of the fire front and are given paramount attention by the fire model. Branch wood approximately one-fourth inch to 1 inch in diameter is considered 10-hour fuel while 100-hour fuels include the range from 1 to 3 inches. One-thousand-hour fuels are 3- to 8-inch logs. They are beyond the range of consideration in the fire model and are not considered in this manual.

Because dead fuels respond to temperature, humidity, and solar radiation, we must have methods to account for these effects upon fuel moisture.[5] Temperature and humidity can be dealt with in a straightforward manner. Solar radiation is a more difficult problem, particularly in mountainous terrain, where the aspect and steepness of the slope can affect the amount of solar radiation as can the amount of shading by trees and clouds. Also, day length has an important effect. These effects are accounted for in the tables for estimating dead fuel moisture.

Estimating Fine Dead Fuel Moisture with Tables

For many fire prediction situations it is necessary to estimate fuel moisture at an inaccessible location or from a weather forecast. A set of tables,[6] specifically designed for this task, is provided. The method appears complex, but in fact consists of simply determining a reference fuel moisture for worst-case conditions, and then in another table finding a correction for the fire site or projection point. There are procedures for day or night.

The back of the fire behavior worksheet provides a form for recording data and computing moisture content of the fine fuels (1-hour TL fuels). Instructions for completing the form are explained by exhibit II-2.

The method uses temperature and relative humidity to determine a reference fuel moisture. The temperature and humidity are assumed to have been measured according to standard procedures for a weather shelter, or received in a forecast. The instructions refer to a projection point (that is, the location at which you wish to predict fire behavior) and may be at a different location from where the temperature and humidity are measured or forecast.

The remaining information needed to complete the form is used to adjust for solar heating. Note that if the projection point is more than 2,000 ft above or below the elevation where temperature and humidity are measured, these tables are not applicable. You must get another measurement closer to the projection point, get a forecast for that elevation, or use the method in appendix D for making large elevation adjustments.

Also note that the time of measurement or forecast should lie within the same time period that the fire prediction is made. The tables by themselves are not used for making moisture estimates for some future time.

Estimates for valley bottoms (taken from column B in table F) are for inversion conditions. Cold air draining into a steep, narrow valley accumulates to form a pool of cold, damp air that can fill the valley to a considerable depth. This condition needs a substantial correction added to the moisture conditions at a dry site above the valley floor.

The tables may be used to adjust the moisture of fuels in valley bottoms from conditions measured on the slopes above, but do not use weather data taken beneath a valley inversion and attempt to infer fuel moistures at drier sites upslope. The corrections are too large and uncertain, and you may get meaningless results.

When extreme inversions do not exist, and the air is being mixed by general winds (downslope winds will not cause mixing), use the nighttime reference fuel moisture without correction for elevation. The corrections are for solar radiation and are not applicable at night.

If you are using nomograms to estimate fire behavior, only one dead fuel size is necessary and the adjusted value for fine fuels taken from the tables may be used directly. If larger fuels are present and are noticeably wetter than the fine fuels, then the fine fuel moisture can be adjusted to account for this effect on fire spread. This will usually occur in a drying trend because large fuels dry slower and remain wetter than the fine fuels. The adjustment should not be great unless large fuels dominate the complex. Experience with your fuels is necessary to determine the right amount of adjustment.

If the TI-59 calculator and CROM are being used, fuel moisture values obtained from the tables are entered on line 7 of the fire behavior worksheet. The calculator will estimate a 10-hour fuel moisture value from the temperature/humidity and 1-hour moisture value. To do this it is only necessary to store a zero for 10-hour fuel moisture before the calculations are begun. If you are uncertain about how to calculate 10-hour moisture with the calculator, a first approximation can be made by adding 1 percent to the 1-hour value for 10-hour fuels and 2 percent to the 1-hour value for the 100-hour fuel moisture. Enter the 10-hour fuel moisture on line 8, and the 100-hour fuel moisture on line 9.

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[5] Blackmarr (1971) presents fuel moisture data for several fuel types found in the Southeast.

[6] The unpublished tables presented here were developed from work initiated by Steve Sackett at the Rocky Mountain Station and later modified by Bob Burgan and Jack Cohen at the Intermountain Station. Tables simplified for rapid field use are given in the field handbook for the S-390 fire behavior course.

Exhibit II-2. Guidelines for fine dead fuel moisture calculations worksheet.

For each fire behavior projection point, it is necessary to include a fine, dead fuel moisture. Following is a line by line description of the worksheet to be used in calculating the appropriate fuel moisture input to the fire behavior model. This worksheet is printed on the reverse side of the fire behavior worksheet.

Values that describe conditions are either recorded on a blank line or a code letter is circled. Values that are read from tables or calculated are recorded in boxes.

		PROCEDURES
a. Projection point	________	Record the number of the projection point for which a fire behavior prediction is to be made. This corresponds to the number recorded on line 1 of the fire behavior worksheet.
b. Day or night (D/N)	D/N	Daytime projections are for 0800-1959. Nighttime projections are for 2000-0759. Circle the appropriate letter. If day, complete lines c through m. If night, complete lines n through w.
DAYTIME CALCULATIONS		Daytime calculations use c through m.
c. Dry bulb temperature, °F	________	Dry bulb temperature is determined for the time period in question either by measurement or forecast. The site location may or may not be at the projection point. Record temperature, °F.
d. Relative humidity, %	________	Record relative humidity for the time period in question.
e. Reference fuel moisture, % (from table A)	☐	Go to table A. Determine reference fuel moisture percent from the intersection of temperature and relative humidity shown on lines c and d. Record reference fuel moisture, percent.
f. Month	________	Record the month in question. This determines whether table B, C, or D is used.
g. Exposed or shaded (E/S)	E/S	Determine whether fine dead fuels ahead of projection point is EXPOSED (<50%) to solar radiation, or SHADED (≥50%) from solar radiation. This can be due to cloud cover and/or canopy cover. Circle appropriate letter.
h. Time	________	Record the expected time when the projection point will be used to estimate fire behavior. This should correspond to the time recorded in the heading of the fire behavior worksheet. The temperature/RH forecast or measurement must be for the same time period as the projection time point.
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	Record the elevational difference between the location of the projection point and temperature/RH site location. If the difference is ±1000' circle L (site location); 1000'-2000' above, circle A (above location); 1000'-2000' below circle B (below location). If the projection point is more than 2000' above or below the temperature/RH site location, get a new forecast or reading.
j. Aspect	________	Record the aspect of the projection point location.
k. Slope	________	Record the slope percent at the projection point location
l. Fuel moisture correction, % (from table B, C or D)	☐	From information on lines f, g, h, i, j, and k, determine appropriate daytime correction table (B, C, or D).
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	☐	Record the sum of lines e and l. The fine dead fuel moisture percent is determined by adding the fuel moisture correction to the reference fuel moisture. This value is transferred to line 7 of the fire behavior worksheet.

Exhibit II-2.(con).

Fine dead fuel moisture corrections.

		PROCEDURES
NIGHTTIME CALCULATIONS		Nighttime calculations use lines n through x.
n. Dry bulb temperature, °F		Dry bulb temperature is determined for the time period in question either by measurement or forecast. The site location may or may not be at the projection point. Record temperature, °F.
o. Relative humidity, %		Record relative humidity for the time period in question.
p. Reference fuel moisture, % (from table E)		Go to table E. Determine reference fuel moisture percent from the intersection of temperature and relative humidity shown on lines n and o. Record reference fuel moisture, %.
Use table F only if a strong inversion exists <u>and</u> a correction must be made for elevation or aspect change.		If a strong inversion exists <u>and</u> a correction must be made for elevation or aspect change, continue with lines q through x. Otherwise record the value from p on line x.
q. Aspect of projection point		Record the aspect of the projection point.
r. Aspect of site location		Record the aspect of the temperature/RH site location.
s. Time		Record the expected time when the projection point will be used to estimate fire behavior. This should correspond to the time recorded in the heading of the fire behavior worksheet. The temperature/RH forecast or measurement must be for the same time period as the projection point time.
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	Record the elevational difference between the location of the projection point and temperature/RH site location. If the difference is ±1000' circle L (site location); 1000'-2000' above, A (above location); 1000'-2000' below, B (below location). If the projection point is more than 2000' above or below the temperature/RH site location, get a new forecast or reading.
u. Correction for projection point location (from table F)		Go to table F. Use the information on lines q, s, and t to determine the moisture correction for the projection point.
v. Correction for site location (L) (from table F)		Go to table F. Use L and the information on lines r and s to determine the moisture correction for the temperature/RH site location.
w. Fuel moisture correction, % (line u - line v)		Determine the difference between the projection point correction and the site location correction. Subtract line v from line u. Record the difference as + or -.
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)		Determine the fine dead fuel moisture by applying the fuel moisture correction to the reference fuel moisture. Line w is added to line p (watch the sign of line w). This value is transferred to line 7 of the fire behavior worksheet.

Exhibit II-2.(con).

TABLE A

REFERENCE FUEL MOISTURE

DAY TIME
0800-1959

RELATIVE HUMIDITY (PERCENT)																					
Dry Bulb Temperature (°F)	0 ↓ 4	5 ↓ 9	10 ↓ 14	15 ↓ 19	20 ↓ 24	25 ↓ 29	30 ↓ 34	35 ↓ 39	40 ↓ 44	45 ↓ 49	50 ↓ 54	55 ↓ 59	60 ↓ 64	65 ↓ 69	70 ↓ 74	75 ↓ 79	80 ↓ 84	85 ↓ 89	90 ↓ 94	95 ↓ 99	100
10 - 29	1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	14
30 - 49	1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	13
50 - 69	1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	13
70 - 89	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
90-109	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
109+	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	12

GO TO TABLE B, C, or D FOR CORRECTIONS

TABLE B

DAYTIME
0800-1959

DEAD FUEL MOISTURE CONTENT CORRECTIONS

MAY JUNE JULY

EXPOSED – LESS THAN 50% SHADING OF SURFACE FUELS																			
		0800➤			1000➤			1200➤			1400➤			1600➤			1800➤		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30%	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	4
	31%+	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	4
E	0-30%	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	4
	31%+	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	6
S	0-30%	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	3
	31%+	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	3
W	0-30%	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	3
	31%+	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	2
SHADED – GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
E	0%+	4	4	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	6
S	0%+	4	4	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
W	0%+	4	5	6	3	4	5	3	3	4	3	3	4	3	4	5	4	4	5

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

Exhibit II-2.(con).

TABLE C

DAYTIME
0800-1959

DEAD FUEL MOISTURE CONTENT CORRECTIONS

FEBRUARY MARCH APRIL/AUGUST SEPTEMBER OCTOBER

		EXPOSED - LESS THAN 50% SHADING OF SURFACE FUELS																	
		0800 ➤			1000 ➤			1200 ➤			1400 ➤			1600 ➤			1800 ➤		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30%	3	4	5	1	2	3	1	1	2	1	1	2	1	2	3	3	4	5
	31%+	3	4	5	3	3	4	2	3	4	2	3	4	3	3	4	3	4	5
E	0-30%	3	4	5	1	2	3	1	1	1	1	1	2	1	2	3	3	4	5
	31%+	3	3	4	1	1	1	1	1	1	1	2	3	3	4	5	4	5	6
S	0-30%	3	4	5	1	2	2	1	1	1	1	1	1	1	2	3	3	4	5
	31%+	3	4	5	1	2	2	0	1	1	0	1	1	1	2	2	3	4	5
W	0-30%	3	4	5	1	2	3	1	1	1	1	1	1	1	2	3	3	4	5
	31%+	4	5	6	3	4	5	1	2	3	1	1	1	1	1	1	3	3	4
SHADED - GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	6	4	5	5	3	4	5	3	4	5	4	5	5	4	5	6
E	0%+	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6	4	5	6
S	0%+	4	5	6	3	4	5	3	4	5	3	4	5	3	4	5	4	5	6
W	0%+	4	5	6	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

TABLE D

DAYTIME
0800-1959

DEAD FUEL MOISTURE CONTENT CORRECTIONS

NOVEMBER DECEMBER JANUARY

		EXPOSED - LESS THAN 50% SHADING OF SURFACE FUELS																	
		0800 ➤			1000 ➤			1200 ➤			1400 ➤			1600 ➤			1800 ➤		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30%	4	5	6	3	4	5	2	3	4	2	3	4	3	4	5	4	5	6
	31%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0-30%	4	5	6	3	4	4	2	3	3	2	3	3	3	4	5	4	5	6
	31%+	4	5	6	2	3	4	2	2	3	3	4	4	4	5	6	4	5	6
S	0-30%	4	5	6	3	4	5	2	3	3	2	2	3	3	4	4	4	5	6
	31%+	4	5	6	2	3	3	1	1	2	1	1	2	2	3	3	4	5	6
W	0-30%	4	5	6	3	4	5	2	3	3	2	3	3	3	4	4	4	5	6
	31%+	4	5	6	4	5	6	3	4	4	2	2	3	2	3	4	4	5	6
SHADED - GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
S	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
W	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

Exhibit II-2.(con).

TABLE E

REFERENCE FUEL MOISTURE

NIGHT TIME
2000-0759

	RELATIVE HUMIDITY (PERCENT)																				
Dry Bulb Temperature (°F)	0 ↓ 4	5 ↓ 9	10 ↓ 14	15 ↓ 19	20 ↓ 24	25 ↓ 29	30 ↓ 34	35 ↓ 39	40 ↓ 44	45 ↓ 49	50 ↓ 54	55 ↓ 59	60 ↓ 64	65 ↓ 69	70 ↓ 74	75 ↓ 79	80 ↓ 84	85 ↓ 89	90 ↓ 94	95 ↓ 99	100
10 - 29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
30 - 49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
50 - 69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
70 - 89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
90 - 109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

TABLE F

NIGHT TIME
2000-0759

DEAD FUEL MOISTURE CONTENT CORRECTIONS

	2000 ➤			2200 ➤			0000 ➤			0200 ➤			0400 ➤			0600 ➤		
	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N+E	9	1	1	13	1	2	16	2	2	17	1	1	18	1	1	16	2	1
S+W	9	0	1	14	0	1	16	0	2	17	0	1	18	0	0	9	0	1

NOTE: A = 1000'-2000' above size
L = ±1000' of site location
B = 1000'-2000' below site

Following are two examples in which fine dead fuel moisture is calculated. The work is shown on the accompanying calculation forms.

Example 1: Calculate the dead fuel moisture given the following conditions:

Daytime
Dry bulb temperature - 80° F
Relative humidity - 20%
Slope - 35%
Aspect - North
Site exposure - Open
Month - August
Time - 1300
Sky - Clear

(a) What is the dead fuel moisture at your location?

(b) What is it 1,200 ft lower on an east aspect with the same slope?

(c) What is it at your location if the sky is cloudy or there is a forest canopy?

Solution 1: (a) 6%
(b) 4%
(c) 7%

Example 2: Calculate the dead fuel moisture given the following conditions:

Nighttime
Dry bulb temperature - 60° F
Relative humidity - 50%
Aspect - North
Time - 2300

(a) What is the dead fuel moisture at your location?

(b) What is it 700 ft higher on a south slope?

(c) If a strong inversion exists and you are located in the thermal belt, what is the dead fuel moisture 1,500 ft lower (in valley bottom) on the same slope?

Solution 2: (a) 10%
(b) 9%
(c) 22%

Wind[7]

Wind is the most variable factor required to predict fire behavior. It not only changes with time, but also in horizontal and vertical directions. This section tells how to interpret wind information obtained from forecasts or from on-site measurements into inputs for calculations. The procedures deal with the problem of interpreting wind variation over horizontal and vertical space as influenced by topography, vegetation (including trees), and type of wind. The problem of wind variation and how to cope with it during a prediction period is discussed further in the chapter on predicting fire growth from a line of fire.

Many types of wind exist, and most have a repeatable pattern that must be identified to make reliable predictions. Others are not reliable, but since they can strongly influence fire behavior they must be considered. Such winds include winds accompanying thunderstorms, whirlwinds, and nighttime high elevation winds, and are labeled "spurious winds." You may wish to add other winds in your locality to this group. For winds that are predictable, general winds and convective winds, the procedures lead to estimation of the windspeed and direction at the midflame height in surface fuels.

The fire model was developed to predict fire spread based upon the wind that would be present without influence from a fire. This greatly simplifies the problem of fire prediction because it is not necessary to predict the fire's influence upon the wind and allows a forecast to be used for predicting fire behavior. This excludes predictions in severe fire situations for which the fire model was not designed, such as running crown fires or many prescribed fire situations where in-drafts are relied upon to control fire behavior.

The standard height for wind measurements used by land management agencies in this country is 20 ft above the surface, adjusted for vegetation depth (Fischer and Hardy 1976). Most fires in surface fuels burn below the 20-ft height, and since wind is slowed significantly by friction near the surface, the 20-ft windspeed must be adjusted to obtain the correct value for predicting fire behavior. The nomograms published by Albini (1976) have a built-in correction that reduces the 20-ft windspeed by one-half to obtain the midflame windspeed. This is a good approximation for exposed fuels, but will cause overprediction of fire spread in some fuels sheltered by an overstory of trees (Albini and Baughman 1979). The 1978 fire behavior officers' course introduced nomograms revised to use midflame windspeed as the input and to provide a method of inferring midflame windspeed based on the sheltering conditions. These procedures are used in this manual.

WIND INFORMATION REQUIRED FOR PREDICTING SPREAD

The wind input value is the estimated windspeed and wind direction at a height above the surface fuel equivalent to the mid-level height of flames. This information is needed at locations around the fire perimeter where fuels, topography, or microclimate are expected to cause significantly different fire behavior. These locations are known as projection points. Usually two or three projection points are sufficient to estimate the general growth of a fire. The wind estimates should be made for time periods when the wind can be expected to remain reasonably stable. Selection of projection points is further explained in chapter IV.

SOURCES OF WIND INFORMATION

In wildfire situations you must be prepared to use the data available. A fire weather forecast is the best source of wind information. The National Weather Service has special fire weather forecasts available for many areas of the country during the fire season. The areas covered and the service centers are shown in figure II-1. On large project fires in the western United States, one may request a mobile unit and forecaster to come to the fire site. Experience has shown that communications with the forecaster will break down when you depart to a fire and for several hours after you arrive at the scene. The procedures in this section assume that soon after the initial stage of the fire you will reestablish direct access to a forecaster either by phone, radio, or on-site. To facilitate communications with the forecaster, the Fire Weather Special Forecast Request form is available (exhibit II-3). (Instructions are printed on the back of the form.) The form is used to record all meteorological data, not just wind. It also provides for documenting weather observations near the fire site to aid the forecaster.

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[7] The section on "Wind" has changed drastically since it was first taught in 1976. I wish to express sincere appreciation to Clyde O'Dell for repeatedly reformulating the lesson plan; to Frank Albini, Bob Baughman, John Deeming, Jack Cohen, and Don Latham for contributing to modeling of this difficult subject; and to Dave Goens, Frank Gift, John Deeming, and Rod Norum for review and critique.

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	Example	1a	1b	1c	
b. Day or night (D/N)		[✓ D]/N	[✓ D]/N	[✓ D]/N	D/N

DAY TIME CALCULATIONS

c. Dry bulb temperature, °F	80	80	80	
d. Relative humidity, %	20	20	20	
e. Reference fuel moisture, % (from table A)	3	3	3	
f. Month	Aug	Aug	Aug	
g. Exposed or shaded (E/S)	[✓ E]/S	[✓ E]/S	E/[✓ S]	E/S
h. Time	1300	1300	1300	
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/[✓ L]/A	[✓ B]/L/A	B/[✓ L]/A	B/L/A
j. Aspect	N	E	N	
k. Slope	35	35	35	
l. Fuel moisture correction, % (from table B, C, or D)	3	1	4	
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	6	4	7	

NIGHT TIME CALCULATIONS

n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				

Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.

q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point Example	2a	2b	2c	
b. Day or night (D/N)	D/[✓ N]	D/[✓ N]	D/[✓ N]	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F				
d. Relative humidity, %				
e. Reference fuel moisture, % (from table A)				
f. Month				
g. Exposed or shaded (E/S)	E/S	E/S	E/S	E/S
h. Time				
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
j. Aspect				
k. Slope				
l. Fuel moisture correction, % (from table B, C, or D)				
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)				
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F	60	60	60	
o. Relative humidity, %	50	50	50	
p. Reference fuel moisture, % (from table E)	10	10	10	
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point	N	S	N	
r. Aspect of site location	N	N	N	
s. Time	2300	2300	2300	
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/[✓ L]/A	B/[✓ L]/A	[✓ B]/L/A	B/L/A
u. Correction for projection point location(from table F)	1	0	13	
v. Correction for site location (L) (from table F)	1	1	1	
w. Fuel moisture correction, % (line u - line v)	0	-1	12	
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)	10	9	22	

Figure II-1.—Offices participating in fire weather program.

Visit your forecast center and discuss reporting procedures and the type of data you will need.

Weather measurements taken on-site must be used carefully. If the fire extends over several days, an array of data from around the fire can be compiled to aid in predicting windspeed, direction, time of change, and periods of persistence. The location of the measurement must be reconciled with the fire location. Data taken on ridges or mountain passes may have little direct relationship to a fire that is sheltered by topography. If these measurements are carefully documented by time of day, from locations that include valley bottoms as well as midslope and ridges, a pattern of wind behavior can emerge. With this data, the meteorological procedure called persistence forecasting can be used. The best estimate of expected weather, and more particularly wind, is that it will repeat the pattern of the preceding day if the general synoptic weather pattern does not change. Persistence forecasting should be used only when you have assurance from the fire weather forecaster that the general synoptic weather pattern will persist.

There are times when an immediate fire behavior prediction is needed for making an on-the-spot prediction or revising an old prediction. For these cases, an eye-level measurement of the windspeed can be taken at a location upwind of the fire at a distance equivalent to at least 20 flame lengths, or on the flank of the fire. Wind measurement must be practiced. The standard time for averaging windspeed measurements is 10 minutes (Fischer and Hardy 1976). Direct reading anemometers, such as the pith-ball type supplied in the belt weather kit, are impossible to average over such a long time period. Observe the anemometer for at least 2 minutes and select a speed at about the upper two-thirds between the high and low indications. That is, if the readings vary between 5 and 10 mi/h, select 8 mi/h as the representative windspeed. Repeat the reading periodically to see if the wind is increasing, decreasing, or unchanged. Crosby and Chandler (1966) give an excellent discussion of the problems of measuring windspeed with a handheld anemometer.

If an anemometer is not available, the modified Beaufort scale developed by Jemison (1934) may be used. The Beaufort scale provides estimates of windspeed based on the effect of wind upon natural surroundings. These should be considered as 20-ft winds. The scale works in wind ranges and is shown by table II-3. If unable to get close to the fire, data can be used from a location that is similar in regard to slope, aspect, elevation, and sheltering. Such measurements and estimates can be made and applied quickly without the elaborate procedures necessary to interpret a forecast described in this manual. On-site measurements are further discussed by Rothermel and Rinehart (1983).

Exhibit II-3.—Example of Fire Weather Special Forecast Request.

FIRE WEATHER SPECIAL FORECAST REQUEST

(See reverse for instructions)

I. REQUESTING AGENCY WILL FURNISH:

1. NAME OF FIRE OR OTHER PROJECT Rock Creek Burn

2. CONTROL AGENCY Gallatin N.F.

3. REQUEST MADE **TIME†** 1100 MDT **DATE** 9/3/8X

4. LOCATION *(By ¼ Sec - Sec - Twp - Range)* T 7S R6E S 14 & 15

5. DRAINAGE NAME Rock Creek

6. EXPOSURE *(NE. E. SE. etc.)* SE

7. SIZE OF PROJECT *(Acres)** 600 A

8. ELEVATION* **TOP** 7400 **BOTTOM** 6000

9. FUEL TYPE Sage/grass, pockets brush/aspen

10. PROJECT ON:
☒ GROUND
☐ CROWNING

11. WEATHER CONDITIONS AT PROJECT OR FROM NEARBY STATIONS *(See example on reverse)*

PLACE	ELEVATION	OB TIME†	WIND DIR.-VEL.		TEMP.		‡(Leave blank)		REMARKS
			20 FT.	EYE LEVEL	DRY	WET	RH	DP	*(Indicate rain, thunderstorms, etc. Also wind condition and 10ths of cloud cover.)*
Site 1	7380	1040		SW 8	60	46	37	34	Clear
Site 2	6000	1045		W 2/3	52	43	50	34	Clear
Car-bella	5000	Yesterday 1330	S 8		69	51	29	36	10-H FM 10% clear

12. SEND FORECAST TO:
PLACE Dispatch Bozeman
VIA Teletype
ATTN: *(Name, if applicable)* Larry Keown

II. FIRE WEATHER FORECASTER WILL FURNISH:

13. FORECAST AND OUTLOOK **TIME† AND DATE:** 9/4/80 1122 MDT

(SPECIFY WIND - 20 FOOT OR EYE LEVEL)

This afternoon. . . Sunny, little warmer and drier.
Maximum temperature at 6000' - 75 Minimum humidity at 6000' - 24
Maximum temperature at 7400' - 70 Minimum humidity at 7400' - 26

Eye level winds . . . light upslope (S'ly) 3-5 mi/h mid slopes and top. Light and variable bottom at noon becoming upslope (south) 8-12 mi/h mid-through late afternoon. Very good smoke dispersal to 16,000 ft. MSL afternoon. Winds aloft 12,000 ft. Southwest 18 mi/h.

Tonight . . . Clear with good, rapid temperature and humidity recovery.

Outlook for tomorrow . . . Sunny, not much change temperature and humidity. Decreasing southwesterly winds aloft.

NAME OF FIRE WEATHER FORECASTER Paterson

FIRE WEATHER OFFICE NWS, Billings, MT

III. REQUESTING AGENCY WILL COMPLETE UPON RECEIPT OF FORECAST

IV. FORECAST RECEIVED: **TIME†** **DATE** **NAME**

Explanation of Symbols:
† Use 24-hour clock to indicate time. Example: 10:15 p.m. = 2215; 10:15 a.m. = 1015.
*** For concentrations (as groups of lightning fires) specify "Concentration"; then give number of fires and size of largest. If concentrations are in more than one drainage, request special forecast for each drainage.**
‡ No entry necessary. To be computed by the Fire Weather Forecaster.

Table II-3.— Modified Beaufort scale for estimating 20-ft windspeed

Wind class	Range of speeds	Nomenclature
	Mi/h	
1	≤3	Very light – smoke rises nearly vertically. Leaves of quaking aspen in constant motion; small branches of bushes sway; slender branchlets and twigs of trees move gently; tall grasses and weeds sway and bend with wind; wind vane barely moves.
2	4-7	Light – trees of pole size in the open sway gently; wind felt distinctly on face; loose scraps of paper move; wind flutters small flag.
3	8-12	Gentle breeze – trees of pole size in the open sway very noticeably; large branches of pole-size trees in the open toss; tops of trees in dense stands sway; wind extends small flag; a few crested waves form on lakes.
4	13-18	Moderate breeze – trees of pole size in the open sway violently; whole trees in dense stands sway noticeably; dust is raised in the road.
5	19-24	Fresh – branchlets are broken from trees; inconvenience is felt in walking against wind.
6	25-31	Strong – tree damage increases with occasional breaking of exposed tops and branches; progress impeded when walking against wind; light structural damage to buildings.
7	32-38	Moderate gale – severe damage to tree tops; very difficult to walk into wind; significant structural damage occurs.
8	≥39	Fresh gale – surfaced strong Santa Ana; intense stress on all exposed objects, vegetation, buildings; canopy offers virtually no protection; wind flow is systematic in disturbing everything in its path.

INTERPRETING WINDS

Because windspeed and wind direction are required at the midflame level, which is close to the ground and comparatively remote from overhead synoptic conditions, the influence of topography, vegetative sheltering, local heating or cooling, and surface friction must be considered. Fortunately, methods for interpreting these effects are available and can be applied if the type of wind or its driving force is known. Furthermore, there is an order to the expected dominance of wind type, according to the associated conditions, such as time of day, topographic conditions, stability of the atmosphere, and so on.

Wind characteristics near the ground depend upon its vertical depth and the forces that drive the wind. If the airflow is deep, as would be expected with local winds generated from general winds aloft, surface friction will slow the air nearest to the surface and produce a velocity profile as shown in figure II-2. Note that the windspeed continually increases with height above the surface until it reaches a constant value. If the speed at some height is known and the shape of the curve is known, then the windspeed at some lower height can be estimated. The shape of this curve has been studied extensively and a method for estimating windspeed at midflame level has been developed by Albini and Baughman (1979) and Baughman and Albini (1980). Their method also accounts for the sheltering effect of forest cover. Application of this research is presented in step 7 of procedures that follow in this section.

If the wind is generated by differential heating between air near a heated slope and air above the influence of surface heating, then convective slope winds are produced. The velocity profile for this wind (fig. II-3) is different than for winds that have large vertical depths. This flow is described by Albini, Latham, and Baughman (1982). Application of this research is presented in step 8 of the procedures.

From this discussion we can see that the type of wind driving the fire is very important and must be known to make proper interpretation of the midflame windspeed. Before proceeding, a review of the types of winds to be considered is necessary. For a complete review, study carefully U.S. Department of Agriculture Handbook No. 360 by Schroeder and Buck (1970). The comments given below on wind types are taken from their book, with some editorial changes.

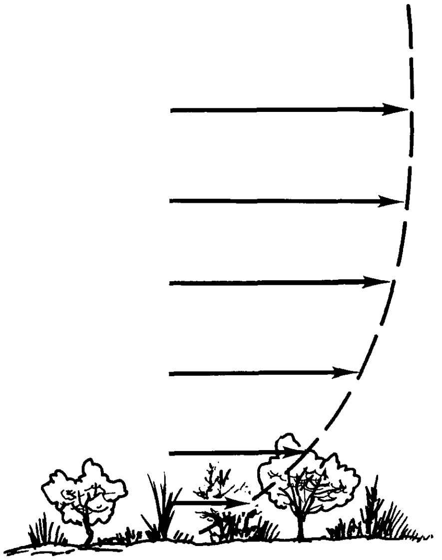

Figure II-2.—General wind velocity profile near surface.

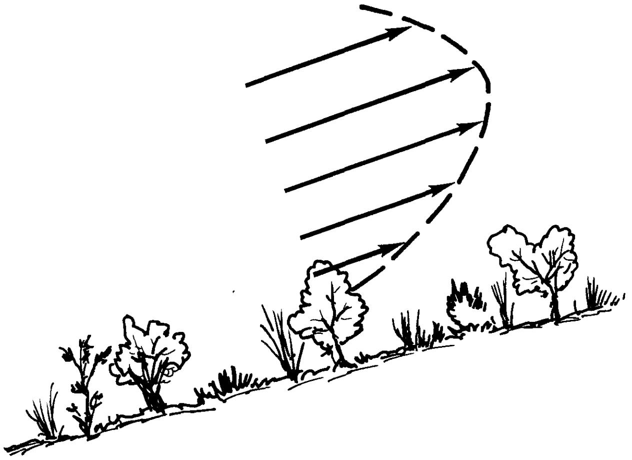

Figure II-3.—Velocity profile of upslope convective winds.

General Winds

"General winds" are produced by the broadscale pressure gradients that are shown on synoptic weather maps. They vary in speed and direction as the synoptic-scale highs and lows develop, move, and decay. General winds will often be referred to as winds aloft, or free-air winds. They are also referred to as frontal winds. Fronts are most commonly thought of in association with precipitation and thunderstorms. But occasionally fronts will cause neither. In these instances, the winds accompanying the frontal passage may be particularly significant to fire behavior.

General winds are usually separated into surface winds and winds aloft. There is no sharp distinction between them, but rather a blending of one into the other. In ascending from the surface through the lower atmosphere, there is a transition in both speed and direction from the surface to the top of the friction layer, which is also called the mixing layer. The depth of this friction or mixing layer depends upon the velocity of the winds aloft, roughness of the terrain, and the intensity of heating or cooling at the surface. The winds aloft above the mixing layer are steadier in speed and direction, but they do change as pressure centers move and change in intensity.

Wildland fires of low intensity may be affected only by the airflow near the surface. When the rate of combustion increases, however, the upper airflow becomes important as an influence on fire behavior. Airflow aloft may help or hinder the development of deep convection columns. It may carry burning embers that ignite spot fires some distance from the main fire. The winds aloft may be greatly different from the surface winds in speed and direction.

Mountains represent the maximum degree of surface roughness and thus provide the greatest friction to low-level airflow. Mountains and their associated valleys provide important channels that establish local wind direction resulting from general winds aloft. Airflow is guided by the topography into the principal drainage channels. General winds blowing across mountain ridges are lifted along the surface to the gaps and crests. If the air is stable, it will increase in speed as it crosses the ridge. Ridgetop winds thus tend to be somewhat stronger than winds in the free air at the same level.

Eddy currents are often associated with bluffs and similarly shaped canyon rims. When a bluff faces downwind, air on the lee side is protected from the direct force of the wind flowing over the rim. If the wind is persistent, however, it may start to rotate the air below and form a large, stationary roll eddy. This often results in a moderate to strong upslope wind opposite in direction to that flowing over the rim. Eddies of this nature are common in the lee of ridges that break off abruptly, and beneath the rims of plateaus and canyon walls.

The variability of general surface winds is somewhat greater during the spring and fall fire seasons in eastern portions of the continent than it is during the summer fire season of the mountainous West. Pressure systems move more frequently and rapidly in the East than in the West. In the western United States, the major mountain chains tend both to hinder the movement of organized highs and lows and to lift winds associated with them above much of the topography. Strong surface heating in summer also diminishes the surface effects of these changes.

Foehn Winds

Foehn winds represent a special type of local wind associated with mountain systems. In most mountain areas, local winds are sometimes observed to flow over the mountain ranges and descend the slopes on the leeward side. If the down-flowing wind is warm and dry, it is called a foehn wind. The development of a foehn wind requires a strong high-pressure system on one side of the mountain range and a corresponding low, or trough, on the other side.

Such pressure patterns are most common to the cool months. Therefore, foehn winds are more frequent in the periods from September through April than during summer months.

Foehn winds have local names such as Chinook, East winds, North and Mono winds, and Santa Ana winds. They have been carefully studied in the West, and a person working in these areas should become familiar with their expected behavior.

Convective Winds

Slope Winds

Slope winds are local diurnal winds, which occur on all sloping surfaces. They flow upslope during the day as a result of surface heating, and downslope at night because of surface cooling. Slope winds are produced by the local pressure gradient caused by the difference in temperature between air near the slope and the air at the same elevation away from the slope. Upslope winds are quite shallow, but their depth increases from the lower portion of the slope to the upper portion (fig. II-4). The depth of this turbulent layer increases as it

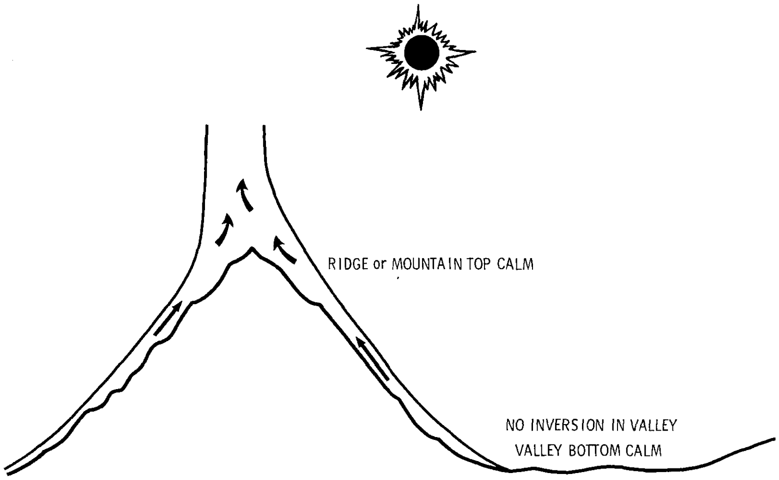

Figure II-4.—Conditions for upslope convective winds.

approaches the top of the slope, where it leaves the slope and vents vertically. Upslope velocities from solar heating will seldom exceed 8 to 10 mi/h at the standard 20-ft height. The shape of the velocity profile for upslope convection winds is shown in figure II–3.

The transition from upslope to downslope wind begins soon after the first slopes go into afternoon shadow and surface cooling begins. In individual draws and on slopes going into shadow, the transition period consists of (1) dying of the upslope wind, (2) a period of relative calm, and then (3) gentle laminar flow downslope. Downslope winds are very shallow, with slower speeds than upslope winds. The cool, denser air is stable and the downslope flow therefore tends to be laminar. Cool, dense air accumulates in the bottom of canyons and valleys, creating an inversion which increases in depth and strength during the night hours.

Valley Winds

Valley winds are diurnal winds that blow up-valley by day and down-valley by night. They are the result of differences in temperatures between air in the valley and air at the same elevation over the adjacent plain (or larger valley). Air in the small, high valleys is heated by contact with the slopes, and the resulting slope wind circulation is effective in distributing the heat through the entire mass of valley air. As the valley air becomes warmer and less dense than the air over the plain, a local pressure gradient is established from the plain to the valley and an up-valley wind begins.

Whereas upslope winds begin within minutes after the sun strikes the slope, the up-valley wind does not start until the whole mass of air within the valley becomes warmed. This is usually in middle or late forenoon, depending on the size of the valley. The up-valley wind reaches its maximum speed in the early afternoon and continues into the evening. Up-valley windspeeds in larger valleys are ordinarily 10 to 15 mi/h. The transition from up-valley to down-valley flow takes place in the early night. The time of transition depends on the size of the valley or canyon and on factors favoring cooling and the establishment of a temperature differential. The transition takes place gradually. First, a downslope wind develops on the slopes surrounding the valley, which deepens during the early night, becoming the down-valley wind. The down-valley wind may be thought of as the exodus or release of the dense air pool created by cooling along the slope. Down-valley speeds are normally less than up-valley—6 to 8 mi/h, reaching their maximum by early morning.

Sea Breezes

The surface sea breeze begins around mid-forenoon, strengthens during the day, and ends around sunset, although the times can vary considerably because of local conditions of cloudiness and the general winds. The breeze begins at the coast and gradually pushes farther and farther inland during the day, reaching its maximum penetration about the time of maximum temperature. Strong general winds produce mechanical mixing, which tends to lessen the temperature difference between the land and the sea surfaces; thus the sea breeze component becomes weak and only slightly alters the general wind flow. In the East, land and sea breezes are most pronounced in late spring and early summer when land and water temperature differences are greatest, and they taper off toward the end of the warm season as temperature differences decrease.

The Pacific sea breeze is characterized by considerable thermal turbulence and may extend inland 30 to 40 miles or more from the water under favorable conditions. The depth of the sea breeze is usually around 1,200 to 1,500 ft, but sometimes reaches 3,000 ft or more. Its intensity will vary with the water-land temperature contrast, but usually its speed is 10 to 15 mi/h.

River systems and other deep passes that penetrate the coast ranges provide the principal inland sea breeze flow routes. Lake breezes can appear along the shores of lakes and other bodies of water large enough to establish a sufficient air temperature gradient.

Spurious Winds

Thunderstorm Winds

Thunderstorm winds are (1) the updrafts predominating in and beneath growing cumulus clouds, (2) downdrafts in the latest stages of full thunderstorm development, and (3) cold air outflow from decaying thunderstorm clouds, which sometimes develops squall characteristics. In mountainous terrain, a thunderstorm downdraft tends to continue its downward path into the principal drainageways. Speeds of 20 to 30 mi/h are common and speeds of 60 to 75 mi/h have been measured. The high speeds and surface roughness cause these winds to be extremely gusty. They are stronger when the air mass is hot, as in the late afternoon, than during the night or forenoon. Although they strike suddenly and violently, downdraft winds are of short duration. Downdrafts can also develop on hot days from towering cumulus clouds.

Whirlwinds

Whirlwinds, or dust devils, are one of the most common indications of intense local heating. Such winds occur on hot days over dry terrain when skies are clear and general winds are light. Whirlwinds are common in an area that has just burned over. The blackened ashes and charred materials are good absorbers of heat from the sun, and hot spots remaining in the fire area may also heat the air. A whirlwind sometimes rejuvenates an apparently dead fire, picks up burning embers, and spreads the fire to new fuels. The presence of whirlwinds is a good indicator that conditions are highly unstable and favorable for upslope convective winds.

Nighttime High-Elevation Winds

During the night, winds may reach dangerously high velocities at high-elevation ridgetops. Baughman's (1981) paper about nighttime ridge winds concludes that windspeeds often increase and may reach maximum values on high mountain slopes during the nighttime hours. Evidence, including published information, supports the contention that this weather phenomenon is due to a low-level jet wind.

Interaction Between Winds

Slope and valley wind systems are subject to interruption or modification at any time by the general winds or by larger scale convective wind systems. Midday upslope winds in mountainous topography tend to force weak general winds aloft over the ridgetops. Frequently the daytime upper winds are felt only on the highest peaks. In this situation the surface winds are virtually pure convective winds. Upslope winds dominate the saddles and lower ridges and combine with up-valley winds to determine windspeeds and directions at the lower elevations. A fire burning to a ridgetop under the influence of upslope afternoon winds may flare up and its spread may be strongly affected as it comes under the influence of the general wind flow.

Convective winds (slope, valley, and sea breezes) may be augmented, opposed, or eliminated by general winds. The influence of these general winds on the convective wind systems varies with the strength of the general wind, its direction relative to the convective circulation, and the stability of the lower atmosphere. The interactions between air flow of different origins, local pressure gradients caused by nonuniform heating of mountain slopes, and the exceedingly complex physical shapes of mountain systems combine to prevent the rigid application of rules of thumb to convective winds in mountain areas. Every local situation must be interpreted in terms of its unique qualities. Differences in air heating over mountain slopes, canyon bottoms, valleys, and adjacent plains result in several different related wind systems. These systems combine in most instances and operate together. The common denominator is up-valley, up-canyon, and upslope flow in the daytime, and down flow at night.

Summarizing the wind types of most concern to fire operation, surfacing of strong upper air winds, either frontal or foehn, can usually be considered the most dominant. In the absence of these, valley winds and sea breezes can be expected to dominate, while upslope daytime winds are the most fragile and least dominant. A summary of the expected range of windspeeds from the different wind types is shown in table II-4.

Table II-4.—Windspeed ranges

Wind type	Expected range of windspeed
Frontal winds	Too broad a range to be specific
Foehn	40 to 60 mi/h common; up to 90 mi/h reported at 20 ft
Land breeze	2 to 3 hours after sunset, 3 to 5 mi/h at 20 ft
Pacific sea breeze	10 to 15 mi/h at 20 ft
Up-valley winds	10 to 15 mi/h, early afternoon and evening at 20 ft
Upslope winds	As high as 4 to 8 mi/h at midflame height; see tables II-7, 8, 9
Downslope winds	3 to 6 mi/h at midflame height

WIND ASSESSMENT PROCEDURES

The procedures that follow are designed to provide the detailed assessment of wind at the midflame height necessary to predict fire behavior and growth. In the process of doing so, data will be assembled that can also be used to predict the possibility of severe fire behavior.

The procedures are more detailed than necessary if a fire weather forecaster is available at the fire site. It is hoped, however, that they will facilitate communication with the forecaster so that you will obtain the specific information needed to predict fire behavior.

The procedure progresses step-by-step, serves as a checklist, and can be applied universally. A local checklist should be developed for each section of the country that has unique fire weather patterns. Such a local list could eliminate extraneous material and highlight local problems not addressed in the universal procedure.

The following factors should be considered as you begin your analysis of wind on the fire:

- How much time do you have to complete your assignment and to predict fire behavior?
- Is the prediction to be for daytime or nighttime? Or must you contend with transition between daylight and darkness?
- Is the fire in level or mountainous terrain?
- Is the fire sheltered beneath standing timber or in exposed fuels?
- Are you dealing with the early stage of the fire without control lines or later stages with most control lines complete and secure?
- Are you near a large body of water that can influence windspeed and direction?
- What has the wind done previously?
- Do you have any measured weather data?
- Where can you get your weather information and how soon?

In a wildfire situation you cannot wait until conditions are within prescription as with prescribed fires. You must contend with the situation at hand. Answers to the above questions can dictate in some cases a very rapid assessment of conditions to meet initial requirements. A flow chart outlining the procedures is shown in figure II-5.

Complete procedures are as follows:

STEP 1. CONTACT FIRE WEATHER METEOROLOGIST

Contact the fire weather meteorologist as early as possible to determine the weather expected at the fire site. In some cases this may be done on your way to the fire. Communications may be disrupted, making it difficult to obtain a forecast. You will then have to rely on observations and reports of persons who have observed the weather and its effects during the initial stages of the fire. It will be most helpful to have a forecast for the next 12 to 24 hours in your pocket when you arrive at the fire.

Determine from the fire weather forecaster if general synoptic conditions are likely to change during the next 12 to 24 hours. Even if no general change is expected, surface weather may change due to daily (diurnal) cycles. The important point is that these changes have a very strong tendency to repeat themselves by time of day; in other words, "persist." If a change in the general synoptic conditions is expected due to frontal movements, or other large scale changes, then you cannot rely on persistence forecasting. The diurnal effects due to heating and cooling will still be taking place, but the resulting wind may be quite different due to the rearrangement of the major pressure pattern.

Use the times of expected changes, either due to frontal passages or other synoptic events or due to diurnal changes, to lay out time periods when weather conditions will remain fairly persistent as well as when changes are expected. Use the times of expected stable periods to help identify projection times and note this at the top of the fire behavior worksheets.

STEP 2. CONSIDER POSSIBILITY OF SPURIOUS WINDS

Review the fire weather forecast for information or warnings about weather events that may be accompanied by strong winds. These may include frontal passages with accompanying thunderstorms, surfacing of strong winds aloft, or a wind reversal such as occurs when a general wind counteracts a sea breeze or valley wind. Both valley winds and sea breezes can be reinforced or disrupted by surfacing of the general winds aloft. One such condition, known as a sundowner, often occurs near Santa Barbara, Calif., and causes severe fire problems. Work with your local fire weather forecaster and be prepared to account for interaction between various winds.

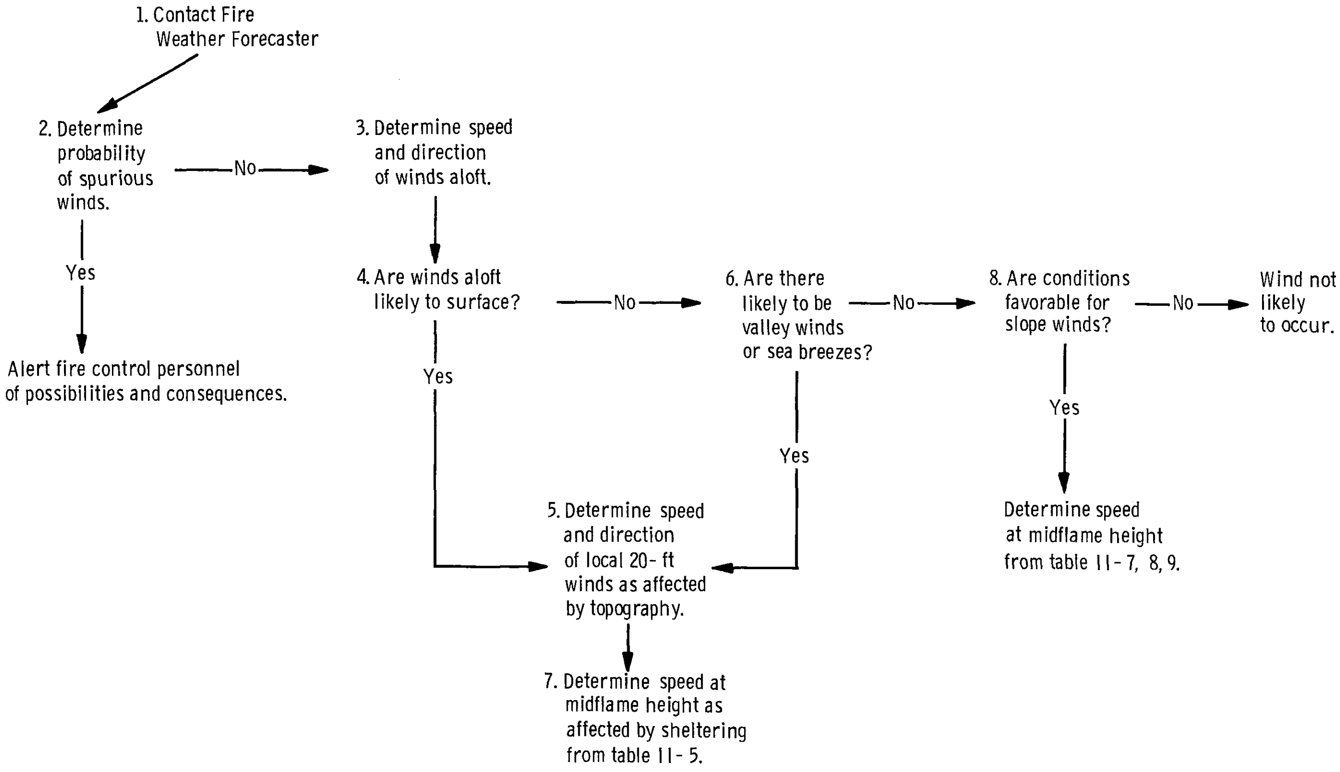

Figure II-5.—Flow chart of wind assessment procedures.

Discuss the weather situation with persons familiar with the local situation. Learn what weather patterns cause problems and the expected time of these events.

Review weather observations. Has there been an occurrence of nighttime high-elevation winds? Is the fire located on the lee side of a ridge, thus making fire whirls a strong possibility?

The occurrence of strong winds for a short time does not lend itself to satisfactory fire growth predictions, but the possible severity of the fire resulting from these winds and the expected time of occurrence should be reported to the fire control forces. Even though accurate predictions of spread cannot be made for spurious winds, an estimate of the fireline intensity and flame length is possible if an estimate of the windspeed is given.

STEP 3. DETERMINE SPEED AND DIRECTION OF THE GENERAL WINDS ALOFT

On a contour map of the fire, place an overlay showing the direction of the general winds aloft, using a few long straight arrows over the fire area. Write the windspeed alongside the arrows. Note the time period on the overlay for which these winds are expected to remain constant (see fig. II-6).

STEP 4. DETERMINE IF WINDS ALOFT ARE LIKELY TO SURFACE

Determine whether or not the general winds aloft are likely to reach the surface. In this instance, the surface is defined as 20 ft above the vegetation. Discuss this with your fire weather meteorologist. If he is not available for discussion, examine the fire weather forecast. If the forecast specifies light upslope winds, then the forecast is essentially saying that the winds aloft will not surface and convective winds will be active. Note the speed of the general winds aloft on the fire weather forecast.

If you do not have a fire weather forecast, but you were able to bring with you or obtain from a general forecast (by radio, television, aviation forecast, or fire lookout observation, or estimate from the movement of low level clouds), the speed and direction of the general winds aloft, you must make your own evaluation of whether these winds will surface. Surfacing of the general winds aloft depends upon several factors:

a. Strength.—Strong winds are more likely to surface than weaker winds aloft.

b. Direction.—Winds aloft that approach the fire area over a long distance, unobstructed by high ridges or mountains, have a better chance of surfacing.

c. Stability.—Very stable air will tend to block or prevent winds aloft from surfacing. Conversely, when mixing is good, the winds are more likely to surface.

Recall from Schroeder and Buck (1970) that the general winds can be held aloft by mountain ridges, by strong convective upflow, or by very stable air resulting from a strong inversion. Ryan (1977) indicates that unless the general winds aloft are sufficiently strong (he estimates the limit to be at least 13 mi/h at the 5,000-ft level), they will have little effect at the surface. If the general winds are not expected to reach the surface, proceed to step 6 and determine if convective winds can be expected. If the winds aloft are expected to surface, determine the expected speed and direction as explained in step 5.

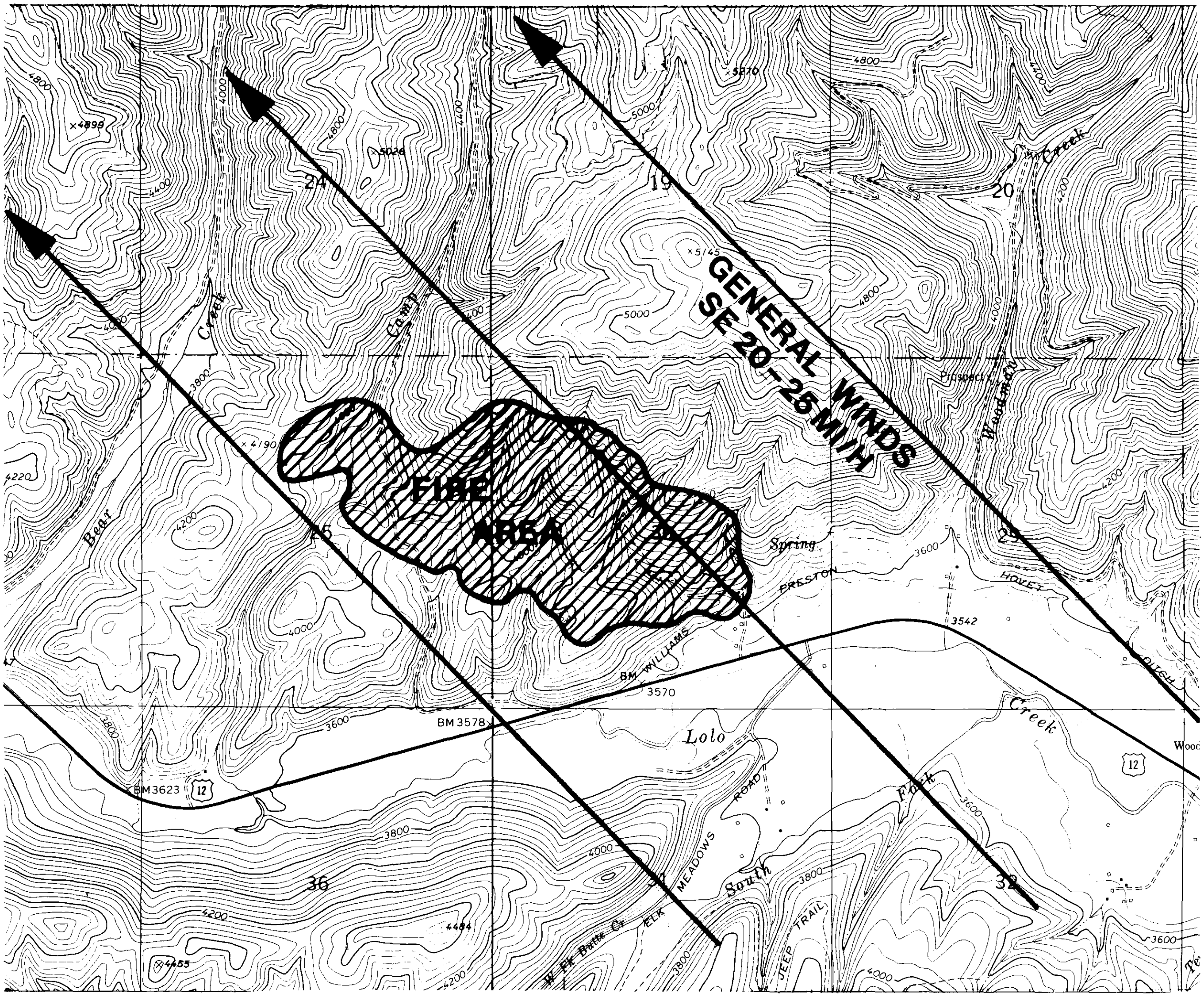

Figure II-6.—Diagrammatic layout of general winds aloft.

STEP 5. DETERMINE THE SPEED AND DIRECTION OF THE LOCAL 20-FT WINDS

Place the wind overlay upon a topographic map of the fire area. Study the topography, taking into account the mountains, ridges, valleys, and exposed slopes. Mentally, bring the general wind aloft down toward the surface. The general wind can be pictured to move as a blanket of air over terrain features or around them, but generally moving in the same direction after a barrier is passed. Consider air as a fluid that can flow just as water could flow over or around a rock in a stream. Adjust its direction and velocity to fit the terrain. Look upwind of the fire area. How far can the wind travel without terrain obstructions before it reaches the fire? If the distance is long, across a major valley or large lake, the wind will sweep into the fire area with little restraint and have speeds only slightly less than the general wind. If the unobstructed approach distance is short because of terrain blockage, then the wind will be slowed considerably. In such cases ridgetop winds may be high, but the valley winds will be low. Estimate intermediate speeds on the slopes. The important consideration is the effect of the terrain and not the sheltering effect of the trees. On the overlay draw arrows that represent your best estimate of the direction of the resulting 20-ft wind (fig. II-7). Beside the arrow write the estimated windspeed. Use a range of windspeeds, if you prefer, such as 5 to 8 mi/h. As you become proficient at this you will note that it is natural to draw longer arrows for the positions where stronger winds are expected such as across ridgetops, and shorter arrows where terrain features will block or slow the flow. Do not attempt an exact scale of the lengths, but keep them relatively consistent.

While drawing the arrows, be concerned with both direction and speed. Use the topography information on the map to decide whether it would be easier for the wind to go up a slope and over the top or to change direction and flow around an obstructing terrain feature and up a nearby valley. On the lee side of ridges look for a flow reversal where the wind changes direction and flows back up the ridge. This is an area where highly variable winds can develop.

In most fire situations, the fire behavior officer will obtain wind information from as many locations around the fire as possible, such as from fire lookout towers, from an anemometer set up near the fire camp, and from observers on ridges,

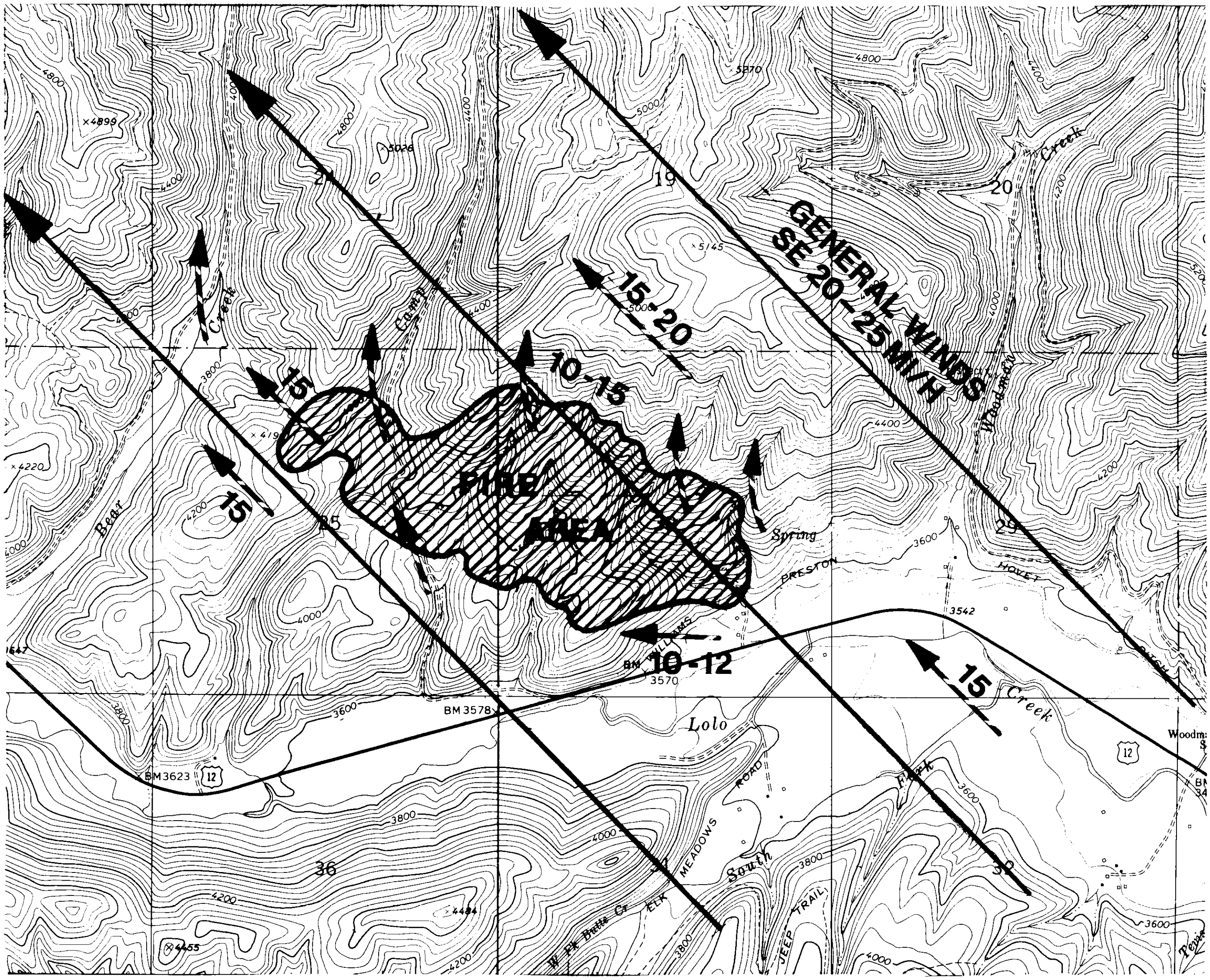

Figure II-7.—Diagrammatic layout of local winds as influenced by topography.

on the fireline, and other significant locations around the fire area. Initial estimates of windspeed and direction are the most difficult. After a day or two on a fire, recognizable wind patterns tend to develop, and interpretations of windspeed and direction can be made at intermediate points between the lookouts at the top of mountains and the observation points in valley bottoms.

Chapter IV will discuss how to locate projection points at strategic locations around the fire. Be sure you have drawn an arrow representing the direction of the 20-ft wind, and an estimate of its speed near all projection points. Enter the value of the 20-ft windspeed at each projection point on line 11 of the fire behavior worksheet. Use separate columns for each projection point.

STEP 6. DETERMINE THE PROBABILITY OF VALLEY WINDS OR SEA BREEZES

If the general winds aloft are not expected to surface at the fire site at the time for which you are predicting wind, determine if valley winds or sea breezes are likely to develop. Whether or not valley winds will occur or whether there will be slope winds without valley winds depends not only on the heating and resulting convective flow as discussed earlier, but also on the direction of the general winds aloft and stability of the valley air. If a nighttime inversion has filled the valley, the valley winds will not begin until the inversion has been broken. Upslope flow will begin well before up-valley flow when inversions are present in the morning. When the inversion has been broken, exposure of the valley to the flow of the general winds aloft is a primary consideration regarding the expected onset of valley winds.[8]

On the overlay show the direction of the wind flow, taking into account the general layout of the valley systems as shown in Schroeder and Buck (1970). The speed will be highest in the major valleys, 10 to 15 mi/h at the 20-ft level.

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[8] Personal communication with Clyde O'Dell and Frank Gift, U.S. Weather Service fire meteorologists at the Boise Interagency Fire Center.

If the fire is located near a coastline, land and sea breezes must be considered. The daily land and sea breezes tend to occur quite regularly when there is no significant influence from the general wind flow. When general winds are sufficiently strong, however, they usually mask the land and sea breezes. A general wind blowing toward the sea opposes the sea breeze and, if strong enough, may prevent its development.

The speed of sea breezes may reach 10 to 15 mi/h at the 20-ft level under favorable conditions and extend inland 30 to 40 miles. When blocked by mountains, they tend to follow major river drainages.

The land breeze begins 2 to 3 hours after sunset, and ends shortly after sunrise. It is a more gentle flow than the sea breeze, usually about 3 to 5 miles per hour. The land air, having been cooled from below by contact with the ground, is stable. The land breeze, therefore, is more laminar and shallower than the sea breeze.

Draw arrows representing the 20-ft valley winds, land breezes, and sea breezes on the overlay near the fire area just as was done for general winds that surface. Note the probable speed on the arrows. Enter the value of the 20-ft windspeed for each projection point on line 11 of the fire behavior worksheet.

STEP 7. ESTIMATE MIDFLAME WINDSPEED

Steps 5 and 6 produced estimates of the wind at 20 ft above the vegetation. Because wind is slower near the surface, fires with flame heights less than 40 ft must have the wind adjusted to the midflame height. This is done with a wind adjustment table developed from the research of Albini and Baughman (1979).

Table II-5 is designed for quick field reference. Given an estimate of the 20-ft windspeed from steps 5 or 6 and the sheltering conditions near the fire, an estimate of the midflame windspeed can be read directly from the table. The 20-ft windspeed ranges at the head of the columns are the same as used in table II-3, thus facilitating the conversion of windspeed observations based on the Beaufort scale.

Table II-6 displays the adjustment factors used to develop table II-5. If more time is available for making predictions and you wish to avoid the step changes in windspeed and ultimately in rate of spread that table II-5 will produce, then use the wind adjustment factor given in table II-6. Midflame windspeed is obtained by multiplying the 20-ft windspeed by the wind adjustment factor.

Table II-5.— Wind adjustment table—quick reference. Values shown are approximate midflame windspeeds (mi/h) for range of 20 ft windspeed shown at top of column.

Fuel exposure	Fuel model	20-ft windspeed (mi/h)							
		0-3	4-7	8-12	13-18	19-24	25-31	32-38	39 up
		Midflame windspeed (mi/h)							
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	1	3	6	9	13	17	21	24
	13	1	3	5	8	11	14	18	20
	1,3,5,6,11,12 (2,7)[1] (8,9,10)[2]	1	2	4	6	9	11	14	16
PARTIALLY SHELTERED FUELS									
Fuel beneath patchy timber where it is not well sheltered; fuel beneath stands of timber at midslope or higher on a mountain with wind blowing directly at the slope	All fuel models	1	2	3	5	7	8	11	12
FULLY SHELTERED FUELS									
Fuel sheltered beneath standing timber on flat or gentle slope or near base of mountain with steep slopes	All fuel models — Open stands	0	1	2	3	4	6	7	8
	All fuel models — Dense stands	0	1	1	2	2	3	4	4

[1] These fuels are usually partially sheltered.

[2] These fuels are usually fully sheltered.

Table II-6.— Wind adjustment table. Find the appropriate adjustment factor and multiply it by the 20-ft windspeed. Use the result as the midflame windspeed

Fuel exposure	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	0.5
	1,3,5,6,11,12 (2,7)[1] (8,9,10)[2]	0.4
PARTIALLY SHELTERED FUELS		
Fuel 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 slop	All fuel models	0.3
FULLY SHELTERED FUELS		
Fuel sheltered beneath standing timber on flat or gentle slope or near base of mountain with steep slopes	All fuel models Open stands	0.2
	Dense stands	0.1

[1] Fuels usually partially sheltered.

[2] Fuels usually fully sheltered.

The wind adjustment tables contain three sections to account for various sheltering of fuels from wind. These are illustrated in figure II–8.

1. *Exposed fuels.*—The upper section of the wind adjustment tables is used for fuels that are fully exposed (no shelter) to the wind, with no overstory or only scattered trees.

The upper section should also be used for trees that have lost their foliage such as hardwoods in the fall or early spring. Trees that have been defoliated by crown fire or insects expose surface fuels to stronger winds and the upper portion of the table should be used.

The upper section should also be used for fuels that are beneath timber, but near the edge of a clearing. Shade-intolerant trees such as lodgepole or ponderosa pine can have wind penetration an equivalent of 10 tree heights[9] from the edge before it is slowed to the fully sheltered condition. Because of their growth forms, shade-tolerant trees offer more resistance, and the wind will be slowed in five tree heights.[9] Of course the clearing has to be large enough for the wind to build up its speed before hitting the timber edge. The size of the clearing and the penetration distance cannot be specified at this time and experience must be your guide. Clearings for this situation can be natural or manmade, such as clearcuts from logging, lakes, burned-out trees resulting from crown fires, etc.

Fuels on high ridges where trees offer little shelter from wind should also use the upper portion of the chart.

Fuel models not normally found in fully exposed conditions are indicated by footnotes.

2. *Partially sheltered fuels.*—The middle section of the wind adjustment tables is used for partially sheltered fuels. This would include fuel beneath patchy timber or timber that is scattered. Fuel model 2, a grass model, is more often found as a partially sheltered fuel than as a fully exposed fuel. Fuel model 7, when used to represent southern rough, may be partially sheltered.

A mountainside directly exposed to a strong general wind is more likely to have only partially sheltered fuels even though covered with timber. This would be more likely on mid- and upper slopes than on lower slopes.

3. *Fully sheltered fuels.*—The lower portion of the table is used for fully sheltered fuels. Sheltered fuels are found within timber stands. Sheltering can be more or less restrictive, depending on the characteristics of the overstory. Trees that have branches extending all the way to the ground, such as spruce and cedar, can be very restrictive to airflow. These trees are broadly classified as shade-tolerant trees. Shade-intolerant trees typically have less dense crowns and so are less restrictive to windflow. Their conformation tends to be more open, and when growing close together the lower branches defoliate. Pines are typically intolerant, while firs are shade tolerant. Either type can be found in open or in dense stands; a correction factor is provided in the table. Trees and stocking configurations vary so widely that precise instructions cannot be given for all situations. Experience must play a large part in learning to choose the best wind adjustment value.

Enter the value of the wind adjustment factor on line 12 of the fire behavior worksheet. Multiply it by the 20-ft windspeed on line 11 to obtain the midflame windspeed, which is entered on line 13. This should be done in a separate column for the wind conditions at each projection point.

STEP 8. DETERMINE SLOPE WINDS

Upslope winds.—If the general winds are not expected to surface and the fire is not subject to major valley winds or sea breezes, there is still the distinct possibility of slope winds developing that will affect surface fires on mountain slopes. Nighttime downslope winds can almost be guaranteed; however, daytime upslope winds are more uncertain. If the sun is reaching slopes that are not timber covered and there is no disturbance by other winds, upslope winds will develop. Most fire weather forecasts will contain an estimate of their velocity. Slope winds should be forecast at eye level because they cannot be reduced from the 20-ft level by the same procedures used for the deep winds; i.e., general, valley, and sea breezes. If you do not have an eye-level forecast, or you wish to check the value, this can be done with the procedures of Albini and others (1982), which follow.

Midflame windspeeds were developed for 10 of the NFFL stylized fuel models that might be used for predicting fire behavior on open slopes. Fuel models 7, 8, and 9 were not included because they are used only for fuels under standing timber. Model 10 is also an understory fuel, but is sometimes used to represent logging slash overgrown with shrubs, grasses, and forbs, and so it was included. Tree cover on the slope both interferes with the solar heating of the surface and obstructs the development of the convective wind field, so the model cannot be used for tree-covered slopes.

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[9] Baughman, Robert G. Wind at the forest edge. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Forest Fire Laboratory; 1980. Unpublished report.

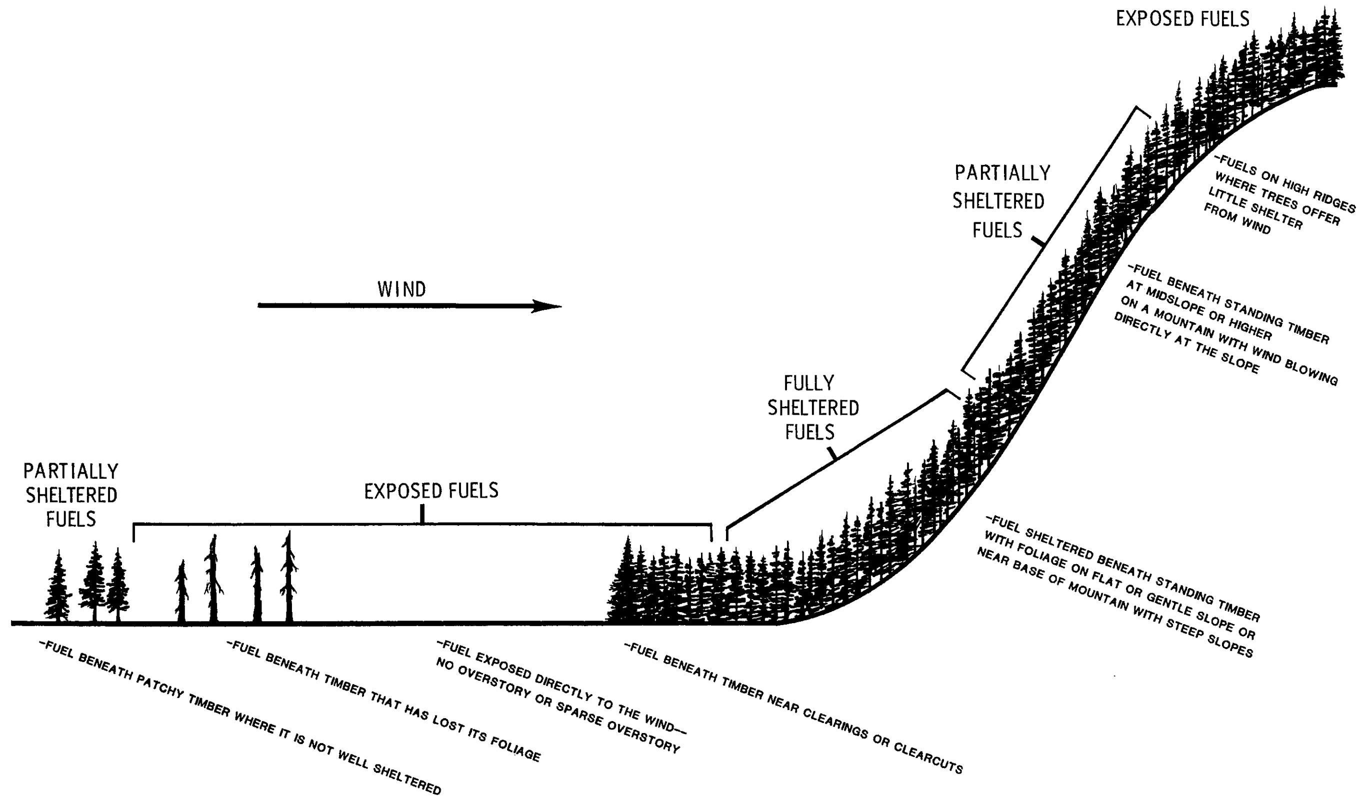


Figure II-8.—Exposure of various fuels to wind.

Two situations are considered:

1. The slope is uniformly covered with the fuel below the fire site, and
2. The slope below the fire site is free of cover.

The first situation might represent a prescribed fire, a new ignition on a slope, or a wildfire backing downslope. The second situation might represent a slope with a rock or scree face, or a fire burning upslope from near the base in which the fuel has burned out behind the fire.

The fuel models used can be divided into "shallow" and "deep" fuelbeds. The "shallow" fuelbeds are represented by models 1, 2, 5, 6, 10, and 11. Midflame windspeeds for these models are a function of slope only. Table II-7 gives midflame windspeeds for these models.

The "deep" fuelbeds, represented by stylized models 3, 4, 12, and 13, exhibit some degree of dependence of midflame windspeed on both slope and elevation above the valley floor. Table II-8 gives the midflame windspeeds for these models for the case of uniform cover below the fire site. For the case of a bare slope below the fire site, use table II-9.

Table II-7.— Midflame windspeeds (mi/h) for "shallow" fuelbeds with upslope convection winds

	Slope (percent)								
Fuel model	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
A. Slope uniformly covered with vegetation below fire site									
Fuel model									
1. Short grass	0.3	0.4	0.5	0.6	0.7	0.8	0.8	0.9	0.9
2. Timber (grass and understory)	.4	.5	.7	.8	.9	1.0	1.1	1.2	1.3
5. Brush	.3	.5	.6	.7	.8	.9	1.0	1.1	1.2
6. Dormant brush, hardwood slash	.5	.7	.9	1.0	1.2	1.3	1.4	1.5	1.6
10. Overgrown slash[1]	.4	.5	.7	.8	.9	1.0	1.1	1.2	1.3
11. Light conifer slash	.3	.4	.5	.6	.7	.8	.9	.9	1.0
B. Slope below fire site free of vegetation cover									
Fuel model									
1. Short grass	0.5	0.8	1.0	1.2	1.4	1.5	1.6	1.8	1.9
2. Timber (grass and understory)	.6	.9	1.2	1.4	1.6	1.8	1.9	2.1	2.2
5. Brush	.9	1.3	1.6	1.9	2.2	2.4	2.6	2.8	2.9
6. Dormant brush, hardwood slash	1.1	1.6	2.1	2.5	2.8	3.1	3.3	3.5	3.7
10. Overgrown slash[1]	.6	.9	1.2	1.4	1.6	1.8	1.9	2.1	2.2
11. Light conifer slash	.6	.8	1.0	1.2	1.4	1.6	1.7	1.8	1.9

[1] Normally called timber litter and understory.

Table II-8.— Midflame windspeeds (mi/h) for "deep" fuelbeds with upslope convection winds. Slope uniformly covered with vegetation below fire site

Fuel model	Slope (percent)								
	20	30	40	50	60	70	80	90	100
FUEL MODEL 3 – Tall Grass									
Ht. above valley floor									
0-300 ft	0.7	1.0	1.2	1.5	1.7	1.9	2.0	2.1	2.2
300-600	.7	1.0	1.3	1.5	1.7	1.9	2.0	2.2	2.3
600-900	.7	1.0	1.3	1.5	1.7	1.9	2.1	2.2	2.3
900-1200	.7	1.0	1.3	1.5	1.7	1.9	2.1	2.2	2.3
1200-1500	.7	1.0	1.3	1.5	1.7	1.9	2.1	2.2	2.3
FUEL MODEL 4 – Chaparral									
Ht. above valley floor									
0-300 ft	1.3	1.9	2.3	2.7	3.0	3.3	3.5	3.7	3.9
300-600	1.3	1.9	2.4	2.8	3.1	3.4	3.7	3.9	4.0
600-900	1.3	1.9	2.4	2.8	3.2	3.5	3.8	4.0	4.2
900-1200	1.3	1.9	2.4	2.9	3.2	3.6	3.8	4.1	4.3
1200-1500	1.3	1.9	2.4	2.9	3.3	3.6	3.9	4.1	4.3
FUEL MODEL 12 – Medium Conifer Slash									
Ht. above valley floor									
0-300 ft	0.7	1.0	1.2	1.4	1.6	1.8	2.0	2.1	2.2
300-600	.7	1.0	1.2	1.5	1.7	1.8	2.0	2.1	2.2
600-900	.7	1.0	1.2	1.5	1.7	1.9	2.0	2.1	2.3
900-1200	.7	1.0	1.2	1.5	1.7	1.9	2.0	2.2	2.3
1200-1500	.7	1.0	1.3	1.5	1.7	1.9	2.0	2.2	2.3
FUEL MODEL 13 – Heavy Conifer Slash									
Ht. above valley floor									
0-300 ft	0.9	1.3	1.6	1.9	2.1	2.4	2.5	2.7	2.8
300-600	.9	1.3	1.6	1.9	2.2	2.4	2.6	2.7	2.9
600-900	.9	1.3	1.6	2.0	2.2	2.4	2.6	2.8	2.9
900-1200	.9	1.3	1.7	2.0	2.2	2.5	2.7	2.8	3.0
1200-1500	.9	1.3	1.7	2.0	2.3	2.5	2.7	2.9	3.0

Table II-9.— Midflame windspeeds (mi/h) for "deep" fuelbeds with upslope convection winds. Slope bare of vegetation below fire site

Fuel model	Slope (percent)								
	20	30	40	50	60	70	80	90	100
FUEL MODEL 3 – Tall Grass									
Ht. above valley floor									
0-300 ft	1.3	1.9	2.4	2.8	3.1	3.4	3.6	3.8	4.0
300-600	1.3	1.9	2.4	2.8	3.2	3.5	3.7	4.0	4.1
600-900	1.3	1.9	2.4	2.9	3.2	3.6	3.8	4.1	4.2
900-1200	1.4	1.9	2.5	2.9	3.3	3.6	3.9	4.1	4.3
1200-1500	1.4	2.0	2.5	2.9	3.3	3.7	4.0	4.2	4.4
FUEL MODEL 4 – Chaparral									
Ht. above valley floor									
0-300 ft	2.7	3.7	4.4	5.0	5.5	5.8	6.1	6.3	6.5
300-600	2.7	3.8	4.6	5.3	5.8	6.2	6.6	6.8	7.0
600-900	2.8	3.9	4.8	5.5	6.1	6.5	6.9	7.2	7.5
900-1200	2.8	3.9	4.9	5.7	6.3	6.8	7.2	7.5	7.8
1200-1500	2.8	4.0	5.0	5.8	6.5	7.0	7.4	7.8	8.1
FUEL MODEL 12 – Medium Conifer Slash									
Ht. above valley floor									
0-300 ft	1.3	1.8	2.2	2.6	3.0	3.2	3.5	3.7	3.8
300-600	1.3	1.8	2.3	2.7	3.0	3.3	3.6	3.8	4.0
600-900	1.3	1.8	2.3	2.7	3.1	3.4	3.7	3.9	4.1
900-1200	1.3	1.8	2.3	2.8	3.1	3.5	3.7	3.9	4.1
1200-1500	1.3	1.9	2.4	2.8	3.2	3.5	3.8	4.0	4.2
FUEL MODEL 13 – Heavy Conifer Slash									
Ht. above valley floor									
0-300 ft	1.6	2.3	2.9	3.3	3.7	4.0	4.3	4.5	4.7
300-600	1.7	2.3	2.9	3.4	3.8	4.2	4.5	4.7	4.9
600-900	1.7	2.4	3.0	3.5	3.9	4.3	4.6	4.9	5.1
900-1200	1.7	2.4	3.0	3.6	4.0	4.4	4.7	5.0	5.2
1200-1500	1.7	2.4	3.1	3.6	4.1	4.5	4.8	5.1	5.3

Downslope winds.—Downslope winds begin to form as soon as shadows form on the slopes. This time can be very late in the day during the middle of the summer in northern latitudes. The depth of the downslope winds rarely exceeds 8 to 10 ft above the ground and they are often much less. They tend to be deeper near the bottom of slopes compared to the upper slope. Their speed can be as high as 3 to 6 mi/h, and occasionally higher near the base of the slope. The speed of the downslope wind should be considered the midflame wind. Downslope winds can flow beneath the timber canopy, whereas upslope winds usually do not.

Enter the midflame windspeed for slope winds on line 13 of the fire behavior worksheet.

Example 1. Refer to figure II–9.

The LaValle Creek Valley opens onto a large flat plain to the south and west of DeSmet. The vegetation in the area shown on the map is sparse grass about 1 ft in height from the valley floor up to 4,000 ft elevation. Above 4,000 ft it is scattered ponderosa pine on the south- and west-facing slopes and Douglas-fir on the north- and east-facing slopes. The highest peaks in this area are 6,500 ft and located to the north about 2 miles.

Assume a cloudy day with general winds from the southwest at 20 to 25 mi/h.

a. Indicate the speed and direction of the general winds on a map overlay.

b. A 20-ft anemometer at point A is indicating southwest winds at 8 to 10 mi/h. Indicate the speed and direction of the 20-ft wind at points B, C, D, E, F.

c. Estimate the midflame windspeed at points B, C, D, E, F, where fuel model 1 applies to grass-covered slopes, fuel model 9 to scattered ponderosa pine slopes, and fuel model 8 to closed canopy Douglas-fir stands.

Solutions to parts a and b are shown on figure II–10.

Solution to part c:

Point	**20-ft wind**	**Fuel model**	**Wind adjustment factor**	**Midflame wind**
B	6.5	1	0.4	3
C	6.5	1	.4	3
D	17.5	1	.4	7
E	15	8	.2	3
F	15	9	.3	5

Explanation of Solution

1b. At points B and C, the wind will follow the contours of these narrow valleys. It will be slowed somewhat by the increased resistance to flow over what it was at point A. Although the air will be funneled through the valley, I would not expect the velocity to increase because of the ever-increasing slope beyond these points.

Point D is exposed on a knob that will experience unobstructed flow. The direction should be from the southwest and the velocity greater than in the valley at A, but not as high as the general winds because the knob is only 4,025 ft while 6,000-ft mountains are just behind it.

Point E is located on the lee side of a ridge that will cause a sharp change of direction in the general wind flow. The airflow can come around from the left or roll over the top. The results will be a turbulent eddy. The speed can be high, but will have larger fluctuations than at other points.

Point F is in a gully on a windward facing slope. The wind direction will follow the gully. The speed will be higher than at B and C, but somewhat less than at D.

1c. You were encouraged to use a range in wind velocities when estimating 20-ft winds, both to realize that there will be fluctuations and to erase the notion that you had to have the precise windspeed. The fire spread model, however, can only accept one windspeed at a time; therefore, to expedite a solution, use the midrange value of your estimate and realize that the calculated rate of spread will also be in the form of a range. When you have time you may want to make a calculation with both ends of the wind range estimate to see the range of uncertainty that can be expected due to wind variation. The midrange values for each 20-ft windspeed were used in the solution and shown in tabular results.

Decimals are used to show how the problems are solved and give resolutions to the answers. Do not expect to be able to predict wind this accurately.

Fuel models are selected from the information given. Point D is barely over 4,000 ft and grass was assumed to persist over the knob.

Wind adjustment factors were taken from table II–6.

At point E it is assumed that a sparse, closed-canopy Douglas-fir stand is on the north side of this ridge. The wind does not blow directly at this stand of trees.

At point F the canopy is sparse and it is on a windward-facing slope, so the surface fuel is only partially sheltered. The midflame wind is found by multiplying the wind adjustment factor at each point by the 20-ft wind at that point.

Example 2

The general wind is calm. It is a clear day. The temperature in the valley is 85° F and relative humidity is 18 percent. Air in the valley is generally calm. An occasional dust devil is formed in the valley and on the slopes. It is 1300 hours on July 1.

a. What is the expected windspeed and wind direction at points G and H on figure II–9? The slope at point G is 33 percent and at point H it is 14 percent.

b. What would be the midflame windspeed at point G if the slope were uniformly covered with 6-ft-deep chaparral brush?

c. If the chaparral were burned away below point G, what would be the midflame windspeed at that point?

d. At night, what speed and direction would you expect the wind to be at point G?

Solution

2a. For the conditions described, upslope convective winds are the most probable type of wind.

The slopes are grass-covered, both above and below the site.

From table II–7A for fuel model 1 on a 33 percent slope, the midflame windspeed would be 0.4 mi/h.

The slope at point H is only 14 percent, so the midflame wind as indicated by table II–7A will be less than 0.3 mi/h.

2b. Fuel model 4 is 6 ft deep. For deep fuelbeds, the elevation height above the valley floor is needed. Point G is about 300 ft above the valley floor. From table II–8, the midflame windspeed would be 1.9 mi/h.

2c. From table II–9, the midflame windspeed would be 3.7 mi/h.

2d. Downslope winds on this small foothill would probably not be very much—certainly less than the 3 to 5 mi/h quoted in the text. Point G is subject, however, to down-valley winds after transition to down-valley flow begins in the early evening. For this small valley, down-valley wind would probably be on the order of 3 to 5 mi/h at the 20-ft level.

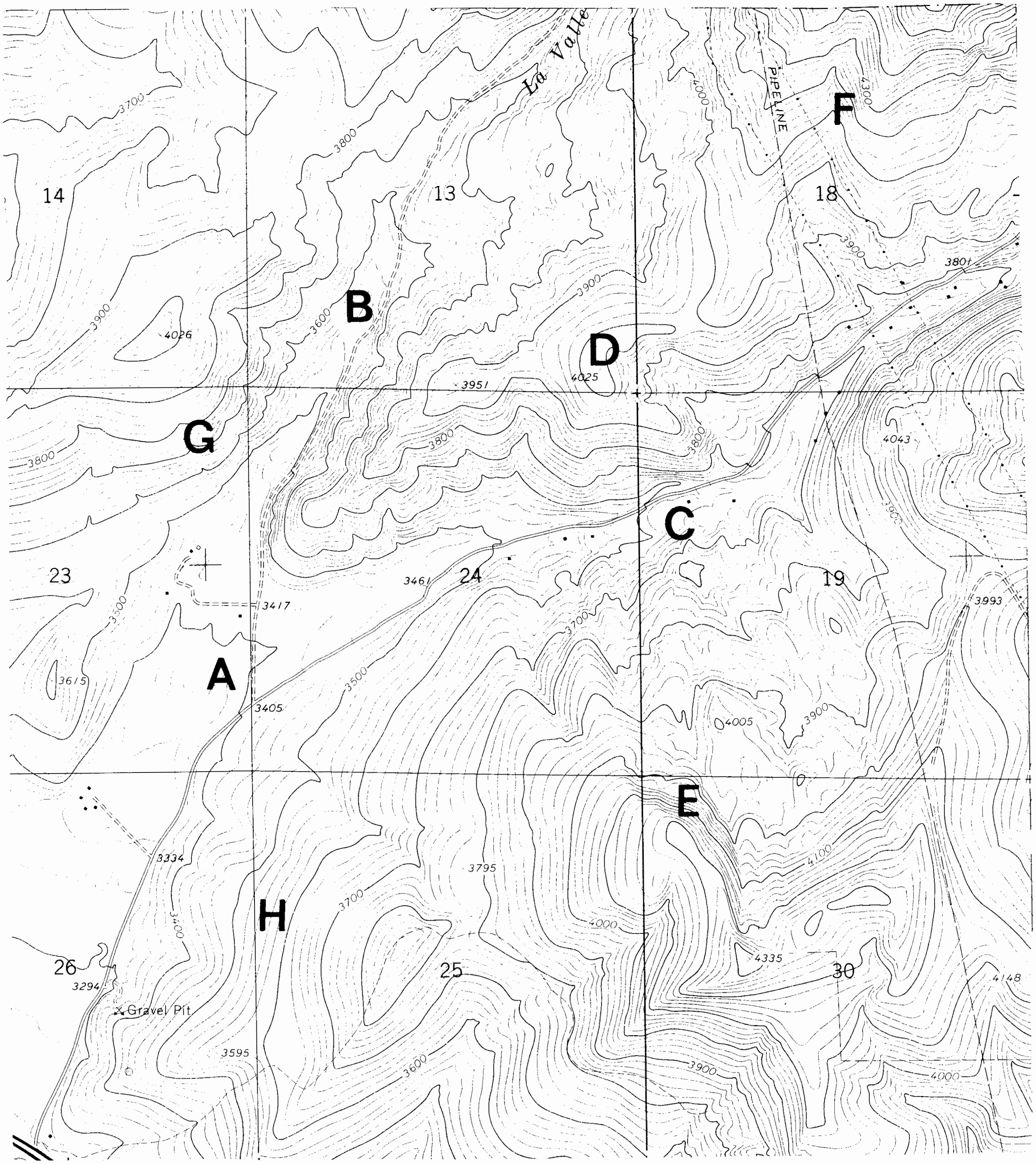


Figure II-9.—Map of LaValle Creek for wind examples.

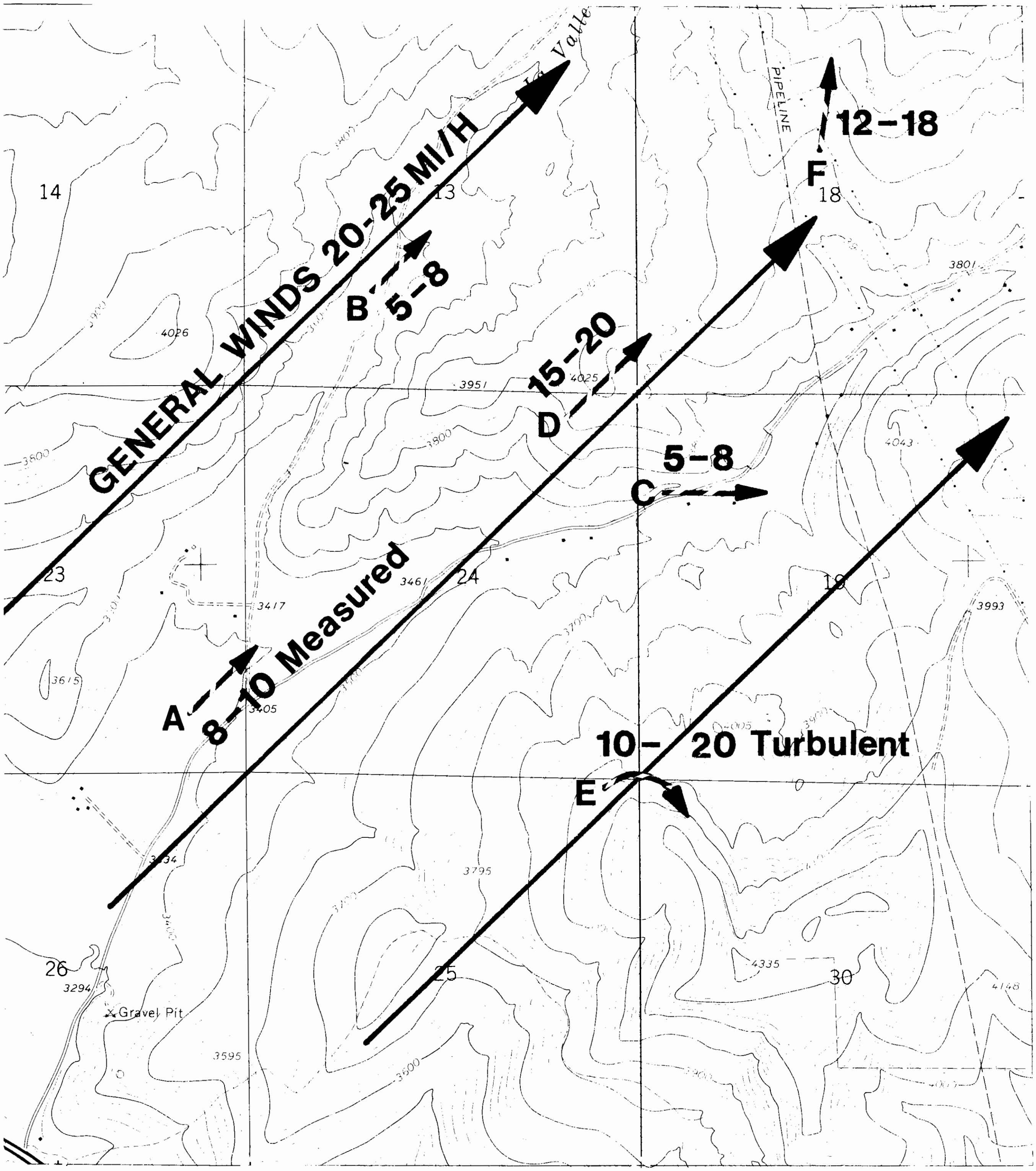


Figure II-10.—Solution to wind exercise 1 shown on map of LaValle Creek.

Slope

Fire can spread significantly faster up a slope than on level terrain in the same fuels. Flame length will also be greater on a slope. The fire model uses positive slope much as it uses wind to adjust rate of spread and flame length. The input used by the model to account for slope is the maximum percent slope of the terrain above the fire. The fire model does not account for negative slopes and will not accept negative values. If you are concerned with a fire backing down a slope, an approximate rate of spread may be calculated by using zero slope as the input. Cases where the wind is driving the fire downslope or cross-slope are discussed in chapter IV, under "Line Fire."

The objective of this section is to illustrate how to determine percent slope as needed for predicting fire behavior.

Both wind and slope tilt the flame over the unburned fuel and bring it to ignition temperature sooner than if they were not present. This causes faster spread rates and longer flame lengths. Slope is particularly important at low windspeeds. At higher windspeeds the wind can dominate the fire so that the effect of slope is not as apparent. Slope is much easier to assess than wind because the latter is so changeable. Slope can be frustrating, however, in rough terrain. Learn to disregard small undulations with respect to the size of the fire or that the fire may cross in a time that is short compared to the observed run time. The shorter the time for preparing your prediction, the less precise you can be on slope determination and accounting for its variation.

It is necessary to be able to make slope determinations from observations on-site or from a topographic map.

DETERMINING SLOPE ON-SITE

In many situations, an estimation of slope is sufficiently accurate. A better method is to measure the slope with an instrument such as a clinometer. Slopes steeper than 100 percent do not normally support vegetation. Slopes usually look much steeper when viewed from the top down than from the bottom up. Slopes can often be judged more accurately from a distance. As you drive to a fire, note the angles of the terrain against the skyline. Do the same thing on-site. Turn 90 degrees and look at the end of the valley to see the slope as a line. If you are on a uniform section that is representative of the general slope, rest one end of a 4- to 6-ft stick on the slope and hold the other end so the stick is as horizontal as possible. The slope can then be estimated from the angle where it rests on the ground or as the ratio of height of the stick from the ground to the length of the stick. Although this sounds crude, it is about the accuracy needed, and the accuracy you can expect to achieve when estimating other variables.

TOPOGRAPHIC MAPS

In many situations, even in the field, you will be working with topographic maps or maps with elevation contours. There are a great many methods, tables, and shortcuts for determining slope from a contour map. If you have a favorite one and it works well, use it. Only the direct calculation method will be discussed here.

The slope between two points is simply the change in elevation between two points divided by the horizontal distance between them. This ratio multiplied by 100 gives the slope in percent.

The process can be summarized in five steps:

1. Determine the contour interval. This is the elevation change between adjacent contour lines.

Example: 40 ft

2. Determine the map scale and conversion factor. The map scale must be found in terms of the number of feet that each inch on the map represents (ft/in).

a. Map scales are usually given as the number of inches per mile, such as 2 inches/mi, or as a representative fraction such as 1:31,680. Use table II-10 to convert these map scales to feet per inch.

Table II-10.— Conversion factors for map scale

Representative fraction	Inches/mile	Feet/inch
1:253,440	1/4	21,120
1:126,720	1/2	10,560
1:63,360	1	5,280
1:31,680	2	2,640
1:24,000	2-5/8 (2.64)	2,000
1:21,120	3	1,760
1:15,840	4	1,320
1:7,920	8	660

Example: 2 inches/mi = 2,640 ft/inch
and
1:31680 = 2,640 ft/inch

b. If table II-10 is not available, use the spacing of section lines to determine the map scale. Normally section line spacing is 1 mile; be careful of foreshortened sections; look around on the map and find square sections with equal spacing. Measure the distance with a ruler graduated in inches and tenths of inches. Divide 5,280 by the map distance between section lines.

Example: Measured map distance is 2.64 inches

$$\text{Map scale} = \frac{5{,}280}{2.64} = 2{,}000 \text{ ft/inch}$$

3. Determine rise in elevation by counting contour intervals and convert to feet.

Example: 11 contour intervals at 40 ft per interval
equals 440 ft.

4. Measure the horizontal distance with a ruler graduated in inches and tenths of inches, and convert to feet with the map scale from step 2.

Example: 1.2 inches × 2,640 ft/inch
equals 3,168 ft.

5. Divide the rise in elevation from step 3 by the horizontal distance from step 4.

$$\text{Example: } \frac{440}{3{,}168} \times 100 = 14\%$$

When slope is determined, enter it on line 14 of the fire behavior worksheet.

SLOPE EXAMPLES

Samples: When using the contour map that follows, calculate the slope between the following pairs of points:

A and B
C and D
E and F
F and H
G and H

Solutions:

A and B Step 1: The contour interval given on the map is 20 ft.

Step 2: The map scale conversion factor from table II-10 for a scale of 1:24000 is 2,000 ft per inch.

Step 3: There are 35 contour intervals between A and B. The rise in elevation is 35 × 20 = 700 ft.

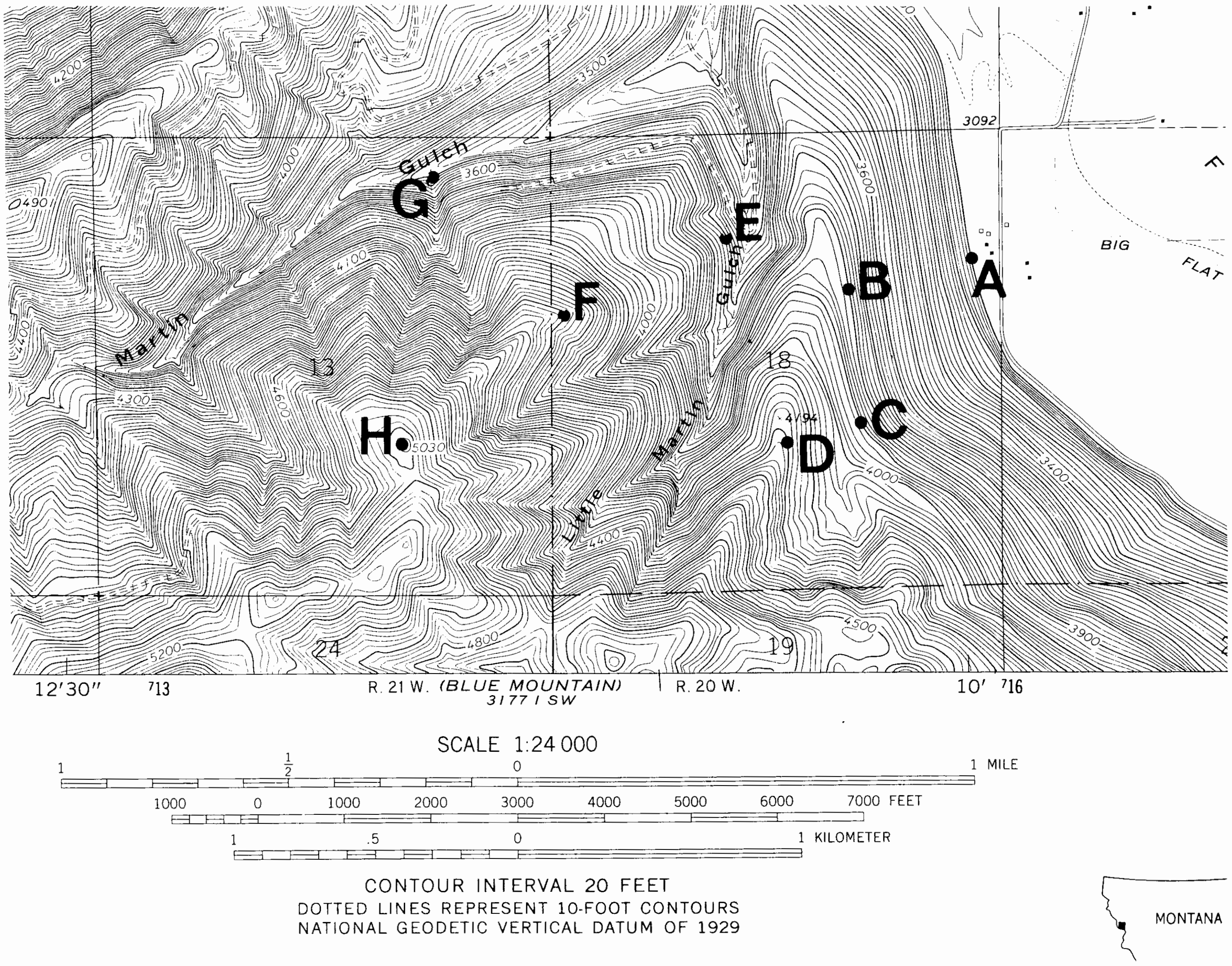
Step 4: The distance between points A and B on the map is 0.72 inches. The horizontal distance is 0.72 × 2,000 = 1,440 ft.

Step 5: The slope is $\frac{\text{rise}}{\text{horz. dist.}} = \frac{700}{1{,}440} \times 100$ $= 49\%$.

C and D	Vertical rise	= 15 × 20	= 300 ft
	Horizontal distance	= 0.42 × 2,000	= 840 ft
	Slope	$= \frac{300}{840} \times 100$	= 36%
E and F	Vertical rise	= 40 × 20	= 800 ft
	Horizontal distance	= 1.5 × 2,000	= 3,000 ft
	Slope	$= \frac{800}{3{,}000} \times 100$	= 27%
F and H	Vertical rise	= 31 × 20	= 620 ft
	Horizontal distance	= 1.2 × 2,000	= 2,400 ft
	Slope	$= \frac{620}{2{,}400} \times 100$	= 26%
G and H	Vertical rise[10]	= 5,030 − 3,500	= 1,530 ft
	Horizontal distance	= 1.55 × 2,000	= 3,100 ft
	Slope		= 49%

---

[10] In this example the difference in elevation between G and H rather than the number of contour intervals was used to determine the vertical rise.



CHAPTER III

CALCULATING FIRE BEHAVIOR

Fire Behavior Worksheets

The fire behavior worksheet (exhibit II-1) has been designed for use with both the nomograms and the TI-59 calculator. The sheet is intended for recording input data, showing the results of calculations, and displaying results needed for plotting fire growth and interpreting fire behavior. The reverse side of the worksheet is a form to estimate fine dead fuel moisture, using the tables described in the fuel moisture section.

INPUT DATA

Lines 1 through 18 provide the data required for calculations and lines 19 through 28 indicate the resulting fire behavior predictions. Values that are used as direct input to the TI-59 are indicated by the calculator overlay label abbreviation and the calculator register number. The keystroke sequence for obtaining output from the TI-59 is given on the worksheet.

The following is a line-by-line description of how to use the worksheet. This is followed by additional information concerning special uses of the worksheet.

Head - Enter the name of the fire.

Enter the name of the fire behavior officer or person responsible for predicting fire behavior.

Sequentially number the sheets and indicate the total number of sheets used to complete the fire growth for the overall time period.

Enter the date and time at which the calculations are made.

Because this is a forecast of expected fire behavior, record the date for which the forecast is made and the applicable time period for the calculations. Your fire experience and ability to interpret meteorological forecasts can contribute strongly here by helping you choose time intervals during which conditions are expected to be relatively constant.

All calculations made on one sheet should be for the same time interval. Use successive sheets for successive time intervals.

Line 1 - *Projection point.* A projection point is a place from which fire growth will be projected. (Refer to chapter IV, "Estimating Spread from a Line of Fire.")

Record the number of a projection point that will be associated with the same point on the map. All subsequent data in the column pertain to conditions in the direction of fire spread from that point.

Line 2 - *Fuel model proportion, pct*

If the two-fuel-model concept is being used, record an estimate of the proportion of the area that is covered by each fuel model. The fuel that covers most of the area should be placed in the second column. The sum of the two must total 100 percent. If one fuel model is used, leave this line blank.

Line 3 - *Fuel model*

Record the number of fuel model (13 available) that most closely matches the fuels ahead of the projection point.

If the fuels cannot be matched by one fuel model due to nonuniformity, use the two-fuel-model concept. Record the numbers of the fuel models in adjacent columns. (Refer to the two-fuel-model concept in the fuels section of chapter II.)

Line 4 - *Shade*

Enter a value of 0, 1, 2, or 3 based on shading due to either cloud or canopy cover or both for 0–10 percent, 10–50 percent, 50–90 percent, or 90–100 percent, respectively. This code is used by the TI-59 to calculate 1-hour fuel moisture. The tables for estimating fuel moisture only use an estimate of less than 50 percent shading or more than 50 percent shading.

Line 5 - *Dry bulb temperature,* °F

Enter the air temperature expected during the projection period.

Line 6 - *Relative humidity, pct*

Enter the relative humidity expected during the projection period.

RH is used in estimating fuel moisture from the tables and with the TI-59.

Line 7 - *1 H TL FM, pct*

Moisture of fine dead fuel determined from the tables can be used with either the nomograms or the TI-59. When used with the TI-59 it is equivalent to the 1-hour timelag fuel moisture. When the nomograms are used it is the only dead fuel moisture necessary, and lines 8 and 9 of the worksheet are not used.

Of the three dead fuel moisture values that can be entered for the TI-59, 1 H TL FM is by far the most important.

Line 8 - *10 H TL FM, pct*

If the TI-59 is being used, an estimate of the 10-hour timelag fuel moisture is needed for most fuel models. If a fire danger weather station is nearby, the fuel stick moisture content can be used for the 10 H TL FM. If there has been a long-term drying period, the 10 H TL FM can be assumed to be 1 or 2 percent wetter than the 1 H TL FM calculated for afternoon conditions.

Line 9 - *100 H TL FM, pct*

If the TI-59 is being used, enter an estimate for 100-hour timelag fuel moisture. In a long-term drying cycle, the 100-hour value can be estimated as 1 or 2 percent wetter than the 10-hour value.

Line 10 - *Live fuel moisture, pct*

Estimate live fuel moisture from the guides given in the fuel moisture section.

Line 11 - *20-ft windspeed, mi/h*

The standard height for measuring and forecasting wind is 20 ft above the vegetation. A value of the speed and direction must be carefully estimated by taking into account several rather subjective factors. See the section on wind in chapter II. If the tables for slope winds are used, the value obtained is the midflame windspeed and no 20-ft wind value or adjustment factor is necessary.

Line 12 - *Wind adjustment factor*

Enter the factor that is read from the wind adjustment table II–6. When the 20-ft windspeed is multiplied by the wind adjustment factor, the result is the midflame windspeed. If table II–5 is used, the wind adjustment factor is not entered.

Line 13 - *Midflame windspeed, mi/h*

If midflame windspeed is estimated from 20-ft windspeed, canopy cover, and topography, enter the value obtained by multiplying 20-ft windspeed (line 11) by the wind adjustment factor (line 12). Alternatively, an estimate of the midflame windspeed can be made without measurement or calculation with tables II-3 and II-5.

If a portable handheld anemometer is used to measure the windspeed near the fire and under the same sheltering conditions that the fire will experience, the measured value may be used directly as midflame windspeed for most fuels. For tall shrubs, 4–6 ft, the midflame wind should be measured at 8–10 ft above the ground rather than eye level.

Line 14 - *Maximum slope, pct*

Enter the maximum slope of the terrain above the projection point.

Line 15 - *Projection time, h*

Record the length of the projection time period; this time is determined as the difference between the beginning and ending time of the projection time recorded in the heading. Projection time is used to find spread distance, map distance, perimeter, and area (lines 23 through 26).

Line 16 - *Map scale, in/mi*

If the TI–59 is being used, enter the map scale in **inches per mile.**

If the nomograms are being used, leave this line blank.

Map scale is used only to calculate map distance (line 24).

Line 17 - *Map conversion factor, in/ch*

If nomograms are being used, enter the map conversion factor in inches per chain from the table below. To plot the spread distance from the nomograms on the map overlay, it is necessary to determine the number of inches equivalent to the spread distance in chains. The conversion factor can be calculated as follows:

Conversion factor = Map scale divided by 80 where the map scale is inches per mile.

Example: Map scale = 1/2 inch per mile

Map conversion factor = 0.5/80 = 0.00625

The following conversion table covers most standard map scales:

Map scale (inches/mi)	**Conversion factor (inches/chain)**
1/4	0.00312
1/2	.00625
1	.0125
2	.025
2-5/8	.0328
4	.05

If the TI–59 is being used, leave this line blank.

Line 18 - *Effective windspeed, mi/h*

If the nomograms are being used, use the lower left-hand quadrant to determine the effective windspeed from midflame windspeed (line 13) and maximum slope (line 14).

If the TI–59 is being used, leave this line blank.

FIRE BEHAVIOR OUTPUTS

The data assembled in lines 1 through 18 are used to calculate the fire behavior at each projection point. Either the nomograms or the TI–59 calculator can be used.

A description of the meaning of each of the outputs given on lines 19 to 28 of the fire behavior worksheet is given below:

Line 19 - *Rate of spread, ch/h*

The rate of advance of the "head" of a fire is called the forward rate of spread. (Computed by TI–59 and nomograms.)

Line 20 - *Heat per unit area, Btu/ft²*

This is the amount of heat released per square foot during the time that area is within the flaming front. The use of this intensity term will be explained in conjunction with the fire characteristics chart. (Computed by TI–59 and nomograms.)

Line 21 - *Fireline intensity, Btu/ft/s*

This is the amount of heat released (in Btu's) per foot of fire front per second. It is related to the difficulty of containment of a fire. Fireline intensity is based on both the rate of spread and the heat per unit area of the fire. (Computed by TI–59 and nomograms.)

Line 22 - *Flame length, ft*

This is the average length of the flame at the projection point (fig. III–1). Under no-wind, no-slope conditions, flame length and flame height are the same. Under strong winds or steep slopes there can be a significant difference. (Computed by TI–59 and nomograms.)

Flame length can be used as an alternative, observable measure of fireline intensity.

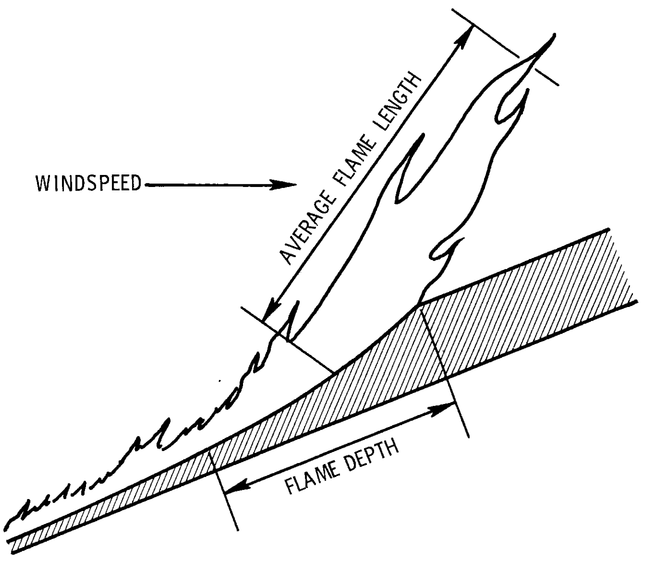


Figure III-1.—Depiction of flame dimensions.

Line 23 - *Spread distance, ch*
This is an estimate of the probable forward movement of the head of the fire during a specified time period. When nomograms are used, spread distance is obtained by multiplying rate of spread (line 19) by projection time (line 15). (Calculated directly by the TI-59.)

Line 24 - *Map distance, in*
This is an estimate of the progress of the fire front for mapping purposes. When nomograms are used, map distance is determined by multiplying spread distance (line 23) by the map conversion factor (line 17). (Calculated directly by TI-59.)

Line 25 - *Perimeter, ch*
This is an estimate of the perimeter of a fire started from a point and having a shape that is approximately elliptical. When nomograms are used it is determined from table IV-2. (Calculated directly by the TI-59.)

Line 26 - *Area, a*
This is an estimate of the area in acres of a fire started from a point source and having a shape that is approximately elliptical. When nomograms are used, it is obtained from table IV-3. (Calculated directly by the TI-59.)

Line 27 - *Ignition component, pct*
This is an estimate of the probability that a firebrand will cause an ignition that will evolve into a fire that is large enough to be "reportable." This is not the same as the probability of ignition which is discussed in chapter IV in the crowning and spotting section. Ignition component incorporates probability of ignition and rate of spread. (IC is calculated directly by the TI-59.)

Line 28 - *Reaction intensity, Btu/ft^2/ min*
This is the rate of heat released per square foot per minute. It should not be confused with fireline intensity, which is the value usually associated with the intensity of a fire. Reaction intensity is an important output of the fire model and can be expected to be important for relating to fire effects. (It is calculated directly by the TI-59.) Methods for manual calculation are given in appendix C.

Calculating Fire Behavior With Nomograms

A nomogram is a group of interconnecting graphs that can be used to solve a mathematical equation or series of equations. Albini (1976) developed a set of nomograms for calculating fire behavior, utilizing the equations of Rothermel's fire model.

The nomograms presented here have been modified from Albini's original version. The primary change has been to use midflame windspeed, rather than 20-ft windspeed, as an input. Albini used 20-ft windspeed, with a wind reduction factor of one-half, which was the prevailing assumption at that time, to predict fire behavior in all conditions. To correct the overprediction of fire spread in cases where the fuels were sheltered by an overstory of trees, the method of calculating windspeed in sheltered fuel presented by Albini and Baughman (1979) was adopted (see "Wind," chapter II).

Another change was to replace reaction intensity with heat per unit area as one of the outputs.

There are two nomograms for each of the 13 fuel models: a low windspeed version and a high windspeed version. Both give the same answers, but better resolution can be obtained from the low windspeed version, so it should be used whenever possible. Nomograms for the 13 fire behavior fuel models are given in appendix A.

Nomograms will provide an estimate of rate of spread, fireline intensity, flame length, and heat per unit area. The fire behavior worksheet specifies the input data and is used to record the outputs. It has been designed for use with either the nomograms or the TI-59. Not all values are used with both systems; consequently, some lines on the fire behavior worksheet will not be used. Whenever the worksheet is needed, the line number on the left-hand margin will be referred to.

For the nomograms, data on the following lines are necessary:

3 Fuel model
7 Fine dead fuel moisture
10 Live fuel moisture for some fuels
13 Midflame windspeed
14 Maximum slope

Fuel models 2, 4, 5, 7, and 10 contain living fuel. The procedures for fuels with live fuel moisture are somewhat different than for the fuel models that have only dead fuel. Methods for calculating fire behavior with fuel models containing only dead fuels will be covered first.

It is assumed that a worksheet (exhibit III-1) has been prepared with the required information. Select the nomogram for the fuel model designated on line 3 of the fire behavior worksheet.

There are four parts to the nomogram. These are called quadrants and are referred to as "upper" and "lower" (referring to the top and bottom of the page) and by "left" and "right." Solving a fire spread problem on a nomogram requires initial preparation followed by a run through all four quadrants, with a continuous line starting and finishing in the upper right quadrant. All of the answers are read in the upper right quadrant. Solutions for the examples given in exhibit III-1 are shown on exhibits III-2 and III-3.

The nomogram should be placed on a flat surface. Lines should be drawn with a narrow 10- or 12-inch transparent straightedge or ruler. The underlying 1/4-inch grid should be used to keep your lines true with those on the nomogram, i.e., parallel and forming right angles at intersections.

Exhibit III-1.—Fire behavior worksheet with examples for nomograms.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 1

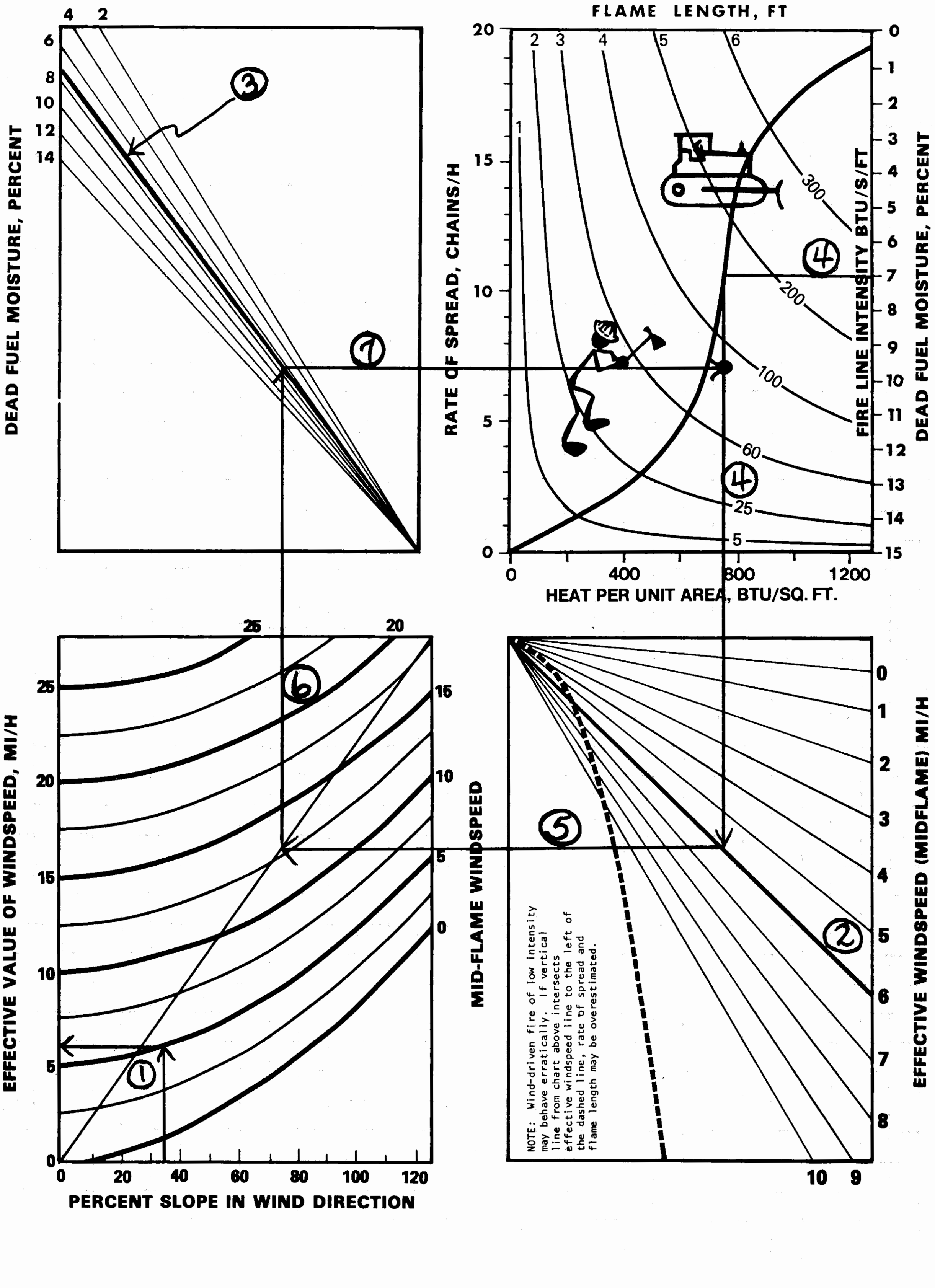
NAME OF FIRE Old Smokey
FIRE BEHAVIOR OFFICER Flaming Aero
DATE 12/4/81
TIME 1420
PROJ. PERIOD DATE 12/5/81
PROJ. TIME FROM 1200 to 1400

	INPUT DATA		Dead Fuel Example		Live Fuel Example		TI-59 Reg. No.
1	Projection point		①		②		
2	Fuel model proportion, %		100		100		
3	Fuel model		11		5		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0		0		60
5	Dry bulb temperature, °F	DB	55		55		61
6	Relative humidity, %	RH	22		22		62
7	1 H TL FM, %	1H	7		7		28
8	10 H TL FM, %	10H	7		7		63
9	100 H TL FM, %	100H	7		7		30
10	Live fuel moisture, %	LIVE	-		200		33
11	20-foot windspeed, mi/h		(12)	( )	(12)	( )	
12	Wind adjustment factor		(.4)	( )	(.4)	( )	
13	Midflame windspeed, mi/h	M WS	5		5		79
14	Maximum slope, %	PCT S	35		35		80
15	Projection time, h	PT	2		2		81
16	Map scale, in/mi	MS	-		-		82
17	Map conversion factor, in/ch		-		-		
18	Effective windspeed, mi/h		6		6		

	OUTPUT DATA							
19	Rate of spread, ch/h	[A]	ROS	7		7		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	760		240		90
21	Fireline intensity, Btu/ft/s	[B]	INT	85		30		53
22	Flame length, ft	[R/S]	FL	4		2		54
23	Spread distance, ch	[C]	SD	14		14		42
24	Map distance, in	[R/S]	MD	-		-		43
25	Perimeter, ch	[D]	PER	-		-		40
26	Area, acres	[R/S]	AREA	-		-		89
27	Ignition component, %	[E]	IC	-		-		44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	-		-		52

Exhibit III-2.—Example of nomogram solution with dead fuel only.

11. LIGHT LOGGING SLASH-LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

GENERAL INSTRUCTIONS—EITHER LIVE OR DEAD FUEL

Step 1.—Determine effective value of the midflame windspeed. (This step combines wind and slope.) Note the slope given on line 14 of the fire behavior worksheet. In the lower left quadrant, find the percent slope and draw a vertical line to the top of the quadrant. On the right-hand side of the lower left quadrant, find the midflame windspeed given on line 13 of the fire behavior worksheet. Follow the curved windspeed line until it intercepts the vertical line just drawn. At the intersection, draw a horizontal line to the left-hand margin. The effective windspeed is read off the margin. For the example in exhibit III-2 the effective windspeed is 6 mi/h. Record the effective midflame windspeed on line 18 of the fire behavior worksheet.

The construction lines drawn in the lower left quadrant are not used again.

Step 2.—Prepare the lower right quadrant by locating a ray (line from the origin) that represents the effective windspeed. Such lines are already in the quadrant to guide you. Interpolate if necessary to establish a ray for the effective windspeed determined in step 1. This line will be used later as a turning line when taking the run through the nomogram.

Note: The lower right quadrant contains a curved dashed line. A note in this quadrant reads:

> Wind-driven fires of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and fireline intensity may be overstated.

If the vertical line from the upper right quadrant intersects the curved dashed line before reaching the designated effective windspeed ray, stop at the intersection with the dashed line and draw a line into the lower left quadrant from that intersection. This will produce a lower rate of spread and fireline intensity than would result if you continued past the curved dashed line and used the designated effective windspeed line.

FUEL MODELS WITH DEAD FUELS ONLY

Step 3.—For nomograms with no live fuel. This step prepares the upper left quadrant. On the edge of the quadrant find the dead fuel moisture value given on line 7 of the fire behavior worksheet. If necessary to interpolate, construct a new ray for this fuel moisture.

All preparations have been made and you can begin your run around the nomogram.

Step 4.—Begin in the upper right quadrant. In the right hand margin locate the dead fuel moisture from line 7 of the fire behavior worksheet. Draw a horizontal line across the upper right quadrant until it intercepts the S-shaped curve. Through this interception draw a vertical line from the top of the upper right quadrant into the lower right quadrant until it meets the ray designating the effective windspeed or intercepts the curved dashed line as described in step 2 (see exhibit III-2).

Step 5.—Note the diagonal line in the lower left quadrant. This is the next turning line. From the interception of the effective windspeed in the lower right quadrant, draw a horizontal line into the lower left quadrant where it intercepts the diagonal line. (Pay no attention to the previously constructed lines from step 1 in the lower left quadrant.)

Step 6.—At the intersection of the turning line in the lower left quadrant draw a vertical line into the upper left quadrant until it intercepts the appropriate ray for the fuel moisture found in step 3 (see exhibit III-2).

Step 7.—At the intercept with the dead fuel moisture ray in the upper left quadrant, draw a horizontal line into the upper right quadrant, extending it until it intercepts the vertical line constructed in step 4 at the beginning of the run. Draw a small circle at this intercept (see exhibit III-2).

You have run the line through all four quadrants; you can now read the answers.

Rate of spread.—Read at the left-hand margin of the upper right quadrant where the horizontal line from step 7 enters the quadrant. In exhibit III-2, the rate of spread is 7 ch/h. Record rate of spread on line 19 of the fire behavior worksheet.

Fireline intensity.—Determine from the small circle drawn in step 7 in the upper right quadrant. The fireline intensity numbers are indicated on each curved line running through the quadrant. Interpolate between lines. In exhibit III-2, the fireline intensity is about 85 Btu/ft/s. Record fireline intensity on line 21 of the fire behavior worksheet.

Flame length.—The small circle drawn in step 7 lies on, near, or between the family of curved lines; follow the nearest line to the top of the upper right quadrant and see the flame lengths marked in feet. Use the location of the circle between these lines to estimate flame length. Do not be exact. The nearest foot is sufficient in most cases. In exhibit III-2, the flame length is about 4 ft. Record flame length on line 22 of the fire behavior worksheet.

Heat per unit area.—Read on the lower horizontal axis of the upper right quadrant where it is crossed by the vertical line drawn in step 4. In exhibit III-2, the heat per unit area is 760 Btu/ft^2.

After some practice you will find that it is only necessary to draw lines in the upper right quadrant when you make the trip around the nomogram; tic marks at intersections in the other quadrants are sufficient.

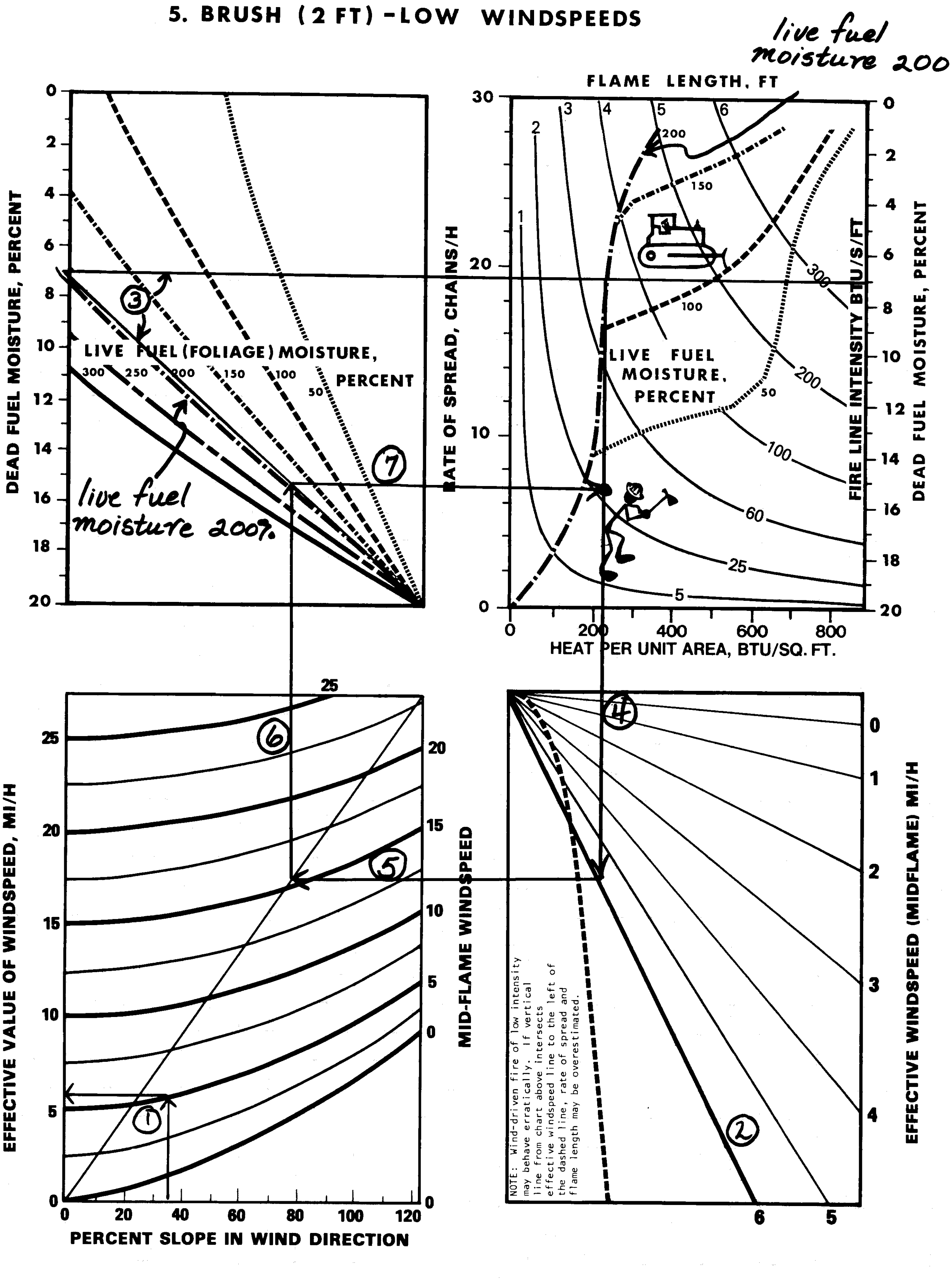
FUEL MODELS WITH LIVE AND DEAD FUELS

Fuel models 2, 4, 5, 7, and 10 have living fuels requiring a different procedure in step 3. Do not be discouraged; Albini has designed the nomograms to account for this extra variable with little extra effort.

Step 3 with live fuel.—Find the dead fuel moisture on the right side of the upper right quadrant and on the left side of the upper left quadrant. Draw a line across both quadrants at the designated dead fuel moisture. See the worked example in exhibit III-3. In the upper left quadrant find the intersection of the horizontal line just drawn with a slightly curved line representing the live fuel moisture given on line 10 of the fire behavior worksheet. Lay your straightedge between the intersection just found and the origin and draw a ray out to the margin as shown in exhibit III-3. This line will be the turning ray in the upper left quadrant when you make your run around the nomogram (exhibit III-3). Note that for some fuel models and some conditions the slightly curved lines are so straight that this step provides little correction.

Step 4 with live fuels.—Locate the S-shaped curve that comes the closest to matching the live fuel moisture at the start of your run in the upper right quadrant. You can interpolate between these lines if desired. The run will end at the intersection of this vertical line. All other steps are the same as used for dead fuel.

Exhibit III-3.—Example of nomogram solution with live and dead fuels.



5. BRUSH (2 FT) - LOW WINDSPEEDS

live fuel moisture 200%.

live fuel moisture 200%.

NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

INTERPRETATION OF CURVES DISPLAYED ON THE NOMOGRAMS

Note that the more severe the fire conditions are, i.e., dry fuels, high winds, the further you will be from the origin or center of the paper as you travel around the nomogram.

Note the effect of the S-shaped curve in the upper right nomogram. When fuels are very dry, i.e., less than 5 percent, the line curves away from the center quite sharply, which will produce high intensities. When the fuel becomes wet the line drops sharply to the origin. This is a region of uncertain fire behavior because of the very wet fuels. The moisture of extinction can be read off the bottom of the right-hand margin where the curve reaches zero. This is the moisture at which fire can no longer spread with a sustained fire front. It will be different for different fuel models.

In the lower right quadrant note the curved dashed line. This line designates a limiting windspeed at which a further increase in windspeed would not necessarily make the fire spread faster. The limit is set by the reaction intensity which for each fuel model is set by the fuel moisture. If the reaction intensity becomes too low, the wind will overpower the flame and blow it into fingers of fire that will be cooled, diluted, and eventually blown out.

The influence of wind and slope upon fire behavior and their respective effects can be seen in the lower left quadrant. At low windspeeds an increase in slope produces a higher effective windspeed than it does at higher windspeeds.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 2

NAME OF FIRE Nomogram Exercises FIRE BEHAVIOR OFFICER ______

DATE ______ TIME ______

PROJ. PERIOD DATE ______ PROJ. TIME FROM ______ to ______

INPUT DATA Only the direct inputs needed to calculate the first four outputs with the nomograms are given. TI-59 Reg. No.

1	Projection point Exercise No.		1	2	3	4	
2	Fuel model proportion, %		100	100	100	100	
3	Fuel model		6	1	3	9	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE					60
5	Dry bulb temperature, °F	DB					61
6	Relative humidity, %	RH					62
7	1 H TL FM, %	1H	4	8	12	22	28
8	10 H TL FM, %	10H					63
9	100 H TL FM, %	100H					30
10	Live fuel moisture, %	LIVE					33
11	20-foot windspeed, mi/h		( )	( )	( )	( )	
12	Wind adjustment factor		( )	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	0	5	25	20	79
14	Maximum slope, %	PCT S	60	20	60	0	80
15	Projection time, h	PT					81
16	Map scale, in/mi	MS					82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h		3	5	26	20	

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	23	87	700	8	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	530	80	650	170	90
21	Fireline intensity, Btu/ft/s	[B]	INT	250	140	8300	15	53
22	Flame length, ft	[R/S]	FL	5½	4½	29	1	54
23	Spread distance, ch	[C]	SD					42
24	Map distance, in	[R/S]	MD					43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 2

NAME OF FIRE Nomogram Exercises FIRE BEHAVIOR OFFICER ____
DATE ____ TIME ____
PROJ. PERIOD DATE ____ PROJ. TIME FROM ____ to ____

INPUT DATA

								TI-59 Reg. No.
1	Projection point			5	6			
2	Fuel model proportion, %			100	100			
3	Fuel model			10	5			
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE					60
5	Dry bulb temperature, °F		DB					61
6	Relative humidity, %		RH					62
7	1 H TL FM, %		1H	6	4			28
8	10 H TL FM, %		10H					63
9	100 H TL FM, %		100H					30
10	Live fuel moisture, %		LIVE	100	100			33
11	20-foot windspeed, mi/h			( )	( )	( )	( )	
12	Wind adjustment factor			( )	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	12.5	10			79
14	Maximum slope, %		PCT S	60	60			80
15	Projection time, h		PT					81
16	Map scale, in/mi		MS					82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h			14	12			

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	35	80			88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1400	700			90
21	Fireline intensity, Btu/ft/s	[B]	INT	850	1000			53
22	Flame length, ft	[R/S]	FL	10	11			54
23	Spread distance, ch	[C]	SD					42
24	Map distance, in	[R/S]	MD					43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

Calculating Fire Behavior with the TI-59 Calculator

GENERAL

The TI-59 handheld calculator contains a small interchangeable module. Two thousand modules preprogramed to compute fire behavior were distributed to fire management agencies throughout the country. The program is explained in the user's manual prepared by Burgan (1979). Instructions for operating the calculator are not repeated in this manual except where new material has been added or clarification is needed. A copy of Burgan's manual[1] should be available for everyone using a chip. A 3-day training session on operation of the TI-59 with the chip was developed at the Northern Forest Fire Laboratory[2] for persons receiving the chip. The operating instruction summary used in that course is shown in exhibit III-4. These are instruction summaries and should not be used as sequential procedures. A copy of the keyboard overlay is given in exhibit III-5. It is important to know which inputs affect which outputs so that the calculator can be operated efficiently and changes made quickly. A matrix showing the interactions is given in exhibit III-6. This manual is compatible with material presented in the TI-59 training course.

The TI-59 fire behavior chip utilizes the same fire behavior worksheet used with the nomograms (exhibit II-1). The inputs utilized by the chip are identified by the lines that have an overlay label and register number alongside.

Exhibit III-4.—TI-59 operating instruction reminder.

FIRE BEHAVIOR COMPUTATIONS

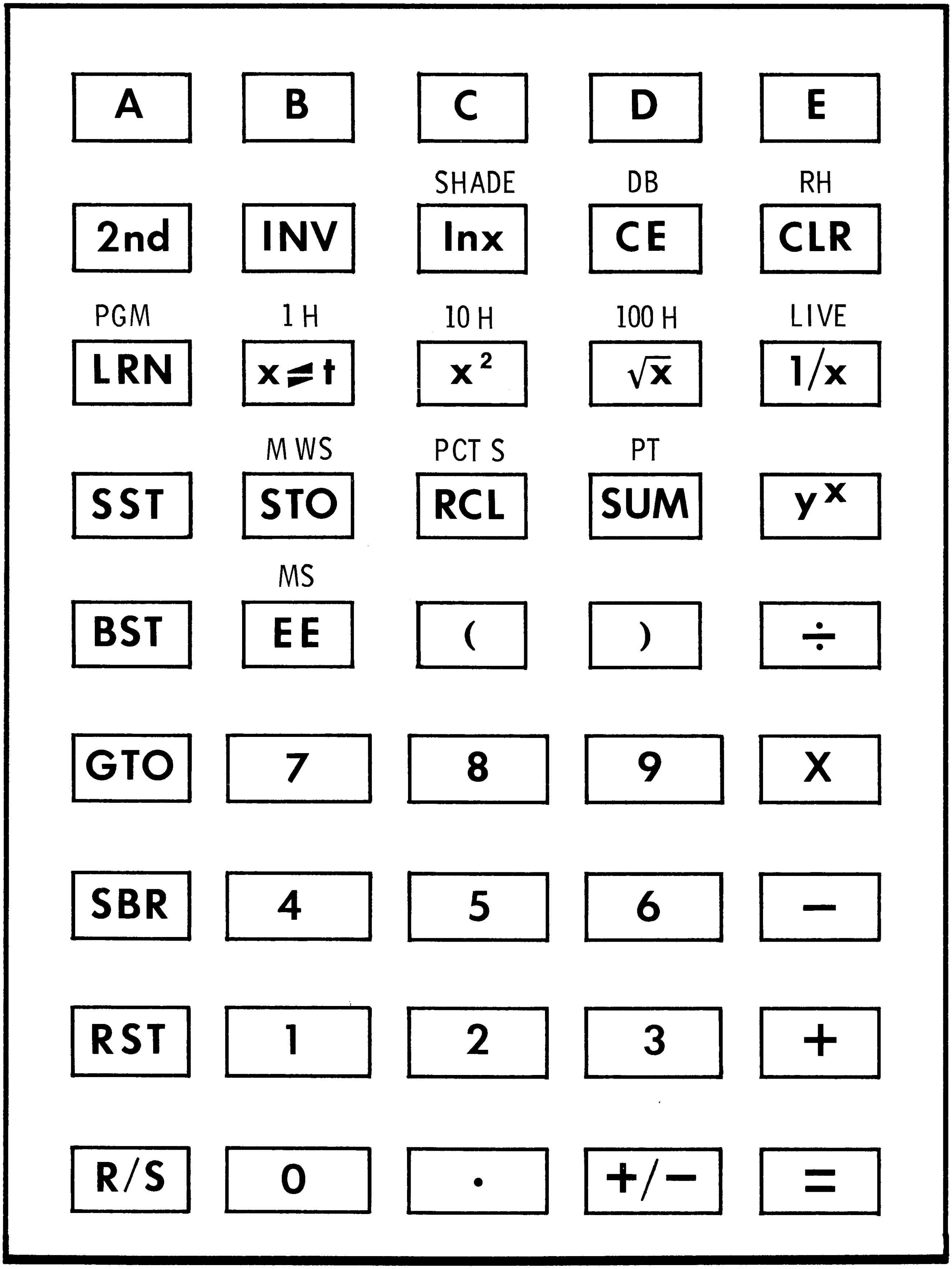
Select program and enter fuel model	2nd PGM 2 SBR R/S (display = -4.) *fuel model number* R/S
Enter input	*value* SBR KEY
Check input	SBR 2nd KEY
Obtain output	A R/S B R/S C R/S D R/S E R/S
Check input or output	RCL *register number*
Change fuel model	SBR R/S (display = -4.) *fuel model number* R/S
Display all decimals	INV 2nd (
Set number of decimal places	2nd (*number of places*
Check all input and obtain output	SBR 2nd SHADE R/S R/S ... R/S
Calculate 1 H and 10 H	*value* SBR SHADE *value* SBR DB 0 SBR 10 H *value* SBR RH (must proceed next step) R/S (1 H is displayed) SBR 2nd 10 H (10 H is displayed)
Calculate 1 H when 10 H is known	*value* SBR SHADE *value* SBR DB *value* SBR 10 H *value* SBR RH (must proceed next step) R/S (1 H is displayed)

---

[1] Copies obtainable from Intermountain Forest and Range Experiment Station, Research Information, 507 25th St., Ogden, UT 84401. Ask for Fire Danger/Fire Behavior Computations with the Texas Instruments TI-59 Calculator: User's Manual, USDA For. Serv. Gen. Tech. Rep. INT-61.

[2] Unpublished instructions for calculating the NFDRS indexes and fire behavior, by Andrews, Burgan, and Rothermel.

Exhibit III-5.—TI-59 fire behavior keyboard overlay.



A	B	C	D	E
2nd	INV	SHADE lnx	DB CE	RH CLR
PGM LRN	1 H $x \rightleftharpoons t$	10 H x^2	100 H $\sqrt{x}$	LIVE 1/x
SST	M WS STO	PCT S RCL	PT SUM	y^x
BST	MS EE	(	)	÷
GTO	7	8	9	X
SBR	4	5	6	−
RST	1	2	3	+
R/S	0	.	+/−	=

Exhibit III-6.—Interaction matrix between inputs and outputs.

CALCULATED OR OUTPUT VALUES

		1-hour timelag fuel moisture	10-hour timelag fuel moisture	Rate of spread	Heat per unit area	Fireline intensity	Flame length	Spread distance	Map distance	Perimeter	Area	Ignition component	Reaction intensity
INPUT VALUES		1 H^1	10 H^1	ROS	H/A	INT	FL	SD	MD	PER	AREA	IC	IR
Fuel model				X	X	X	X	X	X	X	X	X	X
Fuel shading	SHADE	X	X									X	
Dry bulb temperature	DB	X	X									X	
Relative humidity	RH	X	X										
1-H timelag fuel moisture	1 H			X	X	X	X	X	X	X	X	X	X
10-H timelag fuel moisture	10 H^2	X^3		X	X	X	X	X	X	X	X	X	X
100-H timelag fuel moisture	100 H^2			X	X	X	X	X	X	X	X	X	X
Live fuel moisture	LIVE^2			X	X	X	X	X	X	X	X	X	X
Midflame windspeed	M WS			X		X	X	X	X	X	X	X	
Percent slope	PCT S			X		X	X	X	X	X	X	X	
Projection time	PT							X	X	X	X		
Map scale	MS								X				

[1] Optional calculation
[2] Only for fuel models that include these fuel components
[3] Whenever a non-zero value is stored for 10 H TL FM

The TI–59 produces the 10 outputs listed on lines 19 through 28. Interpretation of these outputs is given in chapter IV.

As a reminder, it is not necessary to reenter all inputs when one input is changed. The old entries will remain if they are not specifically changed. This is true of fuel model selection as well. Review Burgan's manual carefully regarding change of inputs.

Similarly, if you are only interested in rate of spread and flame length you need only look at the first four outputs before making a change for a new calculation.

Several examples for using the TI–59 complete with answers follow this section.

Calculating Fire Behavior in Nonuniform Fuels

(The Two-Fuel-Model Concept)

Three columns of the fire behavior worksheet should be used when the two-fuel-model concept is being employed: one column for each fuel model and one column for combined calculation of spread. Enter the fuel model with the largest proportion of fuel in the second column. The fuel model proportion, line 2 of the fire behavior worksheet, is estimated for each fuel model. The two percentages should total 100 percent. The fire behavior calculations are carried out as usual and the results recorded on the worksheet. The rate of spread is weighted by percent cover and recorded in the third column.

Do not try to combine fireline intensities or flame lengths. Unlike rate of spread, which may be averaged over some time to find the spread distance, intensity is important at the time it occurs and should not be averaged or weighted. As a first approximation, simply estimate that the intensity values calculated separately will exist in the same proportion as the estimated cover of each fuel model.

When using the TI–59, the entire operation can be performed with a few keystrokes. The weighted value for rate of spread is then stored in register 88, where it is used to calculate new values of spread distance, map distance, area, and perimeter. The example below and the accompanying worksheet illustrate the process.

EXAMPLE OF THE TWO-FUEL-MODEL CONCEPT PROCEDURES

Results are recorded on the accompanying fire behavior worksheet.

Fuel model 5; 30% cover; rate of spread = 25 ch/h
Fuel model 1; 70% cover; rate of spread = 99 ch/h

Determine weighted rate of spread by the following keystroke sequence:

0.3 × 25 + 0.7 × 99 = 77
STO 88

The weighted rate of spread is now stored in the rate of spread register (88). Do not hit button **A** or the calculator will recalculate rate of spread and erase the value just stored in register 88. Instead, utilize the weighted rate of spread now stored in register 88 to calculate the spread distance, map distance, perimeter, and area with the following keystrokes:

C	read spread distance (chains) in display
R/S	read map distance (inches) in display
D	read perimeter (chains) in display
R/S	read area (acres) in display.

The completed example is shown on the accompanying worksheet.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 1

NAME OF FIRE Two-fuel-model example FIRE BEHAVIOR OFFICER

DATE TIME

PROJ. PERIOD DATE PROJ. TIME FROM to

For simplicity, only those inputs and outputs used in the example are shown

INPUT DATA

							TI-59 Reg. No.
1	Projection point		1	1	1		
2	Fuel model proportion, %		30	70			
3	Fuel model		5	1			
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE					60
5	Dry bulb temperature, °F	DB					61
6	Relative humidity, %	RH					62
7	1 H TL FM, %	1H	5	5			28
8	10 H TL FM, %	10H	–	6			63
9	100 H TL FM, %	100H	–	–			30
10	Live fuel moisture, %	LIVE	–	100			33
11	20-foot windspeed, mi/h		( )	( )	( )	( )	
12	Wind adjustment factor		( )	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	5	5			79
14	Maximum slope, %	PCT S	0	0			80
15	Projection time, h	PT	1	1			81
16	Map scale, in/mi	MS	1	1			82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	25	99	77		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	654	92			90
21	Fireline intensity, Btu/ft/s	[B]	INT	297	168			53
22	Flame length, ft	[R/S]	FL	6	5			54
23	Spread distance, ch	[C]	SD			76.8		42
24	Map distance, in	[R/S]	MD			1.0		43
25	Perimeter, ch	[D]	PER			236		40
26	Area, acres	[R/S]	AREA			376		89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 4

NAME OF FIRE TI-59 Exercises FIRE BEHAVIOR OFFICER ____________

DATE ____________ TIME ____________

PROJ. PERIOD DATE ____________ PROJ. TIME FROM ________ to ________

For simplicity, all input values are assumed including the fuel moisture.

INPUT DATA

							TI-59 Reg. No.
1	Projection point	Exercise No.	1	2	3	4	
2	Fuel model proportion, %		100	100	100	100	
3	Fuel model		5	6	3	5	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0	2	1	0	60
5	Dry bulb temperature, °F	DB	80	72	60	80	61
6	Relative humidity, %	RH	20	18	25	20	62
7	1 H TL FM, %	1H	4	8	10	3	28
8	10 H TL FM, %	10H	5	7	–	5	63
9	100 H TL FM, %	100H	–	5	–	–	30
10	Live fuel moisture, %	LIVE	90	–	–	100	33
11	20-foot windspeed, mi/h		( )	( )	( )	( )	
12	Wind adjustment factor		( )	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	4	2	0	0	79
14	Maximum slope, %	PCT S	30	0	5	0	80
15	Projection time, h	PT	.75	1	1	1	81
16	Map scale, in/mi	MS	4	1	1	1	82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	26	10	4	1	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	717	441	662	733	90
21	Fireline intensity, Btu/ft/s	[B]	INT	339	79	47	17	53
22	Flame length, ft	[R/S]	FL	7	3	3	2	54
23	Spread distance, ch	[C]	SD	19.3	9.8	3.8	1.3	42
24	Map distance, in	[R/S]	MD	1.0	0.1	0.05	0.0	43
25	Perimeter, ch	[D]	PER	61	36	16	6	40
26	Area, acres	[R/S]	AREA	25	10	2	.24	89
27	Ignition component, %	[E]	IC	64	12	3	17	44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	3142	1796	2585	3211	52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 4

NAME OF FIRE TI-59 Exercises FIRE BEHAVIOR OFFICER

DATE TIME

PROJ. PERIOD DATE PROJ. TIME FROM to

INPUT DATA For simplicity, all inputs have been assumed including fuel moisture.

								TI-59 Reg. No.
1	Projection point		Exercise No.	5	6	7	8	
2	Fuel model proportion, %			100	100	100	100	
3	Fuel model			5	5	9	9	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0	0	0	0	60
5	Dry bulb temperature, °F		DB	80	80	80	80	61
6	Relative humidity, %		RH	20	20	20	20	62
7	1 H TL FM, %		1H	3	3	3	3	28
8	10 H TL FM, %		10H	5	5	5	5	63
9	100 H TL FM, %		100H	-	-	7	7	30
10	Live fuel moisture, %		LIVE	100	100	-	-	33
11	20-foot windspeed, mi/h			( )	( )	( )	( )	
12	Wind adjustment factor			( )	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	5	10	0	5	79
14	Maximum slope, %		PCT S	0	0	0	0	80
15	Projection time, h		PT	1	1	1	1	81
16	Map scale, in/mi		MS	1	1	1	1	82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							
	OUTPUT DATA							
19	Rate of spread, ch/h	[A]	ROS	28	72	1	12	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	733	733	448	448	90
21	Fireline intensity, Btu/ft/s	[B]	INT	376	961	9	97	53
22	Flame length, ft	[R/S]	FL	7	11	1	4	54
23	Spread distance, ch	[C]	SD	28	71.5	1.1	11.9	42
24	Map distance, in	[R/S]	MD	0.4	0.9	0	0.1	43
25	Perimeter, ch	[D]	PER	86	185	5	36	40
26	Area, acres	[R/S]	AREA	50	169	0	9	89
27	Ignition component, %	[E]	IC	77	83	18	57	44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	3211	3211	2899	2899	52

FIRE BEHAVIOR WORKSHEET

Sheet 3 of 4

NAME OF FIRE TI-59 Exercises FIRE BEHAVIOR OFFICER ____________

DATE ____________ TIME ____________

PROJ. PERIOD DATE ____________ PROJ. TIME FROM ________ to ________

INPUT DATA For simplicity, all input values have been assumed including fuel moisture.

								TI-59 Reg. No.
1	Projection point		Exercise No.	9	10	11	12	
2	Fuel model proportion, %			100	100	100	100	
3	Fuel model			9	3	3	3	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0	1	1	1	60
5	Dry bulb temperature, °F		DB	80	75	75	75	61
6	Relative humidity, %		RH	20	20	20	20	62
7	1 H TL FM, %		1H	3	2	5	10	28
8	10 H TL FM, %		10H	5	–	–	–	63
9	100 H TL FM, %		100H	7	–	–	–	30
10	Live fuel moisture, %		LIVE	–	–	–	–	33
11	20-foot windspeed, mi/h			( )	( )	( )	( )	
12	Wind adjustment factor			( )	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	10	3	3	3	79
14	Maximum slope, %		PCT S	0	5	5	5	80
15	Projection time, h		PT	1	1	1	1	81
16	Map scale, in/mi		MS	1	1	1	1	82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							
	OUTPUT DATA							
19	Rate of spread, ch/h	[A]	ROS	36	97	69	49	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	448	980	783	662	90
21	Fireline intensity, Btu/ft/s	[B]	INT	300	1736	987	596	53
22	Flame length, ft	[R/S]	FL	6	14	11	9	54
23	Spread distance, ch	[C]	SD	36.5	96.6	68.8	49.1	42
24	Map distance, in	[R/S]	MD	0.5	1.2	0.9	0.6	43
25	Perimeter, ch	[D]	PER	94	330	235	168	40
26	Area, acres	[R/S]	AREA	44	799	405	207	89
27	Ignition component, %	[E]	IC	83	56	30	11	44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	2899	3825	3059	2585	52

FIRE BEHAVIOR WORKSHEET

Sheet 4 of 4

NAME OF FIRE TI-59 Exercises FIRE BEHAVIOR OFFICER ____

DATE ____ TIME ____

PROJ. PERIOD DATE ____ PROJ. TIME FROM ____ to ____

For simplicity, all input values have been assumed including fuel moistures.

INPUT DATA

								TI-59 Reg. No.
1	Projection point	Exercise No.		13	14	15		
2	Fuel model proportion, %			100	100	100		
3	Fuel model			1	1	1		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0	0	0		60
5	Dry bulb temperature, °F		DB	80	80	80		61
6	Relative humidity, %		RH	20	20	20		62
7	1 H TL FM, %		1H	3	3	3		28
8	10 H TL FM, %		10H	-	-	-		63
9	100 H TL FM, %		100H	-	-	-		30
10	Live fuel moisture, %		LIVE	-	-	-		33
11	20-foot windspeed, mi/h			( )	( )	( )	( )	
12	Wind adjustment factor			( )	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	0	5	10		79
14	Maximum slope, %		PCT S	0	0	0		80
15	Projection time, h		PT	1	1	1		81
16	Map scale, in/mi		MS	1	1	1		82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	5	119	446		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	103	103	103		90
21	Fireline intensity, Btu/ft/s	[B]	INT	10	226	844		53
22	Flame length, ft	[R/S]	FL	1	5	10		54
23	Spread distance, ch	[C]	SD	5.3	119	446		42
24	Map distance, in	[R/S]	MD	0.1	1.5	5.6		43
25	Perimeter, ch	[D]	PER	23	367	1164		40
26	Area, acres	[R/S]	AREA	4	909	6919		89
27	Ignition component, %	[E]	IC	10	49	83		44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	939	939	939		52

CHAPTER IV

INTERPRETING FIRE BEHAVIOR AND PREDICTING FIRE GROWTH

Fire Characteristics Chart

The calculations displayed on the fire behavior worksheet have definite meanings and interpretations. Their meaning, however, is not always easy to understand, especially when many numbers are displayed at once. Several methods have been developed to aid interpretation and understanding of the numbers. One of these is a map of fire growth; another is the fire characteristics chart developed by Andrews and Rothermel (1982). The fire characteristics chart (fig. IV-1) has the unique capability of displaying four basic fire characteristics—rate of spread, heat per unit area, flame length, and fireline intensity—as a single point on a chart. Referring to figure IV-1, rate of spread is plotted on the vertical axis and heat per unit area on the horizontal axis. The curved lines represent fireline intensity and flame length. It is interesting to examine the severity (fire severity is used in a general sense; no specific definition is intended) of fires on the chart. If the heat released per unit area is taken as the measure of severity, then fires that plot further to the right are more severe. If rate of spread is the accepted measure of severity, then fires that plot highest on the graph are more severe. If fireline intensity or flame length is the measure (as is done in the National Fire Danger Rating System where it is expressed as the burning index), then fires that plot in bands of equal flame length successively farther from the origin are more severe. In general, the farther a fire's position from the origin, the more severe it will be in terms describing the behavior of surface fires.

Many fires or projection points from a single fire can be plotted on the same chart. A quick glance will explain differences in fire behavior. Fast-spreading fires with low intensity will lie near the vertical axis, illustrating the threat is due to rapid spread. High-intensity, slow-spreading fires such as might occur in old logging slash, will lie to the right near the horizontal axis. Fast-spreading fires with high intensity, such as produced by chaparral or red slash, will lie in the center of the graph well away from the origin.

Interpretations of fireline intensity and flame length in terms of difficulty of control and potential for severe fire behavior (Roussopoulos and Johnson 1975) as given in table IV-1 are illustrated by characters and color shadings on some fire characteristics charts.

The order in which the output values are displayed by the TI-59 calculator makes it easy to use the fire characteristics chart. Rate of spread, the first output, is located on the vertical axis. Heat per unit area, the second output, is located on the horizontal axis. Intersection of lines drawn into the chart from these two points gives fireline intensity and flame length, which are the next two calculator outputs.

You will not be able to plot every fire behavior prediction on this graph. Some points will be beyond the scale. For those areas of the country that have fuels that tend to produce higher heat per unit area values, but lower spread rates, an alternative chart is available (fig. IV-2). The only difference between figure IV-1 and figure IV-2 is the length of the axis. If you want to have one chart that will accommodate all fires, a log scale version is available (fig. IV-3). Note that log scales are not linear and more care must be taken when interpreting the position of the points. Fires with high intensity will show little change in position for a significant change in intensity, whereas low-intensity fires which may be very similar will scatter all over the lower left corner.

Although fires are represented by single points on the chart, it must be remembered that this is only an estimate of fire behavior and a circle would be a better representation of the uncertainty of the calculation. The more nonuniform the fuels and the more uncertainty about the weather forecast, the larger the circle should be. There is no simple way to calculate the uncertainty that is applicable for field use.

Examples of the use of the fire characteristics chart will be given later in this chapter.

Table IV-1.— Fire suppression interpretations.[1] CAUTION: These are not guides to personal safety. Fires can be dangerous at any level of intensity. Wilson (1977) has shown that most fatalities occur in light fuels on small fires or isolated sectors of large fires

Flame length	Fireline intensity	Interpretations
Feet	*Btu/ft/s*	
<4	<100	Fires 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 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.

---

[1] Based on: Roussopoulos, Peter J.; Johnson, Von J. Help in making fuel management decisions. Res. Pap. NC-112. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1975. 16 p.

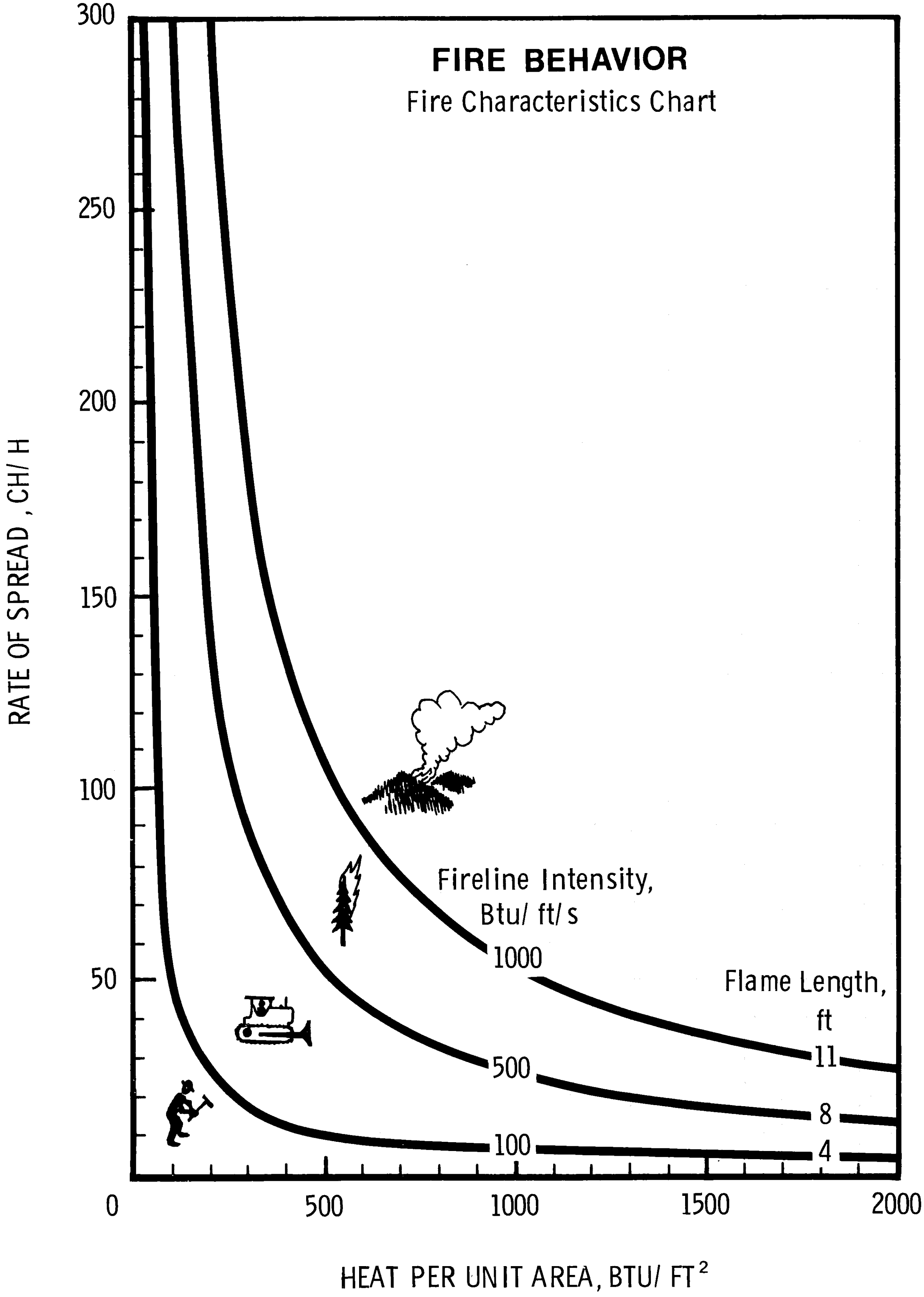


Figure IV-1.—Fire behavior fire characteristics chart.

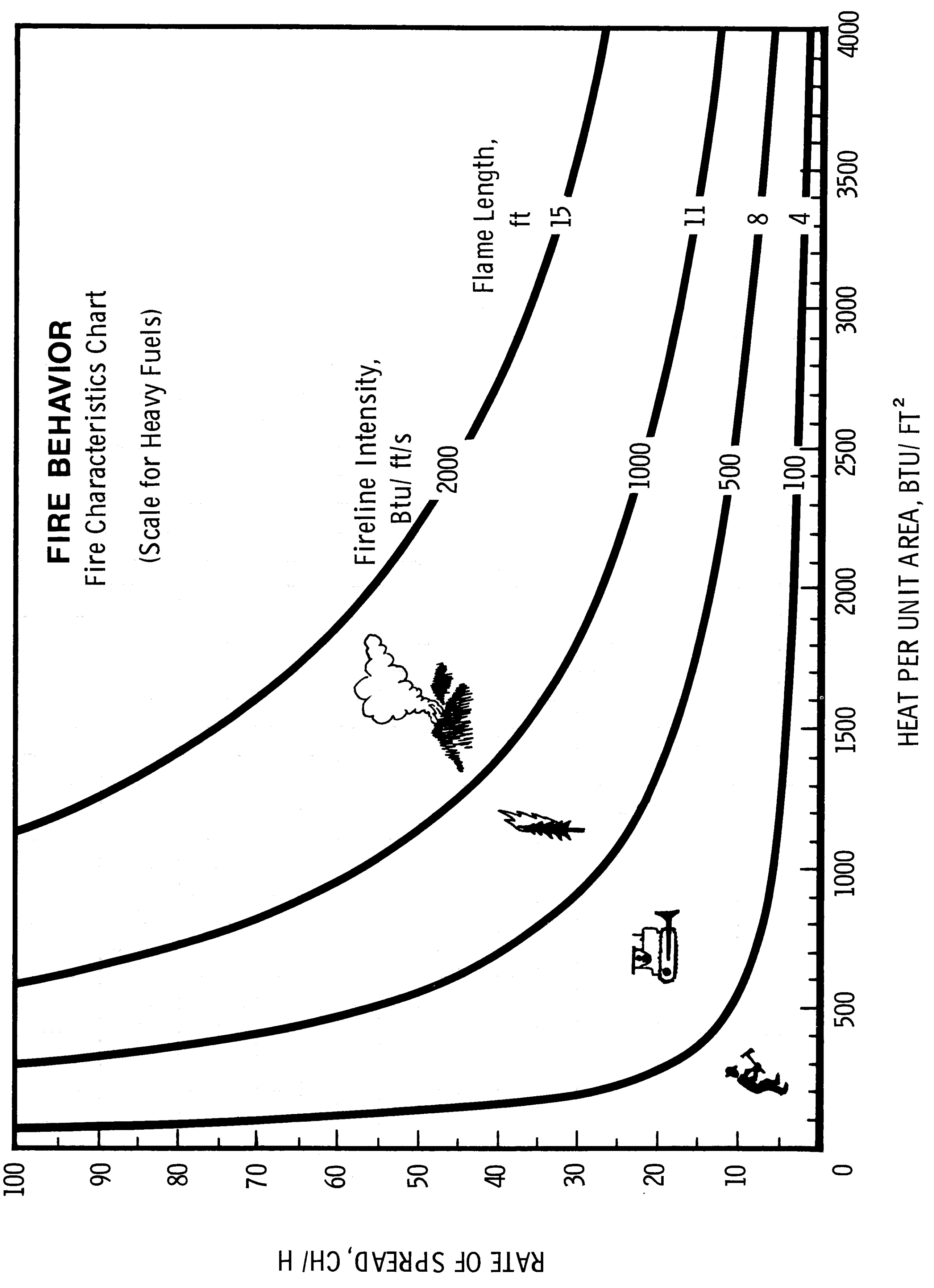


Figure IV-2.—Fire behavior fire characteristics chart scaled for heavy fuels.

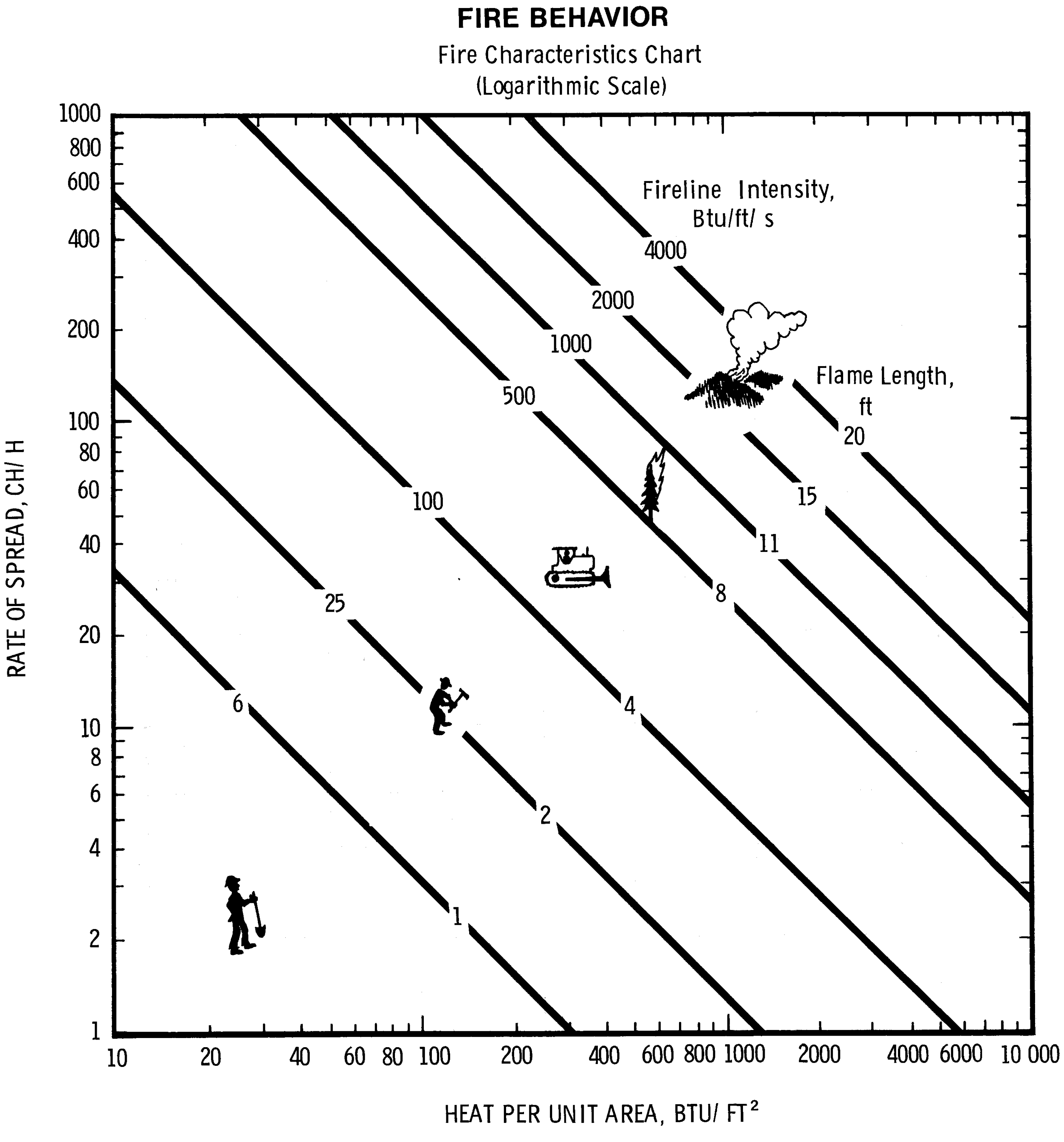


Figure IV-3.—Fire behavior fire characteristics chart with logarithmic scale.

Fire Growth From A Point Source

APPLICABILITY OF POINT SOURCE METHOD

When viewed from above, during initial growth a fire is elliptical or egg-shaped. Strong winds or steep slopes can elongate the shape, but it remains surprisingly consistent until fuels or the wind change. Anderson (1983) developed equations for predicting fire shapes as influenced by the effective windspeed from data taken by Fons.[1] Fire shapes calculated from these equations are shown in figure IV–4. Anderson's equations, which were reported by Albini (1976), will predict both the perimeter and the area of a fire starting from a point source such as a lightning strike or a firebrand. When a fire has become large enough so that there is no interaction between the head and rear of the fire, the fire model can be used to estimate the major spread distance. The spread distance is the product of the projection time and the rate of spread. In figure IV–4, the calculated spread distance "D" is from the point of origin to the furthest advance at the narrow end of the ellipse. If the TI-59 is being used to calculate fire behavior, the spread distance, the perimeter, and the area of the fire based on this elliptical shape can all be obtained as direct outputs. The spread distance and perimeter are expressed in chains. The area is expressed in acres. The effective windspeed is stored internally and is not available for display on the calculator.

For application of the point source method when fire is on a slope, it is assumed that any wind on the fire is blowing within ± 30° of directly upslope.

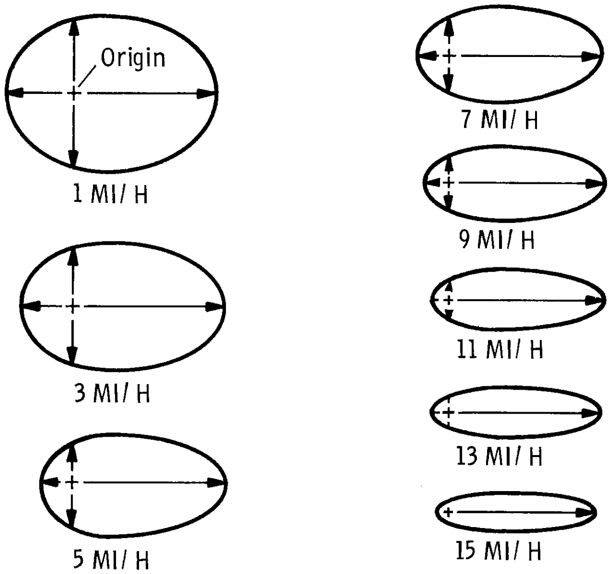


Figure IV-4.—Fire shapes associated with effective windspeeds.

Manual Calculation Procedures

If the TI–59 is not available, the perimeter and area can be determined from a pair of tables developed for the S–390 Fire Behavior Course.[2] To use the tables you will need the effective windspeed from line 18 of the fire behavior worksheet and the spread distance from line 23. As a reminder, spread distance is the rate of spread from line 19 multiplied by the projection time from line 15.

To obtain the perimeter, enter the top of table IV–2 with the effective windspeed and go down the column until you reach the row adjacent to the spread distance. Interpolate between columns and rows as necessary.

Example:

R = 20 ch/h
t = 1 hour
D = 20 chains
Effective windspeed = 9 mi/h
From table IV–2, perimeter = 52 chains

Area is obtained by identical procedures from table IV–3. For the above example: area = 14 acres.

Exercise 1

Given: A spot fire occurs outside a prescribed burn at 1200, the rate of spread is predicted to be 15 ch/h. Effective midflame windspeed is 8 mi/h. A patrol with hand tools and backpack pumps will arrive by 1230. A tractor can be on the fire by 1330.

Solve: The fire perimeter and area when
- the patrol arrives.
- the tractor arrives (hand crew ineffective on the fire front).

Solution:

Time for hand crew to arrive is 1/2 hour.
Spread distance at that time will be 7-1/2 chains.
Perimeter will be about 20 chains.
Area will be about 2 acres.
Note that it was necessary to interpolate between numbers in tables IV–2 and IV–3.
Time for tractor to arrive is 1 hour.
Spread distance at that time will be 15 chains.
Perimeter will be about 40 chains.
Area will be about 9 acres.

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[1] Fons, Wallace L. Forest Fuels Progress Report No. 6, RW-Cal, Fire Behavior, Forest Fuels. Calif. For. and Range Exp. Stn., May 20, 1940. Report on file (unpublished).

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

Table IV-2.— Perimeter estimations for point source fires (from S-390 course material)

Spread distance chains	Effective windspeed, mi/h									
	1	3	5	7	9	11	13	15	17	19
	Chains									
1	3	3	3	2	2	2	2	2	2	2
2	7	6	6	5	5	5	4	4	4	4
3	11	10	9	8	7	7	7	7	6	6
4	15	13	12	11	10	10	9	9	9	9
5	19	17	15	14	13	12	12	11	11	11
6	23	20	18	16	15	15	14	14	13	13
7	27	23	21	19	18	17	17	16	16	16
8	31	27	24	22	21	20	19	19	18	18
9	35	30	27	25	23	22	21	21	20	20
10	39	34	30	28	26	25	24	23	23	23
11	43	37	33	31	29	27	26	26	25	25
12	47	41	36	33	31	30	29	28	27	27
13	50	44	39	36	34	32	31	30	30	29
14	54	47	43	39	37	35	34	33	32	32
15	58	51	46	42	39	37	36	35	34	34
16	62	54	49	45	42	40	39	38	37	36
17	66	58	52	48	45	42	41	40	39	39
18	70	61	55	50	47	45	43	42	41	41
19	74	65	58	53	50	47	46	45	44	43
20	78	68	61	56	52	50	48	47	46	46
21	82	71	64	59	55	53	51	49	48	48
22	86	75	67	62	58	55	53	52	51	50
23	90	78	70	64	60	58	56	54	53	52
24	94	82	73	67	63	60	58	57	55	55
25	98	85	76	70	66	63	60	59	58	57
26	101	88	79	73	68	65	63	61	60	59
28	109	95	86	79	74	70	68	66	65	64
30	117	102	92	84	79	75	73	71	69	69
32	125	109	98	90	84	80	78	76	74	73
34	133	116	104	96	90	85	82	80	79	78
36	141	123	110	101	95	90	87	85	83	82
38	148	130	116	107	100	95	92	90	88	87
40	156	136	122	112	105	101	97	95	93	92
42	164	143	129	118	111	106	102	99	97	96
44	172	150	135	124	116	111	107	104	102	101
46	180	157	141	129	121	116	112	109	107	105
48	188	164	147	135	127	121	117	114	111	110
50	196	171	153	141	132	126	121	118	116	115
52	203	177	159	146	137	131	126	123	121	119
54	211	184	165	152	143	136	131	128	125	124
56	219	191	172	158	148	141	136	133	130	128
58	227	198	178	163	153	146	141	137	135	133
60	235	205	184	169	158	151	146	142	139	138
62	243	212	190	175	164	156	151	147	144	142
64	250	219	196	180	169	161	156	152	149	147
66	258	225	202	186	174	166	160	156	153	151
68	266	232	208	192	180	171	165	161	158	156
70	274	239	215	197	185	176	170	166	163	161

Table IV-2.—(con).

Spread distance chains	Effective windspeed, mi/h									
	1	3	5	7	9	11	13	15	17	19
	Chains									
72	282	246	221	203	190	181	175	171	167	165
74	290	253	227	209	196	186	180	175	172	170
76	297	260	233	214	201	191	185	180	177	174
78	305	266	239	220	206	197	190	185	181	179
80	313	273	245	225	211	202	195	190	186	184
82	321	280	251	231	217	207	199	194	191	188
84	329	287	258	237	222	212	204	199	195	193
86	337	294	264	242	227	217	209	204	200	197
88	344	301	270	248	233	222	214	209	205	202
90	352	308	276	254	238	227	219	213	209	207
92	360	314	282	259	243	232	224	218	214	211
94	368	321	288	265	249	237	229	223	219	216
96	376	238	294	271	254	242	234	228	223	220
98	384	335	301	276	259	247	239	232	228	225
100	392	342	307	282	264	252	243	237	233	230
105	411	359	322	296	278	265	256	249	244	241
110	431	376	337	310	291	277	268	261	256	253
115	450	393	353	324	304	290	280	273	268	264
120	470	410	368	338	317	303	295	285	279	276
125	490	427	383	353	331	315	304	297	291	287
130	509	444	399	367	344	328	317	308	303	299
135	529	462	414	381	357	341	329	320	314	310
140	548	479	430	395	370	353	341	332	326	322
145	568	496	445	409	384	366	353	344	338	333
150	558	513	460	423	397	378	365	356	349	345
155	607	530	476	437	410	391	378	368	361	356
160	627	547	491	451	423	404	390	380	373	368
165	646	564	506	466	437	416	402	392	384	379
170	666	581	522	480	450	429	414	404	396	391
175	686	599	537	494	363	442	426	415	408	402
180	705	616	552	508	476	454	439	427	419	414
185	725	633	568	522	490	467	451	439	431	425
190	744	650	583	536	503	479	463	451	443	437
195	764	667	599	550	516	492	475	463	454	448
200	784	684	614	564	529	505	487	475	466	460
210	823	718	645	593	556	530	512	499	489	483
220	862	753	675	621	582	555	536	522	513	506
230	901	787	706	649	609	581	560	546	536	529
240	940	821	737	677	635	606	585	570	559	552
250	980	855	767	706	662	631	609	594	583	575
260	1019	889	798	734	688	656	634	617	606	598
270	1058	924	829	762	715	682	658	641	629	621
280	1097	958	860	790	741	707	682	665	653	644
290	1136	992	890	819	768	732	707	689	676	667
300	1176	1026	921	847	794	757	731	713	699	690

NOTE: Interpolations will become less accurate at the lower end of this table due to the greater spans between spread distance values and the nonlinear equations used to produce the table. Your interpolated values may differ some what from those given by the TI-59 calculator with CROM.

Table IV-3.— Area estimations for point source fires (from S-390 course material)

Spread distance chains	Effective windspeed, mi/h									
	1	3	5	7	9	11	13	15	17	19
	Acres									
1	.1	.1	.1							
2	.5	.3	.3	.3	.2	.1	.1	.1	.1	
3	1.1	.8	.6	.4	.3	.3	.2	.2	.1	.1
4	1.9	1.4	1	.8	.6	.5	.4	.3	.2	.2
5	2	2	1.6	1.2	.9	.7	.6	.5	.4	.3
6	4	3	2	1.7	1.3	1.1	.8	.7	.5	.4
7	5	4	3	2	1.8	1.4	1.1	.9	.7	.6
8	7	5	4	3	2	1.9	1.5	1.2	.9	.7
9	9	6	5	3	3	2	1.9	1.5	1.2	.9
10	11	8	6	4	3	2	2	1.8	1.5	1.2
11	14	10	7	5	4	3	2	2	1.8	1.4
12	17	12	9	6	5	4	3	2	2	1.7
13	20	14	10	8	6	4	3	3	2	2
14	23	16	12	9	7	5	4	3	2	2
15	26	19	14	10	8	6	5	4	3	2
16	30	21	16	12	9	7	5	4	3	2
17	34	24	18	14	10	8	6	5	4	3
18	38	27	20	15	12	9	7	5	4	3
19	42	30	23	17	13	10	8	6	5	4
20	47	34	25	19	14	11	9	7	5	4
21	52	37	28	21	16	12	10	8	6	5
22	57	41	30	23	18	14	11	8	7	5
23	62	45	33	25	19	15	12	9	7	6
24	68	49	36	27	21	16	13	10	8	6
25	74	53	39	30	23	18	14	11	9	7
26	80	57	43	32	25	19	15	12	9	7
28	92	67	50	38	29	22	18	14	11	9
30	106	77	57	43	33	26	20	16	13	10
32	121	87	65	49	38	29	23	18	14	11
34	137	99	73	56	43	33	26	21	16	13
36	153	111	82	62	48	37	29	23	18	14
38	171	123	92	70	54	42	33	26	20	16
40	189	137	102	77	59	46	36	29	23	18
42	209	151	112	85	66	51	40	32	25	20
44	229	166	123	93	72	56	44	35	28	22
46	250	181	135	102	79	61	48	38	30	24
48	273	197	147	111	86	67	53	42	33	26
50	296	214	159	121	93	73	57	45	36	28
52	320	231	172	131	101	79	62	49	39	31
54	345	250	186	141	109	85	67	53	42	33
56	371	269	200	152	117	91	72	57	45	36
58	398	288	214	163	125	98	77	61	48	38
60	426	308	229	174	134	105	82	65	52	41
62	455	329	245	186	143	112	88	70	55	44
64	485	351	261	198	153	119	94	74	59	47
66	516	373	277	211	163	127	100	79	63	50
68	548	396	295	224	173	135	106	84	67	53
70	580	420	312	237	183	143	112	89	71	56

Table IV-3.—(con).

Spread distance chains	**Effective windspeed, mi/h**									
	1	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**
	Acres									
72	614	444	330	251	194	151	119	94	75	59
74	649	469	349	265	205	160	126	99	79	63
76	684	495	368	280	216	169	133	105	83	66
78	721	521	388	295	227	178	140	111	88	70
80	758	549	408	310	239	187	147	116	92	73
82	797	576	429	326	251	196	154	122	97	77
84	836	605	450	342	264	206	162	128	102	81
86	876	634	471	358	276	216	170	135	107	85
88	917	664	494	375	290	226	178	141	112	89
90	960	694	516	392	303	237	186	147	117	93
92	1003	726	540	410	316	247	195	154	122	97
94	1047	758	563	428	330	258	203	161	128	102
96	1092	790	588	446	345	269	212	168	133	106
98	1138	823	612	465	359	281	221	175	139	110
100	1185	857	638	484	374	292	230	182	145	115
105	1306	945	703	534	412	322	254	201	159	127
110	1434	1038	772	586	453	354	278	220	175	139
115	1567	1134	843	641	495	386	304	241	191	152
120	1706	1235	918	698	539	421	331	262	208	166
125	1852	1340	997	757	585	457	360	285	226	180
130	2003	1449	1078	819	632	494	389	308	245	195
135	2160	1563	1163	883	682	533	420	332	264	210
140	2323	1681	1250	950	734	573	451	357	284	226
145	2492	1803	1341	1019	787	615	484	383	304	242
150	2667	1930	1435	1091	842	658	518	410	326	259
155	2847	2061	1533	1165	899	703	553	438	348	277
160	3034	2196	1633	1241	958	749	590	467	371	295
165	3227	2335	1737	1320	1019	796	627	496	394	314
170	3425	2479	1844	1401	1082	845	666	527	419	333
175	3630	2627	1954	1485	1146	896	705	559	444	353
180	3840	2779	2067	1571	1213	948	746	591	470	374
185	4057	2936	2184	1659	1281	1001	788	624	496	395
190	4279	3097	2303	1750	1352	1056	832	658	523	417
195	4507	3262	2426	1844	1424	1112	876	694	551	439
200	4741	3431	2552	1939	1498	1170	921	730	580	462
210	5227	3783	2814	2138	1651	1290	1016	804	639	509
220	5737	4152	3088	2347	1812	1416	1115	883	702	559
230	6720	4538	3375	2565	1981	1547	1219	965	767	611
240	6827	4941	3675	2793	2157	1685	1327	1051	835	665
250	7408	5362	3988	3031	2340	1828	1440	1140	906	722
260	8013	5799	4313	3278	2531	1978	1558	1233	980	780
270	8641	6254	4652	3535	2730	2133	1680	1330	1057	842
280	9293	6726	5003	3802	2936	2294	1807	1431	1137	905
290	9969	7215	5366	4078	3149	2460	1938	1535	1219	971
300	10668	7721	5743	4364	3370	2633	2074	1642	1305	1039

NOTE: Interpolations will become less accurate at the lower end of this table due to the greater spans between spread distance values and the nonlinear equations used to produce the table. Your interpolated values may differ some what from those given by the TI-59 calculator with CROM.

Exercise 2

Given: A fire is started accidentally in a large clearcut in medium logging slash (fuel model 12). The fire starts at 4 p.m. On site the 20-ft windspeed is 12 mi/h, temperature 63° F, relative humidity 31 percent, skies are clear. The area is level. The date is October 12.

Solve:
- Fuel moisture and midflame windspeed using appropriate tables.
- Rate of spread, flame length, and fireline intensity using nomograms.
- Area and perimeter of fire at 1700 hours.
- Plot fire behavior outputs on a fire characteristics chart.

Solution is shown on accompanying worksheets.

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	Exercise 2			
b. Day or night (D/N)	[✓ D]/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	63			
d. Relative humidity, %	31			
e. Reference fuel moisture, % (from table A)	5			
f. Month	Oct			
g. Exposed or shaded (E/S)	[✓ E]/S	E/S	E/S	E/S
h. Time	1600			
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/[✓ L]/A	B/L/A	B/L/A	B/L/A
j. Aspect	Flat			
k. Slope	0			
l. Fuel moisture correction, % (from table B, C, or D)	2			
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	7			
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists <u>and</u> a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location(from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 1

NAME OF FIRE Point Source Ex. 2 FIRE BEHAVIOR OFFICER
DATE TIME
PROJ. PERIOD DATE PROJ. TIME FROM to

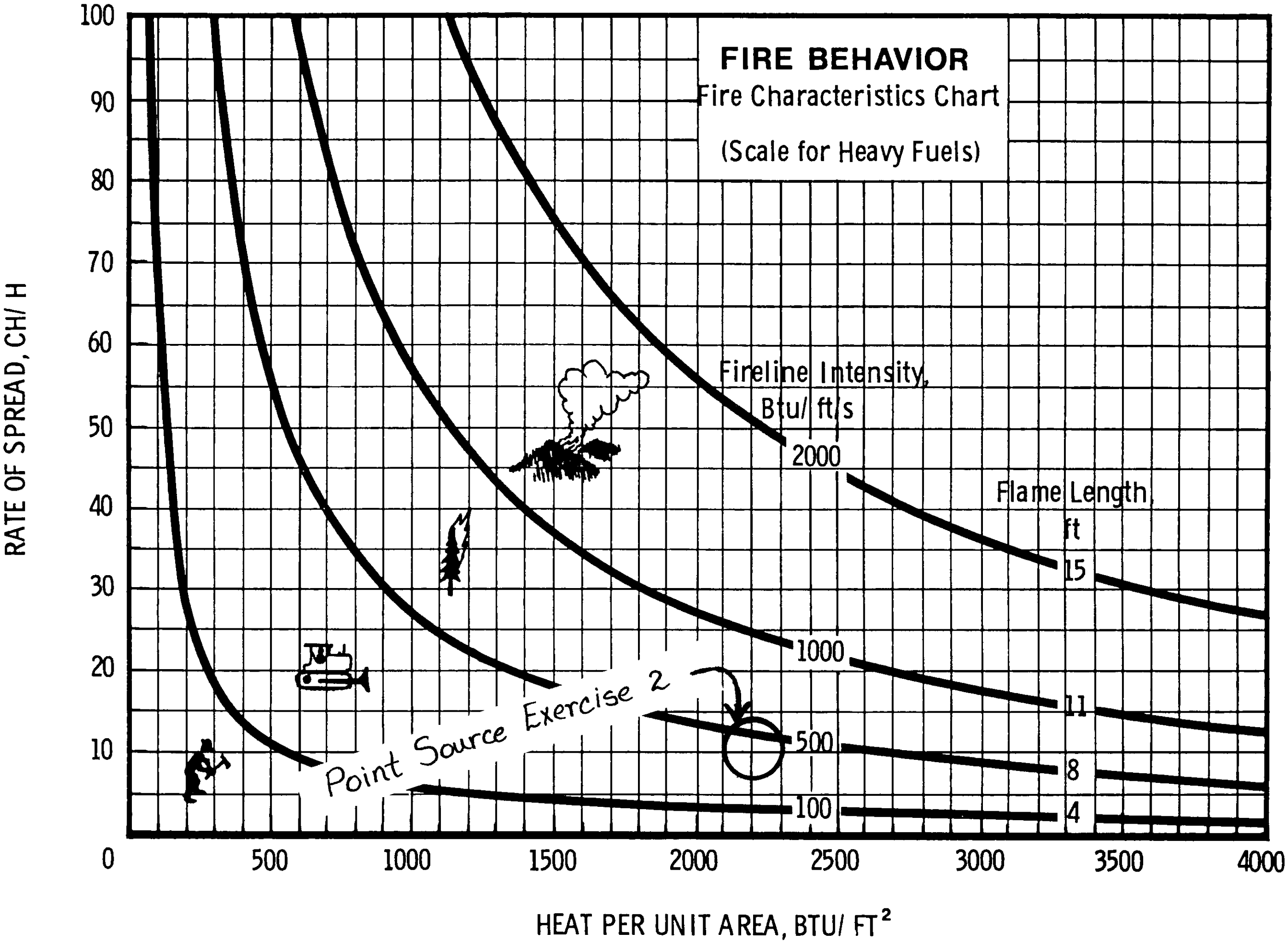
INPUT DATA

Data sheet entries for nomogram solution.

							TI-59 Reg. No.
1	Projection point		1				
2	Fuel model proportion, %		100				
3	Fuel model		12				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE					60
5	Dry bulb temperature, °F	DB					61
6	Relative humidity, %	RH					62
7	1 H TL FM, % from fuel moisture tables	1H	7				28
8	10 H TL FM, %	10H	–				63
9	100 H TL FM, %	100H	–				30
10	Live fuel moisture, %	LIVE	–				33
11	20-foot windspeed, mi/h		(12)	( )	( )	( )	
12	Wind adjustment factor		(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	5				79
14	Maximum slope, %	PCT S	0				80
15	Projection time, h	PT	1				81
16	Map scale, in/mi	MS					82
17	Map conversion factor, in/ch		–				
18	Effective windspeed, mi/h		5				

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	12				88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	2200				90
21	Fireline intensity, Btu/ft/s	[B]	INT	400				53
22	Flame length, ft	[R/S]	FL	7				54
23	Spread distance, ch	[C]	SD	12				42
24	Map distance, in	[R/S]	MD	–				43
25	Perimeter, ch	[D]	PER	36				40
26	Area, acres	[R/S]	AREA	9				89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52



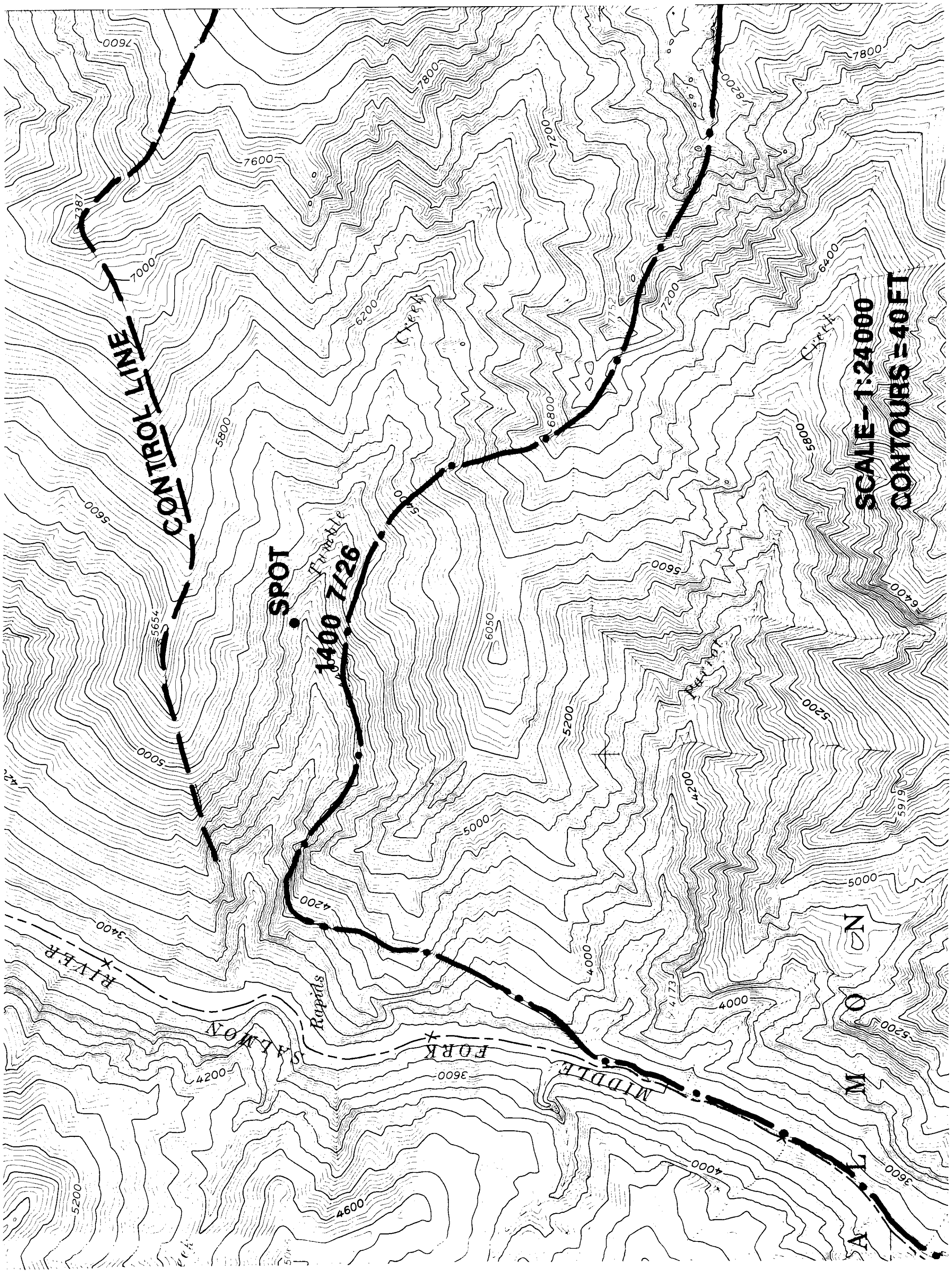
Spot Fire Exercise

(Ship Island Fire, Salmon National Forest, Idaho; July 1979)

Given: A fire is detected on July 25 at 1400 hours by the aerial observer. The location of the fire is shown on the attached map. The attached spot weather forecast was received for the fire area. Use the following inputs:

- Live fuel moisture 100%
- Fuels: model 1 = 20% of area covered
  model 5 = 80% of area covered
- Slope - calculate from map
- Dead fuel moisture - use tables
- Weather inputs from spot forecast.

Problem: What is the potential size of this fire in 1/2 hour? Solution is shown on accompanying worksheets.


CONTROL LINE
SPOT
1400 7/26
SCALE—1:24000
CONTOURS =40FT
MIDDLE FORK SALMON RIVER
Rapids
Tumble Creek
Parrot Creek
Creek
A L M O N
7600
7800
8200
7387
7000
7200
6800
6400
6200
6050
5800
5654
5600
5400
5200
5000
5919
4600
4200
4173
4000
3600
3400

FIRE WEATHER SPECIAL FORECAST REQUEST

(See reverse for instructions)

I. REQUESTING AGENCY WILL FURNISH:

1. NAME OF FIRE OR OTHER PROJECT Ship Island

2. CONTROL AGENCY USFS

3. REQUEST MADE **TIME†** 0630 **DATE** 7/25/79

4. LOCATION *(By ¼ Sec - Sec - Twp - Range)* T21N, R14E, Sec. 1-2, 11-12

5. DRAINAGE NAME Tumble Creek

6. EXPOSURE *(NE, E, SE, etc.)* S

7. SIZE OF PROJECT *(Acres)** 2600

8. ELEVATION* **TOP** 8500 **BOTTOM** 3400

9. FUEL TYPE Douglas-fir, brush

10. PROJECT ON:
☒ GROUND
☐ CROWNING

11. WEATHER CONDITIONS AT PROJECT OR FROM NEARBY STATIONS *(See example on reverse)*

PLACE	ELEVATION	OB TIME†	WIND DIR.-VEL.		TEMP.		‡(Leave blank)		REMARKS *(Indicate rain, thunderstorms, etc. Also wind condition and 10ths of cloud cover.)*
			20 FT.	EYE LEVEL	DRY	WET	RH	DP	
Stoddard L.O.	7540	0630	SSW-15		55	41			Yesterday max. temp. on fire (4800') 87°; min. RH 16%

12. SEND FORECAST TO: **PLACE** Stoddard L.O. **VIA** Radio **ATTN:** *(Name, if applicable)* Rinehart

II. FIRE WEATHER FORECASTER WILL FURNISH:

13. FORECAST AND OUTLOOK **TIME† AND DATE:** __________
(SPECIFY WIND - 20 FOOT OR EYE LEVEL)

SPOT WEATHER FORECAST FOR SHIP ISLAND FIRE ISSUED AT 0700 MDT WEDNESDAY JULY 25 1979

DISCUSSION . . . WINDS ALOFT FROM THE SOUTHWEST TO PERSIST FOR THE NEXT COUPLE OF DAYS. SOME ALTO CUMULUS CLOUDS SOUTHWEST OF THE FIRE AREA NOT LIKELY TO LEAD TO ANY SHOWER OR THUNDERSHOWER ACTIVITY.

TODAY . . . SUNNY. MAX TEMP 90 TO 95 LOWER ELEVATIONS AND 60 TO 65 IN THE HIGHER ELEVATIONS. MIN REL HUM 10 TO 15 PERCENT. WINDS DECREASING SLIGHTLY TO SOUTHWEST 5 TO 10 MI/H REST OF THE DAY BUT OCCASIONAL HIGHER GUSTS TO 20 MI/H AT THE HIGHER ELEVATIONS. GOOD SMOKE DISPERSAL.

TONIGHT . . . FAIR. MIN TEMP IN THE 40'S LOWER ELEVATIONS AND 50'S HIGHER ELEVATIONS. MAX REL HUM 35 TO 45 PERCENT. SURFACE TEMPERATURE INVERSION FORMING. WINDS SOUTHWEST 10 TO 15 RIDGES AND NEAR CALM TO EAST TO SOUTHEAST 4 TO 8 MI/H LOWER ELEVATIONS.

THURSDAY . . . CONTINUED SUNNY WITH LITTLE CHANGE IN TEMP REL HUM AND WIND.

NAME OF FIRE WEATHER FORECASTER

FIRE WEATHER OFFICE

III. REQUESTING AGENCY WILL COMPLETE UPON RECEIPT OF FORECAST

IV. FORECAST RECEIVED: **TIME†** 0730 **DATE** 7/25 **NAME** GEORGE RINEHART

Explanation of Symbols:
- **† Use 24-hour clock to indicate time. Example: 10:15 p.m. = 2215; 10:15 a.m. = 1015.**
- *** For concentrations (as groups of lightning fires) specify "Concentration"; then give number of fires and size of largest. If concentrations are in more than one drainage, request special forecast for each drainage.**
- **‡ No entry necessary. To be computed by the Fire Weather Forecaster.**

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	1			
b. Day or night (D/N)	[✓ D]/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	95			
d. Relative humidity, %	10			
e. Reference fuel moisture, % (from table A)	2			
f. Month	July			
g. Exposed or shaded (E/S)	[✓ E]/S	E/S	E/S	E/S
h. Time	1400			
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/[✓ L]/A	B/L/A	B/L/A	B/L/A
j. Aspect	SW			
k. Slope	80 %			
l. Fuel moisture correction, % (from table B, C, or D)	1			
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	3			
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 1

NAME OF FIRE Ship Island FIRE BEHAVIOR OFFICER George Rinehart
DATE July 24, 1979 TIME 1400
PROJ. PERIOD DATE July 24, 1979 PROJ. TIME FROM 1400 to 1430

INPUT DATA

							TI-59 Reg. No.
1	Projection point		1	1			
2	Fuel model proportion, %		20	80			
3	Fuel model		1	5			
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0				60
5	Dry bulb temperature, °F	DB	95				61
6	Relative humidity, %	RH	10				62
7	1 H TL FM, %	1H	3	3			28
8	10 H TL FM, %	10H	–	4			63
9	100 H TL FM, %	100H	–	5			30
10	Live fuel moisture, %	LIVE	–	100			33
11	20-foot windspeed, mi/h		(12)	( )	( )	( )	
12	Wind adjustment factor		(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	5				79
14	Maximum slope, %	PCT S	80	Ditto			80
15	Projection time, h	PT	.5				81
16	Map scale, in/mi	MS	2.64				82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

.2 x 260 + .8 x 55 = 96 → $\boxed{\text{STO}}$ 88

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	260	55	96		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	108	735			90
21	Fireline intensity, Btu/ft/s	[B]	INT	490	735			53
22	Flame length, ft	[R/S]	FL	8	9			54
23	Spread distance, ch	[C]	SD			48		42
24	Map distance, in	[R/S]	MD			1.6		43
25	Perimeter, ch	[D]	PER			130		40
26	Area, acres	[R/S]	AREA			96		89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

Estimating Spread From a Line of Fire

CONCEPT

When a fire becomes large or irregular in shape, the point source calculations shown in the preceding section are no longer satisfactory for determining its growth. Some sectors of the fire may be under control, while other sectors may be burning into fuels with potential for rapid rate of spread. Shifting winds and irregular terrain can cause irregular burning along the line. On a project fire, the fire's growth from an existing fireline will usually be plotted for briefing the fire planning staff and the fire suppression team. This is a difficult problem, and it requires more encompassing techniques[3] than described up to here in the manual. The concept was described in chapter I in the section labeled "Fire Prediction Process." That section should be carefully reviewed before proceeding.

Close attention must be given to the change in burning conditions with time of day. Fires can become dormant during the night and flare up again as burning conditions improve. Success of these procedures demands that weather forecasts be applied to the time of the day for which they are applicable.

To fully understand these methods, one must complete the exercises at the end of this section. Some of the exercises were designed to stress a technique; others are taken from real fire situations.

It is important to remember that the numbers generated in the calculations are not the final answer. They must be interpreted in terms that are meaningful to members of the fire suppression team and displayed on a map illustrating fire growth.

The depth and detail that are applied to this problem depend upon many factors:

1. The time available to make the fire assessment.
2. The stage of fire development and control actions.
3. Size of the fire.
4. Availability of scouting information.
5. Availability of weather forecasts.
6. Irregularity of the terrain.
7. How well the fuel model and computational methods match the actual fuels and fire behavior.

It may seem that, in many cases, the answers to the considerations mentioned above will be rather negative. Nevertheless, the method has been found to work well when the user has gained proficiency in the technique and in the ability to interpret conditions along the firelines.

PROCEDURES

Preparation

The following material will aid in predicting and presenting fire behavior assessments:

- Topographic map of the fire area with a resolution of at least 2 inches per mile.
- Tablets of Fire Behavior Worksheets.
- Transparent ruler calibrated in inches and tenths of inches.
- Tracing paper.
- Colored felt-tip pens.
- Charts and tables for determining inputs.
- Fire Characteristics Charts.
- Nomograms or TI-59 with fire behavior CROM.

Lay out the known fireline location on a topographic map large enough to accommodate the growth of the fire. Indicate on the map the time that the fire perimeter was located. If you do not have extra maps, use tracing paper overlays for plotting winds and the expected growth of the fire. Obtain a fuel map or draw one with the aid of local help, aerial reconnaissance, or scouting reports. Indicate the general overstory condition and the surface vegetation on the map. Classify the areas in terms of fuel models to the extent possible. These choices may have to be improved as the fire is observed and the fuel stratum carrying the fire is identified.

Determine Projection Time

Specific time periods, when conditions are expected to be reasonably constant, should be designated for making projections. Choice of projection times can help alleviate problems of nonuniform or changing conditions. For example, weather can be broken into 2- to 4-hour periods such as late morning, early afternoon, and late afternoon, when temperature, humidity, and windspeed can be expected to be reasonably uniform, yet different enough to justify a new calculation. Be alert to forecasted changes in windspeed. Be sure to break and restart fire projections at these times.

Abrupt changes in fuels are commonly encountered. This is accentuated in mountainous or steep terrain where the fire can spread up a slope from grass cover into shrub or timber cover. The exact time required to traverse one fuel type is not known. It can be approximated by dividing the expected rate of spread into the width of the fuel strip. As experience is gained, estimates of traverse times can be made. One or two iterations may be necessary to designate a projection time that approximates the time that the fire is in a single fuel type.

Change in slope often occurs in the same places that vegetation or fuel types change. Projection times are usually not based upon expected times for the fire to burn onto a different slope although they could be.

The exercises will illustrate these points.

Select Projection Points

Before selecting the points at which the projections will be made, proceed through the first few steps of the wind estimation process and estimate the local 20-ft winds around the fire perimeter. Select a few points on the fire perimeter that are the most likely to be the origin of significant fire growth. Three points should be adequate for all but very large fires. Often one or two points are adequate for quick assessment during early stages or when most of the fireline is secure. Locations on the downwind side of the fire, with predicted strong local winds, or on the uphill side of a fire on a steep slope, are the usual choices. Fire control actions and areas of very flammable fuel ahead of the fire will also influence the choice of projection points. In some cases the person responsible for fire suppression will want to know the probability of a fire reaching threatened natural or manmade features. Your experience in fire behavior must be used in the choice of projection points. Scouting the fire on the ground or in the air can greatly aid this process. If you cannot scout the fire, learn what the fire has done in previous burning periods, both from documentation (maps) and witnesses.

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[3] The author developed the technique for the fire behavior officer course in 1976, and has modified it based on experience.

Determine Input Data

Identify each projection point on the map with a small number with a circle around it. Place the same number at the head of a column on a fire behavior worksheet. Determine the inputs at each projection point as described in chapter II and enter them in the appropriate column on the fire behavior worksheet.

Determine Spread Distance

If the fire is traveling upslope and the wind is blowing directly upslope or within 30° of maximum slope, data on the fire behavior worksheet may be used according to the instructions up to this point. An arrow equal in length to the map distance should be drawn on the map from the projection point directly up the steepest slope, as shown at projection point 1 in figure IV-5. This arrow or vector represents the expected spread distance of the fire from this point during the projection time. There will be cases when the fire spread direction and wind do not cooperate so nicely and it is necessary to amend the procedures to get a realistic fire growth projection.

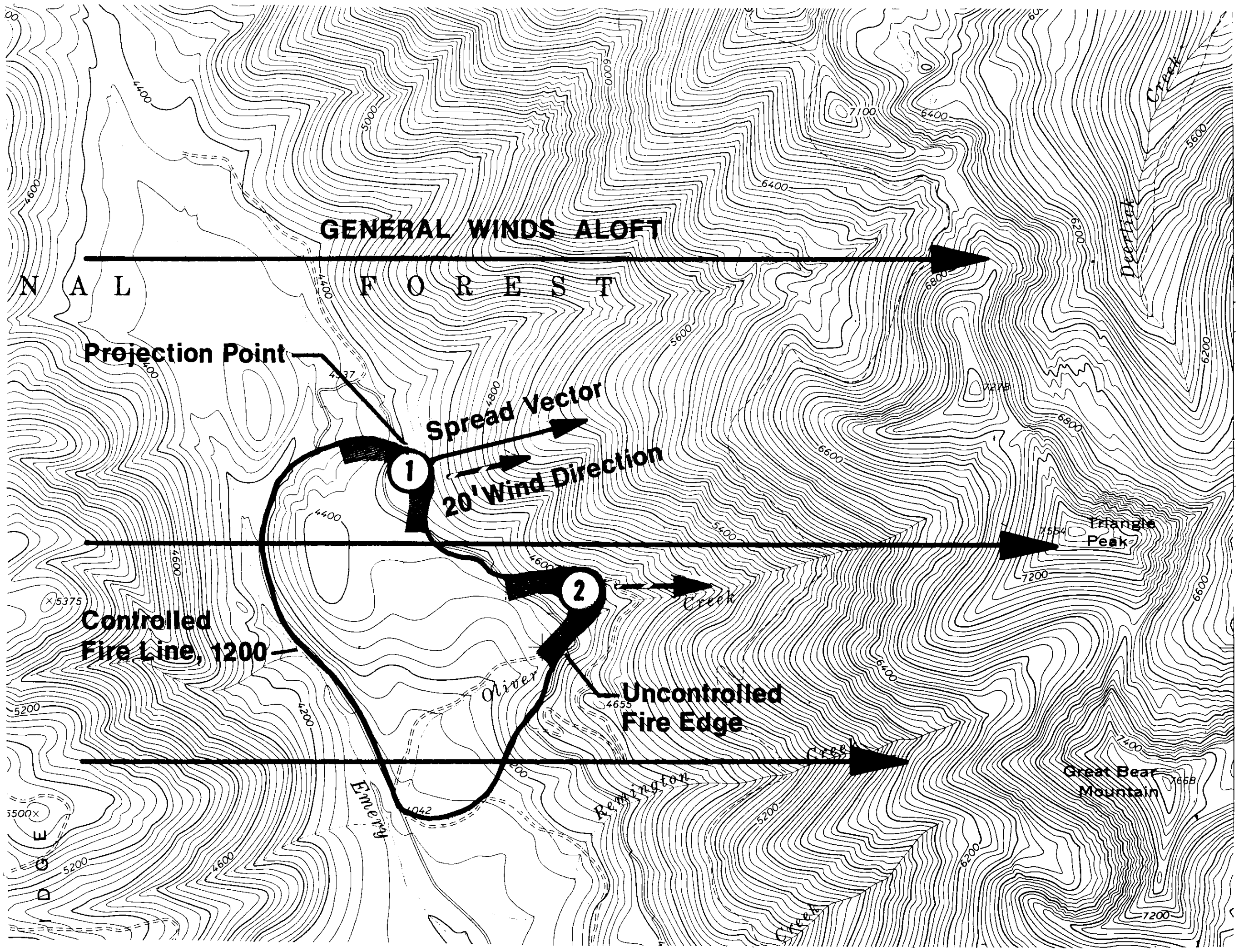


Figure IV-5.—Fire spread vector with wind direction up maximum slope.

Cross-Slope Fire Spread

If the wind is not blowing directly upslope or within ± 30° of upslope, the effect of wind and slope are determined separately and then combined. This is done by the use of vectors on the map.

Step 1.—Use two columns on the fire behavior worksheet. All inputs will be the same for both columns except the midflame windspeed and maximum slope. In the first column enter the midflame windspeed on line 13 as determined from the wind procedure for that projection point and enter zero for maximum slope on line 14. In the second column, reverse the process, with a zero entry for the midflame windspeed, but enter the actual value of maximum slope that lies above the projection point.

Step 2.—Make the calculations necessary to determine map distance. Record the first six outputs, lines 19 through 24 for each column on the worksheet. If the TI-59 is being used, it is only necessary to enter the data once, but change the wind and slope data before the second calculation.

Step 3.—The two map distances just calculated indicate the separate influences of wind and slope on the fire. The combined influence and estimated spread of the fire are found with vectors or arrows on the map. Draw a wind vector on the map from the projection point in the direction of the local 20-ft wind equal to the map distance in the first column. Similarly, draw a slope vector the length of the map distance in the second column directly up the maximum slope as shown in figure IV-6.

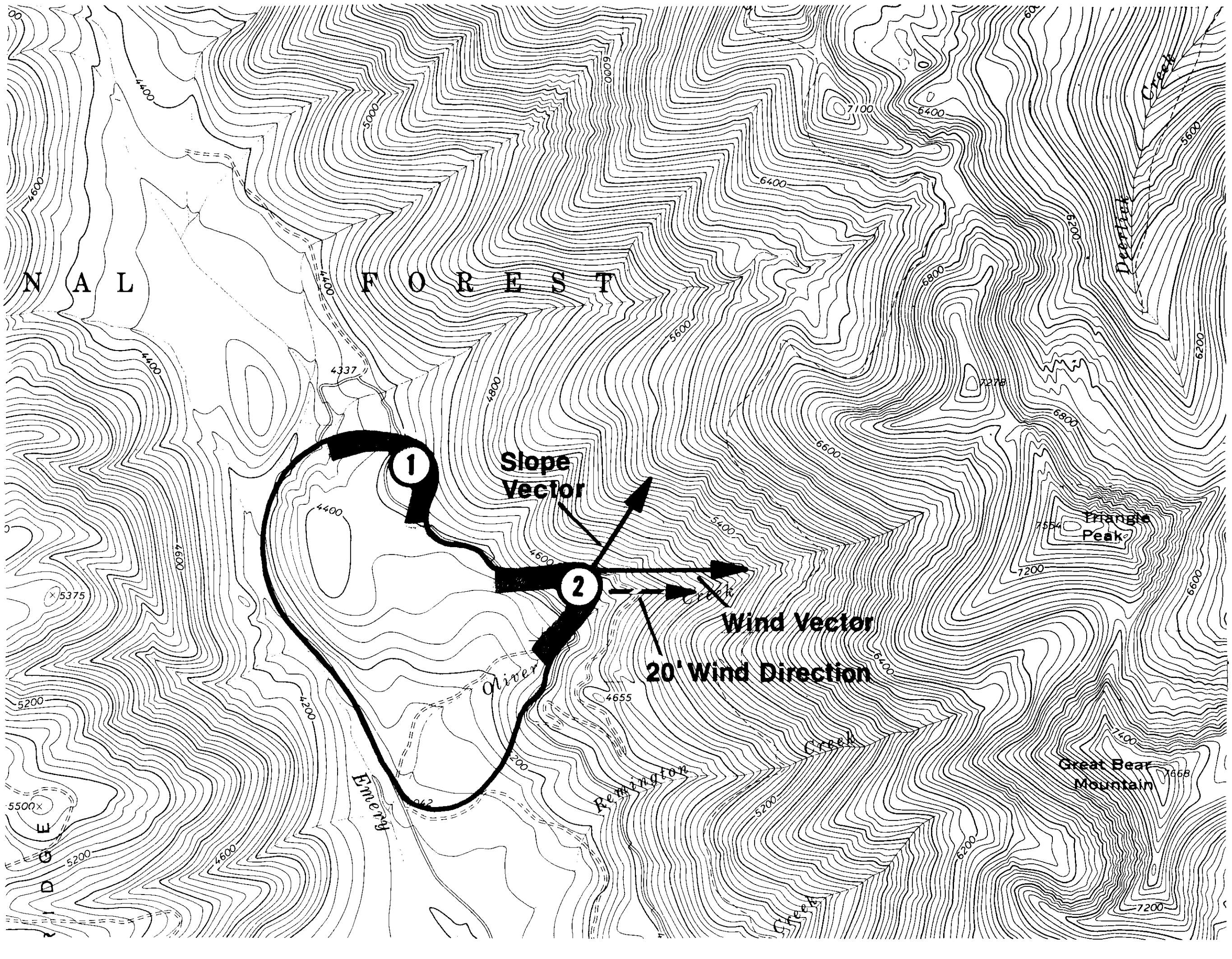


Figure IV-6.—Wind and slope vectors.

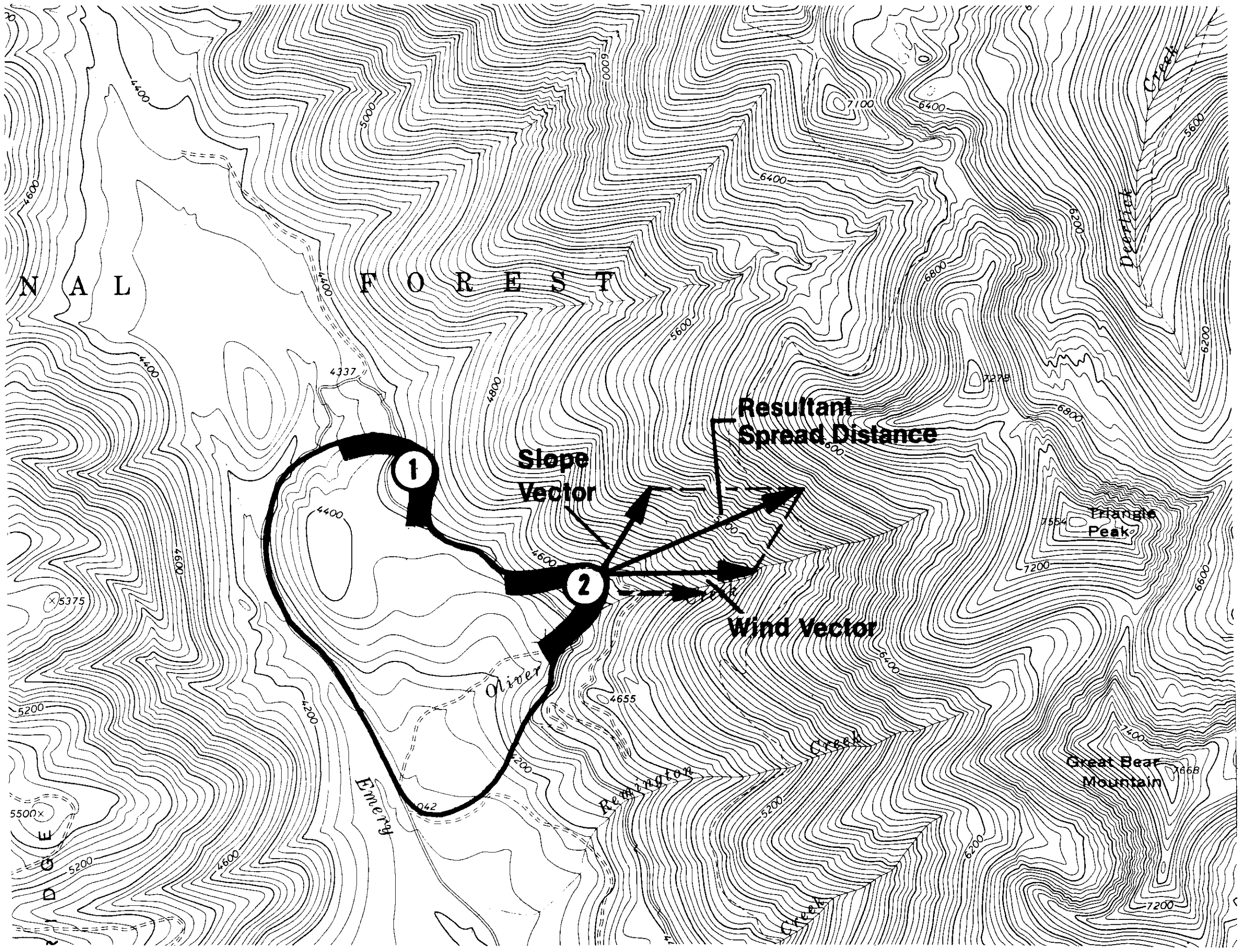


Figure IV-7.—Resultant fire spread vector.

Step 4.—The total distance the fire will spread from the projection point is represented by the resultant of the wind vector and the slope vector. The resultant is found by constructing a parallelogram using the two vectors as the sides as shown in figure IV–7. A parallelogram is constructed with opposite sides parallel and equal in length. The resultant or maximum spread distance is found by drawing an arrow across the parallelogram from the projection point to the opposite corner, as shown in figure IV–7. Complete these four steps for each projection point that has a cross-slope wind.

The same technique is used for winds crossing downslope, but the diagrams may look quite different, depending on the direction of the wind and whether the wind or slope vector is longest. Figure IV–8 presents sample vectors for a range of conditions. If the wind is blowing directly downslope or within ± 30° of directly downslope, the effects of wind and slope will be in direct opposition. Estimate fire spread in the direction of the strongest influence (largest spread distance vector) for a distance equal to the difference of the two. For example, if the wind is blowing directly downhill with a predicted spread distance of 15 chains and the slope vector is 5 chains (slope vector is always upslope), the resultant vector will be downhill a distance of 10 chains.

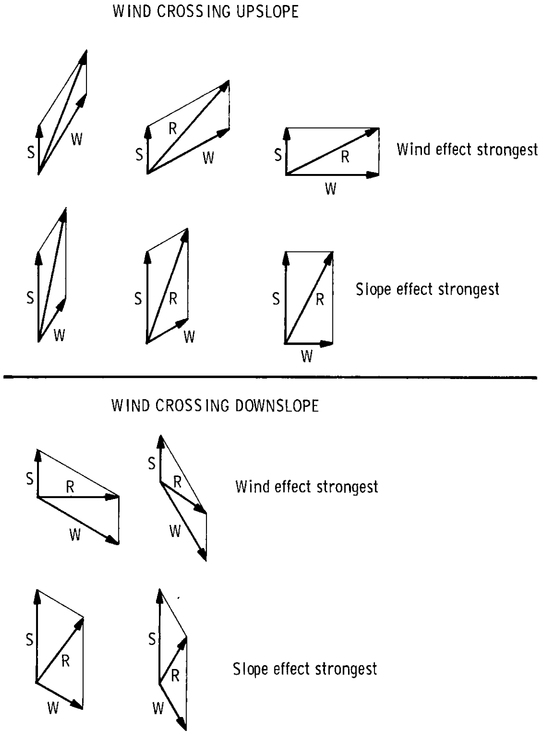


Figure IV-8.—Examples of vectoring in a cross slope wind.

Backing Fire

The previously described methods have been designed for application to the head of the fire. If a prediction of spread and intensity is needed for a backing fire, that is a section of the fireline that is backing into the wind, or downslope, or both, use zero windspeed and zero slope as input values. This should also be considered as the minimum or limiting condition for spread rate when combining vectors.

Limitations

The process just explained will overpredict spread distance if both the wind and slope are low. But for most conditions, the results give good approximations and they are simple enough to apply without the aid of a computer.

Plot New Fire Position

Indicate the spread distance from each projection point with a vector. Use the maximum spread distance vectors as anchor points and sketch the probable location of the fireline. Between vectors, use the general elliptical shape of fire as a guide for segments of the fire. Take into account topography, such as ridges and gullys where fire may be slowed or accelerated by wet or more concentrated fuels. An example is shown in figure IV-9. The line connecting the spread vectors represents the probable growth of the fire during the projection time.

For extended periods the process can be repeated for sequential time periods, using the calculated line for the base of the next projection as shown in figure IV-10. For each new time period set up new projection points along the new fireline on a new overlay and recalculate using a new data sheet.

Interpretation of Spread and Intensity

When the wind is crossing upslope, the resultant spread vector is longer than the individual wind or slope vectors. Therefore, the combined rate of spread and fireline intensity will be greater than the value calculated for either wind or slope alone. In some cases you may wish to know the increased values to help interpret fire intensity. The combined rate of spread is directly proportional to the length of the resultant vector and can be determined by finding the ratio of its length to either the wind or slope vector. Rather than measure and calculate this value, it is easier and quicker to estimate the relative lengths of the resultant spread vector to either the wind or slope vector and then increase the spread rate by that proportion. For example, if the resultant spread vector is half again as long as the wind vector and the rate of spread in the wind column was 10 ch/h, then the combined resultant rate of spread would be about 15 ch/h.

The heat per unit area is not affected by wind or slope so the calculated value is correct for the resultant vector. The fireline intensity is not linearly related, but can be calculated by the formula in the appendix or you can determine it on the fire characteristics chart along with flame length. To do this, use figure IV-1, 2, or 3 and plot the increased rate of spread just estimated for the resultant versus the calculated heat per unit area. The resulting point on the chart indicates the expected fireline intensity and flame length. Interpret fire behavior and resistance to control for this section of the fire by the location of this point. On the same fire characteristics chart plot the behavior of the fire determined at the other projection points.

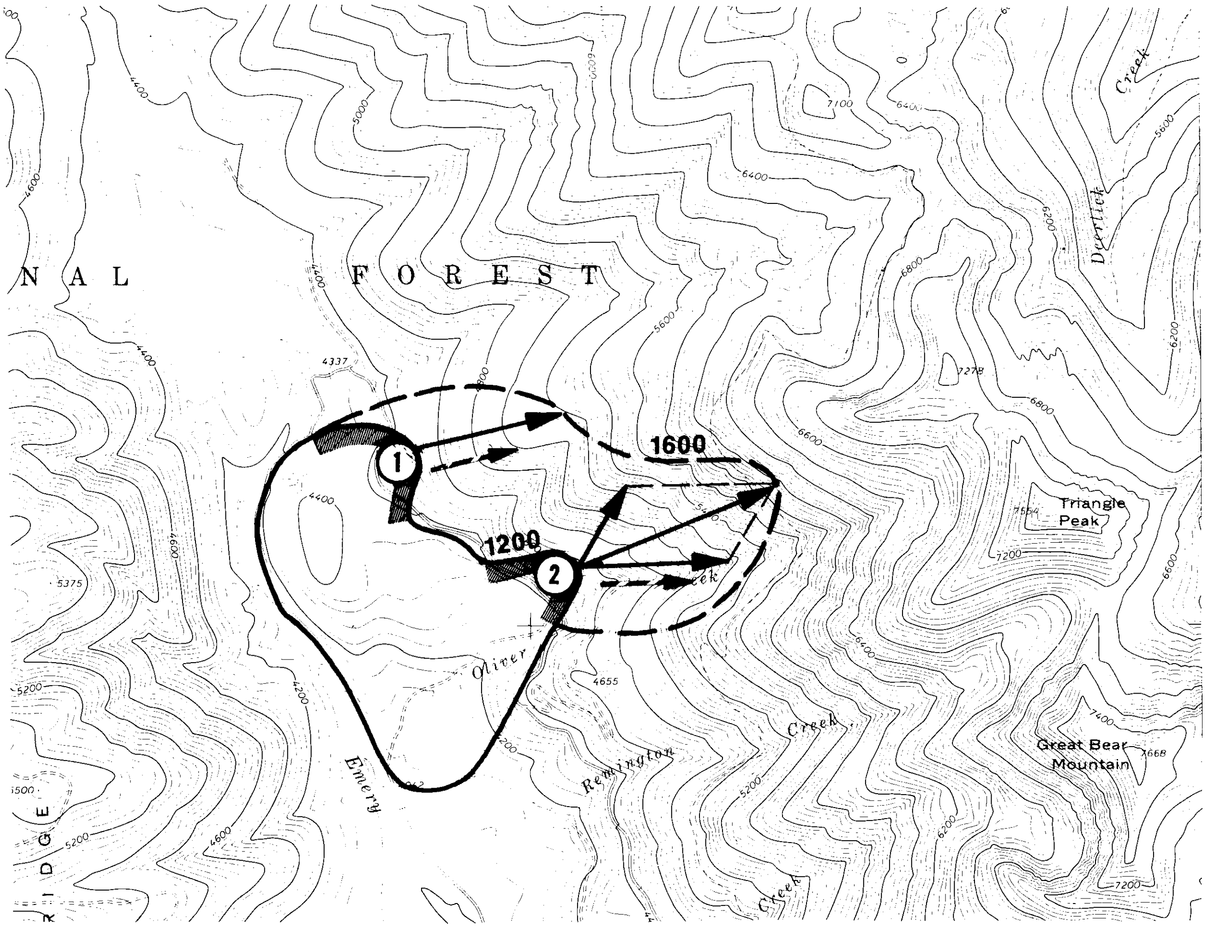


Figure IV-9.—Projected fireline.

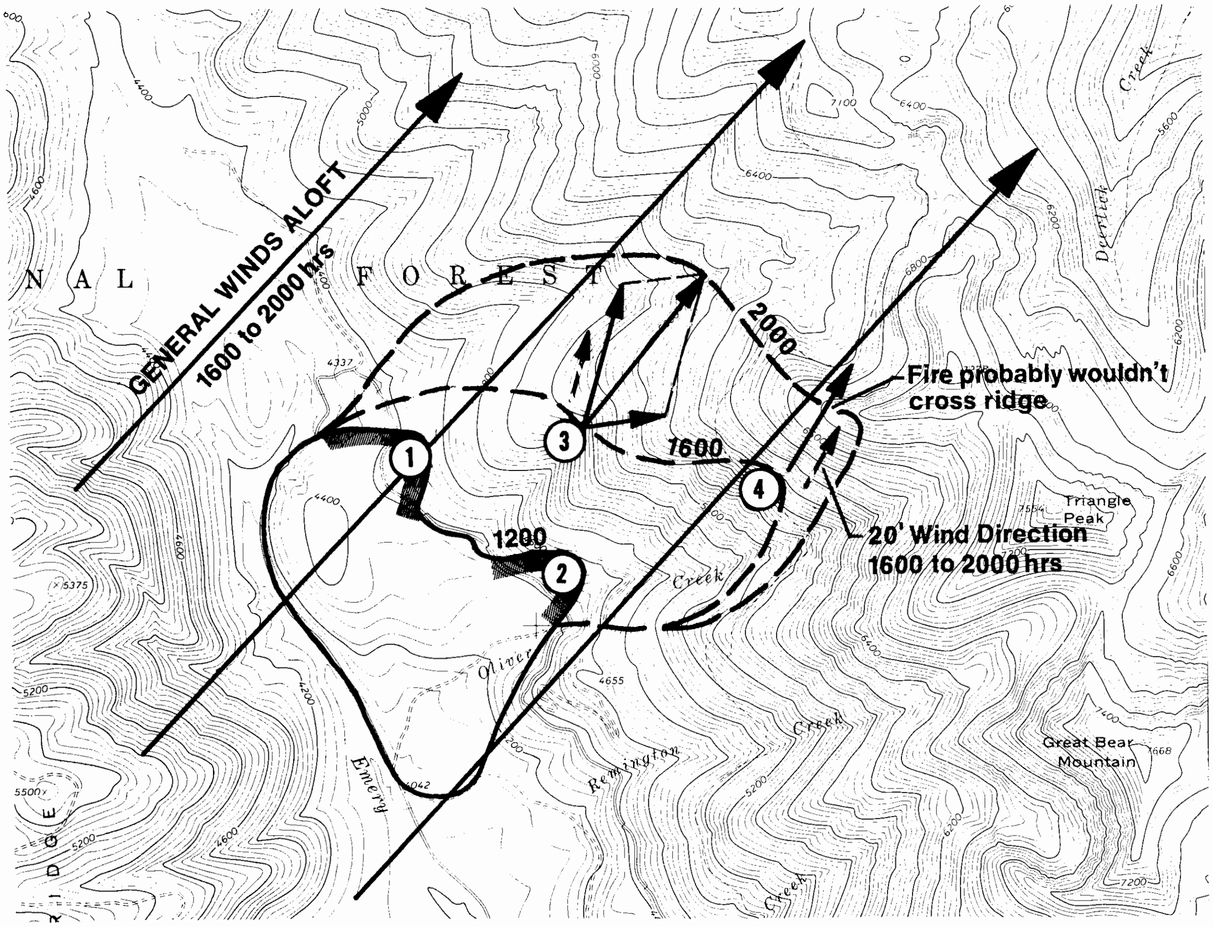


Figure IV-10.—Projected fire spread over sequential time periods.

Interpretation of severe fire and the potential for spotting that may be indicated by the location of the points are presented in the next section.

If the wind is blowing cross-slope in a downhill direction, the effects of wind and slope on fire spread will be counteracting each other rather than reinforcing. The resulting spread distance will be less than if the wind were the same speed on a flat slope. Since the spread distance is less, the actual rate of spread, fireline intensity, and flame length must also be less than the values calculated to indicate the influence of wind and slope separately. If you need these reduced values for interpreting fire behavior, they can be determined as described above.

Transmittal of Information

Use the information on your worksheet, the map projections, and the fire characteristics chart to prepare a fire behavior forecast for briefing the fire overhead team. Do not give raw numbers to the fire overhead team without interpretation unless requested to do so. The entire process of information transfer for an actual fire is illustrated in appendix G.

EXAMPLES

These methods are illustrated in the following examples:

Big Foot Ranch Fire Exercise

(hypothetical fire to illustrate vectoring)

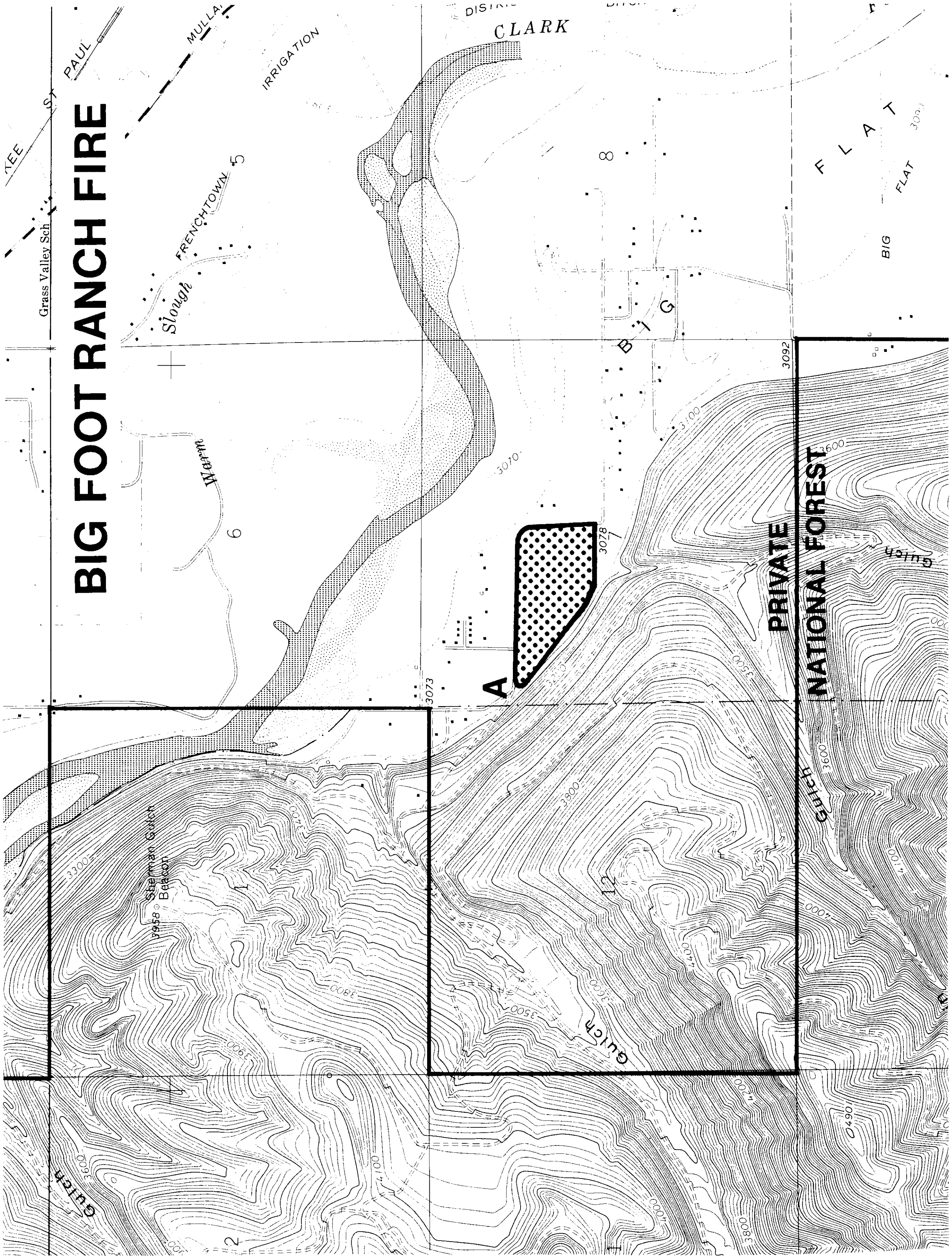
Problem: The Big Foot Ranch has called to let you know they will be burning stubble on their land. You are concerned about the possibility of the fire escaping at point A on the map, because firelines are weak. The burn is to begin at 1300 on March 15.

The general forecast for the day is for a high temperature of 75° F and relative humidity of 38 percent. General winds are east at 15 mi/h. The slope above the burn area is best described as fuel model 6.

1. If a slopover occurs at 1400 hours, show the approximate perimeter of the fire by 1700.
2. Your supervisor wants to know if the fire would reach public land in the first 3 hours.
3. Could firefighters with hand tools control this fire?

Answers:

1. See map.
2. No.
3. The resultant spread vector is 1.6 times as long as the wind vector indicating that the rate of spread is 16 chains per hour. Plotting the resultant rate of spread versus the heat per unit area on a fire characteristics chart indicates the flame length will be at least 4 ft and probably more, making this a difficult fire to control with hand tools until it reaches a natural barrier such as the ridgetop.



BIG FOOT RANCH FIRE

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	A			
b. Day or night (D/N)	[✓ D]/N	D/N	D/N	D/N

DAY TIME CALCULATIONS

c. Dry bulb temperature, °F	75			
d. Relative humidity, %	38			
e. Reference fuel moisture, % (from table A)	5			
f. Month	3			
g. Exposed or shaded (E/S)	[✓ E]/S	E/S	E/S	E/S
h. Time	1400			
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/[✓ L]/A	B/L/A	B/L/A	B/L/A
j. Aspect	E			
k. Slope	44			
l. Fuel moisture correction, % (from table B, C, or D)	2			
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	7			

NIGHT TIME CALCULATIONS

n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				

Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.

q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of ____

NAME OF FIRE Big Foot Ranch

FIRE BEHAVIOR OFFICER Flaming Aero

DATE 3-15

TIME 1400

PROJ. PERIOD DATE 3-15

PROJ. TIME FROM 1400 to 1700

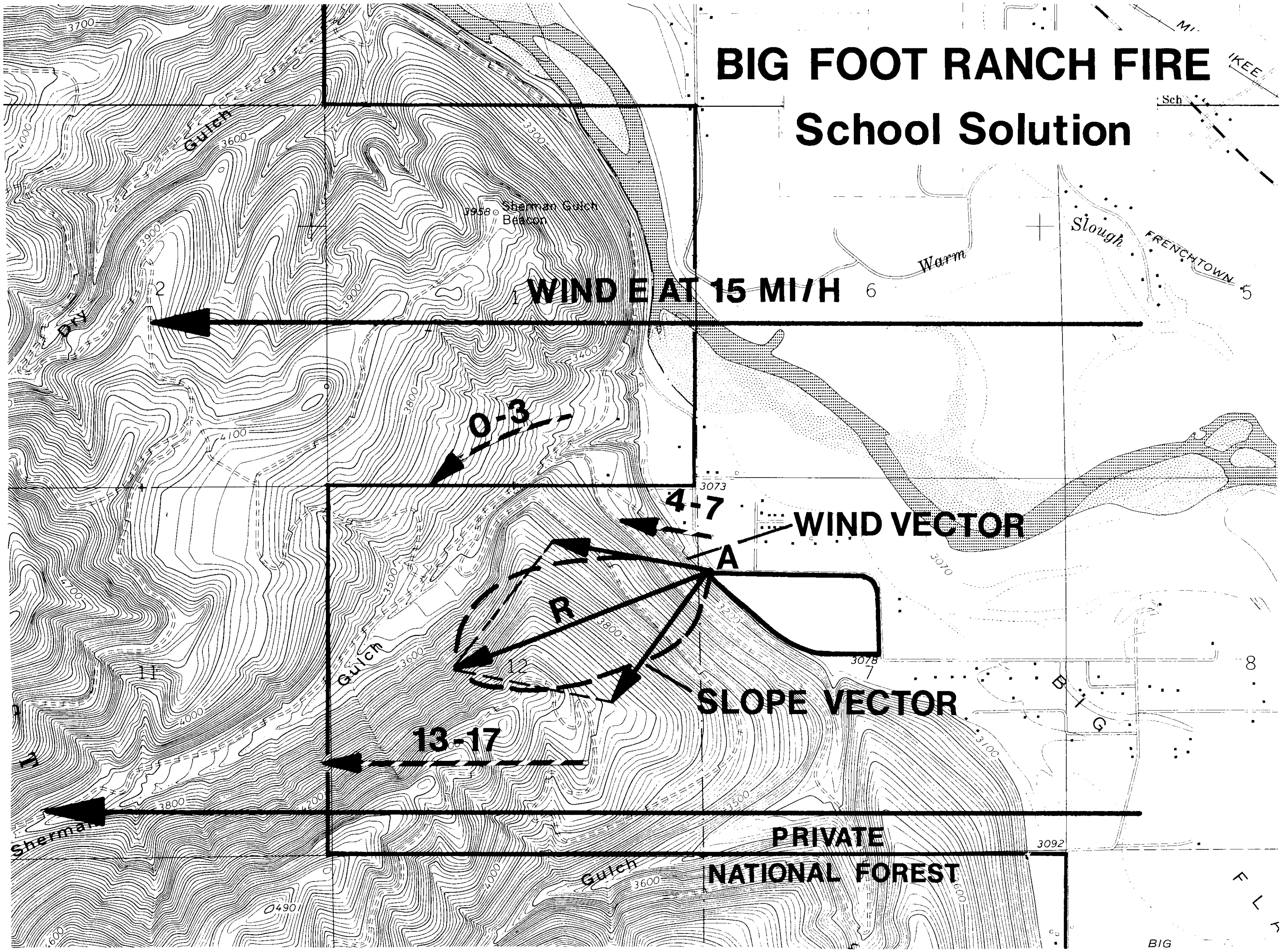
INPUT DATA

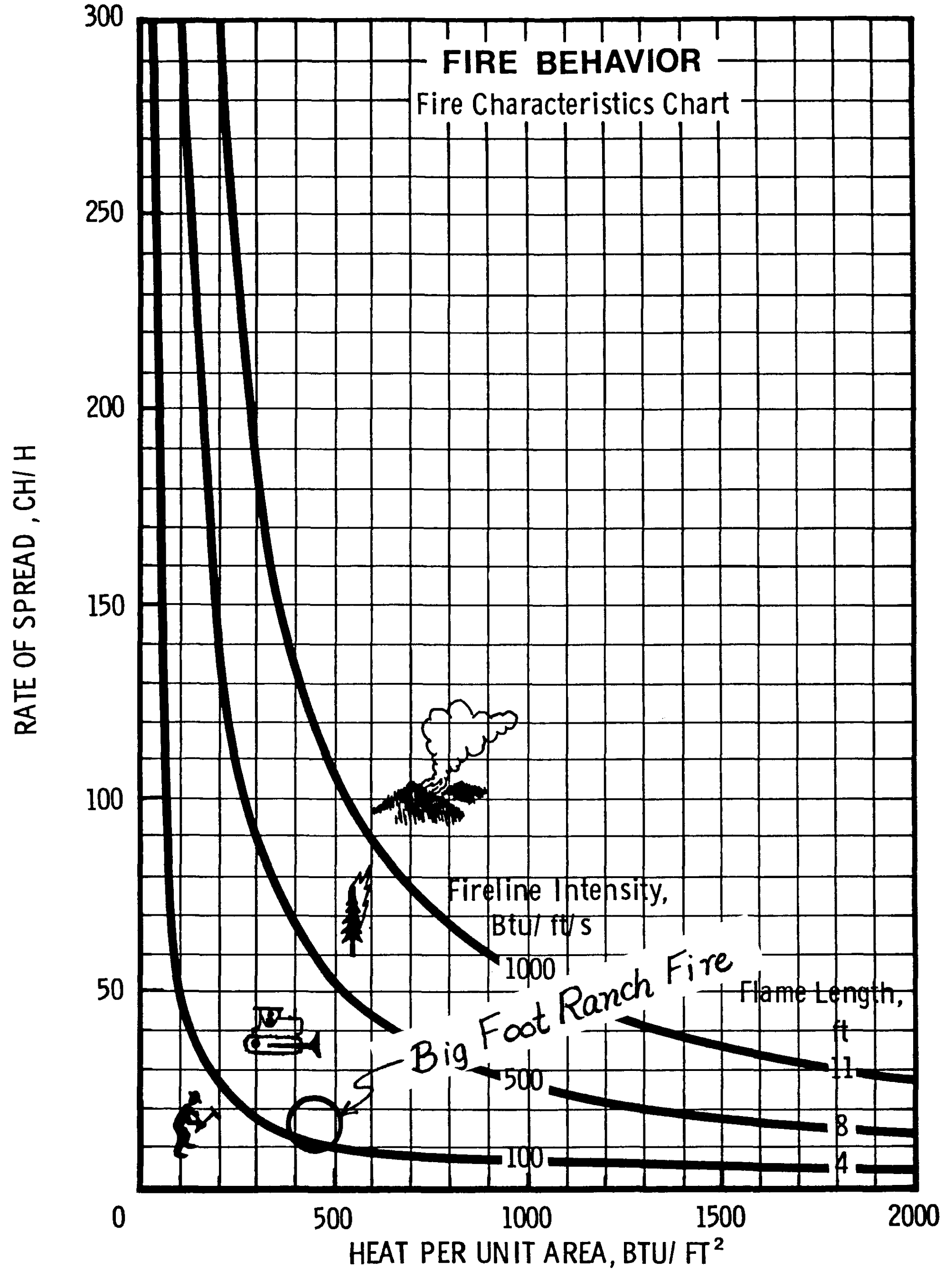
							TI-59 Reg. No.
1	Projection point		A				
2	Fuel model proportion, %		100				
3	Fuel model		6				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0				60
5	Dry bulb temperature, °F	DB	75				61
6	Relative humidity, %	RH	38				62
7	1 H TL FM, %	1H	7				28
8	10 H TL FM, %	10H	9				63
9	100 H TL FM, %	100H	11				30
10	Live fuel moisture, %	LIVE	–				33
11	20-foot windspeed, mi/h		(4-7)	( )	( )	( )	
12	Wind adjustment factor	exposed	(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	2	0			79
14	Maximum slope, %	PCT S	0	44			80
15	Projection time, h	PT	3				81
16	Map scale, in/mi	MS	2.64				82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	10	11			88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	449	449			90
21	Fireline intensity, Btu/ft/s	[B]	INT	85	87			53
22	Flame length, ft	[R/S]	FL	3	4			54
23	Spread distance, ch	[C]	SD	31	32			42
24	Map distance, in	[R/S]	MD	1.0	1.0			43
25	Perimeter, ch	[D]	PER	–	–			40
26	Area, acres	[R/S]	AREA	–	–			89
27	Ignition component, %	[E]	IC	–	–			44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	–	–			52

BIG FOOT RANCH FIRE
School Solution





Independence Wilderness Fire Exercise[4]

The Independence Fire started on July 3, 1979, and was detected on the 4th, hence the name "Independence." The fire occurred on the Moose Creek Ranger District, Nezperce National Forest. The Moose Creek District is entirely within the Selway-Bitterroot Wilderness and under a natural fire program. This fire was allowed to burn freely and was monitored closely throughout the 1979 season.

Ignition occurred on a south slope 6 miles up Bear Creek and the fire burned westward into the wind toward the Selway River for 3 to 4 weeks. North and east spread was arrested because of high dead fuel and live fuel moistures. Spread to the south was inhibited by Bear Creek. Timber on the south and west slopes is scattered ponderosa pine. During this 3- to 4-week period, spread and intensity were low, i.e., 1 ch/h and approximately 25 to 50 Btu/ft/s. Some torching of trees resulted, but most spread was confined to the ground.

The past 3 to 4 weeks indicated consistent up-canyon daytime winds, followed by an inversion each night. The fire was very "predictable." At the mouth of Bear Creek, the light up-canyon winds circulated so that they were coming from the east over this section of the fire (see map).

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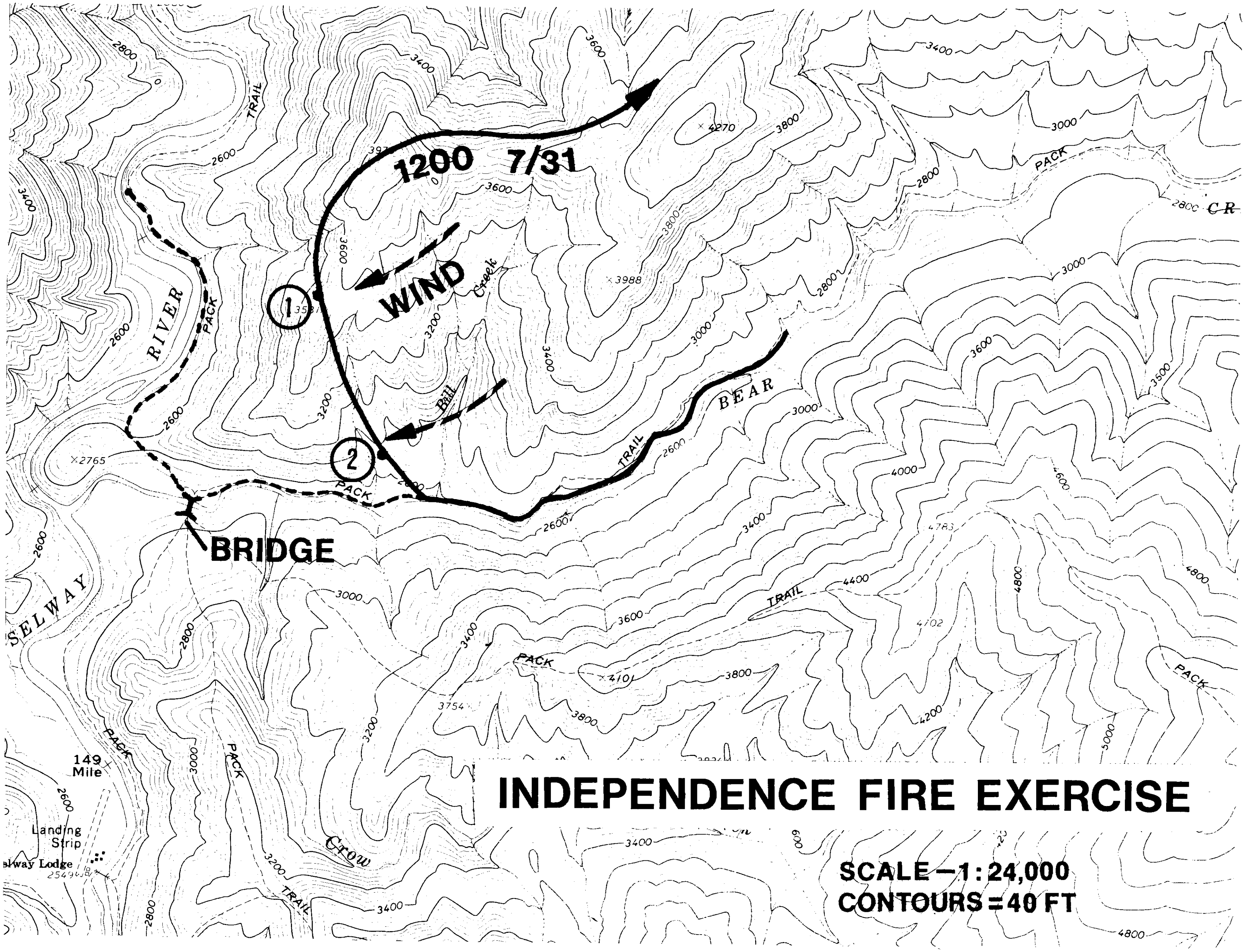
[4] Fire management in the Selway-Bitterroot Wilderness, Nezperce National Forest: a report of the 1979 fire season and Independence Fire, by Larry D. Keown, USDA For. Serv., Northern Region, May 1980.



INDEPENDENCE FIRE EXERCISE

SCALE—1:24,000
CONTOURS=40 FT

Situation:

As the fire approaches the mouth of Bear Creek, concern grows over the safety of two items: the bridge at the mouth of Bear Creek, and private property about 1 mile up the Selway. As district Fire Management Officer (FMO), you have called up a small crew to burn out around the bridge and along the Selway River Trail (marked by ---- on the attached map). Your strategy is to begin the burnout operation when winds become calm (about 1800). Information you have collected is as follows:

Date - July 31, 1979, 1200 hours
Perimeter - see map
Projection points - on map (1 and 2)
Shading - 20–30% canopy
Fuels - Model 9
Fuel moisture - 1-hour - use charts
10-hour - 6% (at nearest NFDRS station)
100-hour - 7%
Live - 100%
Weather - see spot forecast (note: use the local wind direction shown on the map)

FIRE WEATHER SPECIAL FORECAST REQUEST

(*See reverse for instructions*)

I. REQUESTING AGENCY WILL FURNISH:

1. NAME OF FIRE OR OTHER PROJECT INDEPENDENCE	2. CONTROL AGENCY	3. REQUEST MADE TIME† 0800	DATE 7/31
4. LOCATION (*By ¼ Sec - Sec - Twp - Range*)	5. DRAINAGE NAME SELWAY RIVER	6. EXPOSURE (*NE. E. SE. etc.*) WEST	
7. SIZE OF PROJECT (Acres)* 2400	8. ELEVATION* TOP 6500 BOTTOM 2500	9. FUEL TYPE PP. DF	10. PROJECT ON: ☒ GROUND ☐ CROWNING

11. WEATHER CONDITIONS AT PROJECT OR FROM NEARBY STATIONS (*See example on reverse*)

PLACE	ELEVATION	OB TIME†	WIND DIR.-VEL.		TEMP.		‡(*Leave blank*)		REMARKS (*Indicate rain, thunderstorms, etc. Also wind condition and 10ths of cloud cover.*)
			20 FT.	EYE LEVEL	DRY	WET	RH	DP	
FIRE	2700	7/30 1400		W 0-2	87	61			CLEAR
"	2800	7/30 1700		SW 5-7	86	58			"
"	2750	7/31 0745		SW 1-2	53	48			"

12. SEND FORECAST TO: PLACE VIA ATTN: (*Name, if applicable*)

II. FIRE WEATHER FORECASTER WILL FURNISH:

13. FORECAST ~~AND OUTLOOK~~ TIME† AND DATE: ____
(SPECIFY WIND [✓ 20 FOOT] OR EYE LEVEL)

0830 TODAY

FAIR; LAL = 1; CHANCE OF RAIN = 0%; HI TEMP = 90° BOTTOM, 80° TOP; RH = 18% BOTTOM, 12% TOP; WINDS LIGHT, UPCANYON 4-8; GENERAL WINDS W 10-15

NAME OF FIRE WEATHER FORECASTER: LIGHTNING ROD GOENS
FIRE WEATHER OFFICE: MISSOULA

III. REQUESTING AGENCY WILL COMPLETE UPON RECEIPT OF FORECAST

IV. FORECAST RECEIVED: TIME† DATE NAME

Explanation of Symbols:
- † Use 24-hour clock to indicate time. Example: 10:15 p.m. = 2215; 10:15 a.m. = 1015.
- * For concentrations (as groups of lightning fires) specify "Concentration"; then give number of fires and size of largest. If concentrations are in more than one drainage, request special forecast for each drainage.
- ‡ No entry necessary. To be computed by the Fire Weather Forecaster.

FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	1	2		Burnout
b. Day or night (D/N)	[✓ D]/N	[✓ D]/N	D/N	[✓ D]/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	85	85		80
d. Relative humidity, %	16	16		20
e. Reference fuel moisture, % (from table A)	2	2		3
f. Month	7	7		7
g. Exposed or shaded (E/S)	[✓ E]/S	[✓ E]/S	E/S	[✓ E]/S
h. Time	1400	1400		1800
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/[✓ L]/A	B/[✓ L]/A	B/L/A	B/[✓ L]/A
j. Aspect	W	S		S
k. Slope	+30	+30		+30
l. Fuel moisture correction, % (from table B, C, or D)	1	1		3
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	3	3		6
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists <u>and</u> a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

Problem:

1. What will be the probable perimeter at 1800 hours?
2. If the burnout begins after winds subside (1800), would the fire's uphill spread result in intensities great enough to cause torching, crowning, or spotting?

Discussion:

At projection point 1, the fire will be backing down a steep (57 percent) slope. The uphill slope effect is stronger than the downhill wind effect as shown by the spread distances in columns 1 and 2 of worksheet 1. The instructions say, however, that the fire should always be considered to have the capability of spreading at a rate computed with zero wind and zero slope. This calculation was made in column 3 of sheet 1. The spread distance scaled to the map is only 0.2 inches. A vector of this length is plotted. In this situation, however, rolling debris, particularly pine cones, can carry fire down the slope where new fires can be started, which will run back up the slope.

At projection point 2, the wind is blowing cross-slope along the south-facing slope. The projection point was selected about midslope. Discounting the small gully just ahead of the fire, the average slope in this area is about 40 percent. The resultant vector extends beyond a ridge where the fire would have to back down a northwest slope. Its spread would be slowed and so the projected fireline was not extended to the end of the vector. On the south slope, however, the fire would probably spread the length of the resultant vector.

The burnout operation can probably be conducted without problems due to torching, crowning, or spotting. To aid interpretation, all three points are plotted on a fire characteristics chart with log scales, which clearly differentiates these low-intensity fires.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 3

NAME OF FIRE Independence FIRE BEHAVIOR OFFICER FMO

DATE 7/31/79 TIME 1200

PROJ. PERIOD DATE 7/31/79 PROJ. TIME FROM 1200 to 1800

INPUT DATA

							TI-59 Reg. No.
1	Projection point		1	1	1		
2	Fuel model proportion, %		100				
3	Fuel model		9				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	1				60
5	Dry bulb temperature, °F	DB	85				61
6	Relative humidity, %	RH	16				62
7	1 H TL FM, %	1H	3				28
8	10 H TL FM, %	10H	6				63
9	100 H TL FM, %	100H	7				30
10	Live fuel moisture, %	LIVE	100				33
11	20-foot windspeed, mi/h		(4-8)	( )	( )	( )	
12	Wind adjustment factor		(.3)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	2	0	0		79
14	Maximum slope, %	PCT S	0	57	0		80
15	Projection time, h	PT	6				81
16	Map scale, in/mi	MS	2.64				82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	3	7	1		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	448	448	448		90
21	Fireline intensity, Btu/ft/s	[B]	INT	27	58	9		53
22	Flame length, ft	[R/S]	FL	2	3	1		54
23	Spread distance, ch	[C]	SD	20	42	6.8		42
24	Map distance, in	[R/S]	MD	0.7	1.4	0.2		43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 3

NAME OF FIRE Independence FIRE BEHAVIOR OFFICER FMO
DATE 7/31/79 TIME 1200
PROJ. PERIOD DATE 7/31/79 PROJ. TIME FROM 1200 to 1800

INPUT DATA

							TI-59 Reg. No.
1	Projection point		2	2			
2	Fuel model proportion, %		100				
3	Fuel model		9				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	1				60
5	Dry bulb temperature, °F	DB	85				61
6	Relative humidity, %	RH	16				62
7	1 H TL FM, %	1H	3				28
8	10 H TL FM, %	10H	6				63
9	100 H TL FM, %	100H	7				30
10	Live fuel moisture, %	LIVE	100				33
11	20-foot windspeed, mi/h		(4-8)	( )	( )	( )	
12	Wind adjustment factor		(.3)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	2	0			79
14	Maximum slope, %	PCT S	0	40			80
15	Projection time, h	PT	6				81
16	Map scale, in/mi	MS	2.64				82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	3	4			88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1446	1446			90
21	Fireline intensity, Btu/ft/s	[B]	INT	89	95			53
22	Flame length, ft	[R/S]	FL	4	4			54
23	Spread distance, ch	[C]	SD	20	21			42
24	Map distance, in	[R/S]	MD	.7	.7			43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 3 of 3

NAME OF FIRE Independence FIRE BEHAVIOR OFFICER FMO
DATE 7-31 TIME 1200
PROJ. PERIOD DATE 7-31 PROJ. TIME FROM 1800 to 1900

INPUT DATA

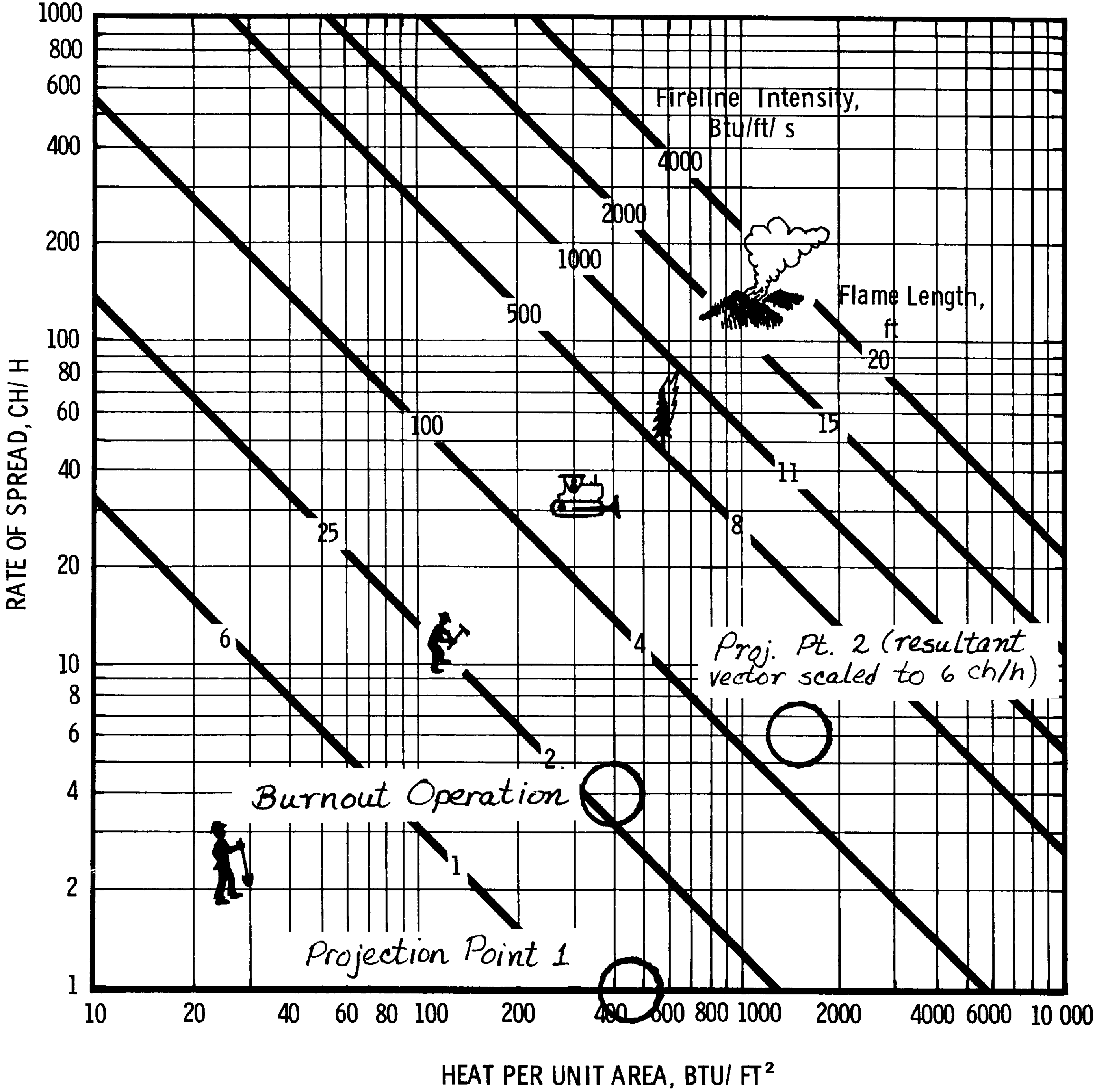
								TI-59 Reg. No.
1	Projection point			Burnout				
2	Fuel model proportion, %			100				
3	Fuel model			9				
4	Shade value	(0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	1				60
5	Dry bulb temperature, °F		DB	80				61
6	Relative humidity, %		RH	20				62
7	1 H TL FM, %		1H	6				28
8	10 H TL FM, %		10H	6				63
9	100 H TL FM, %		100H	7				30
10	Live fuel moisture, %		LIVE	100				33
11	20-foot windspeed, mi/h			(0)	( )	( )	( )	
12	Wind adjustment factor			(-)	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	0				79
14	Maximum slope, %		PCT S	50				80
15	Projection time, h		PT	1				81
16	Map scale, in/mi		MS	2.64				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	4				88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	370				90
21	Fireline intensity, Btu/ft/s	[B]	INT	28				53
22	Flame length, ft	[R/S]	FL	2				54
23	Spread distance, ch	[C]	SD	4.2				42
24	Map distance, in	[R/S]	MD	0.1				43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC	21				44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR

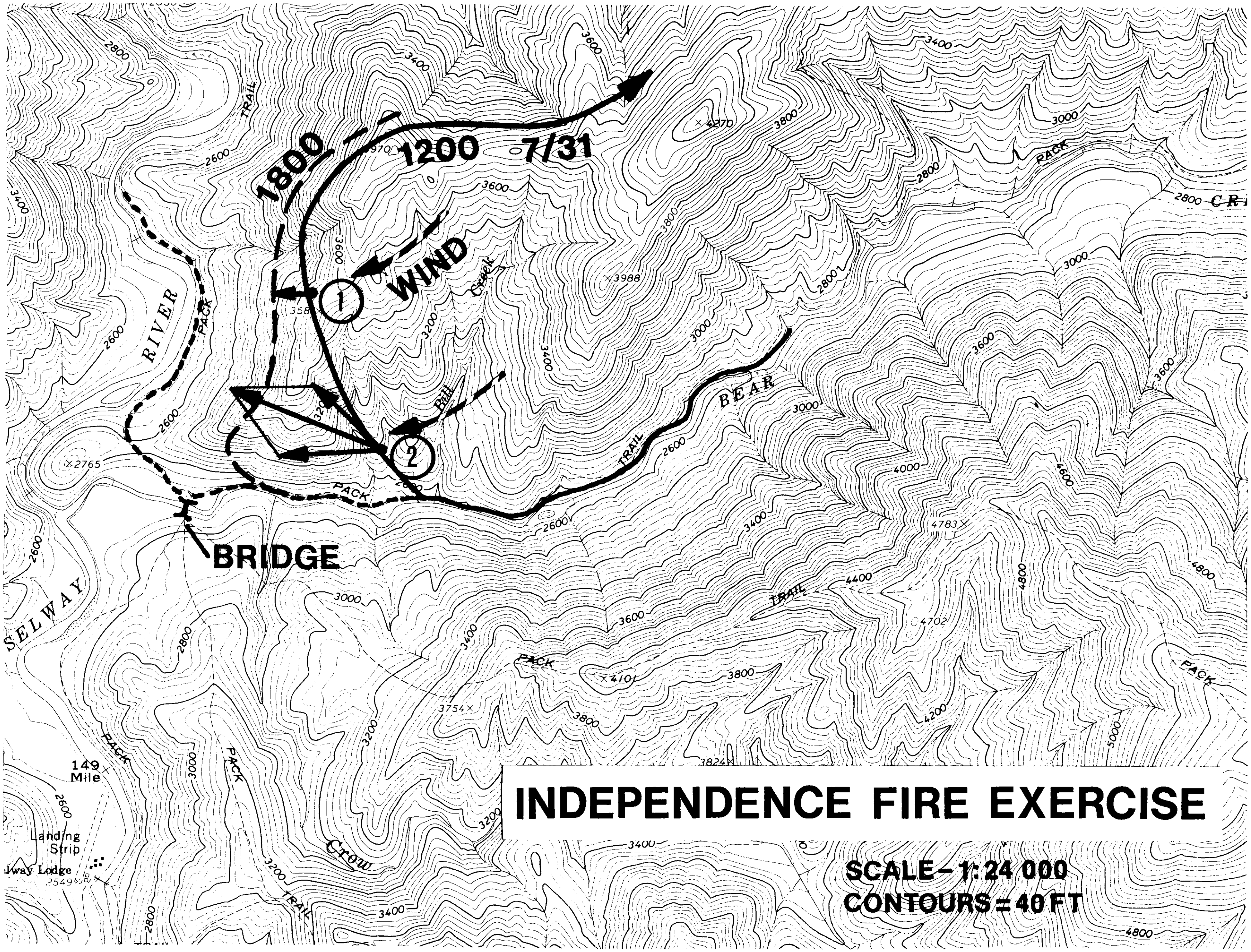
Fire Characteristics Chart
(Logarithmic Scale)



Burnout Operation

Projection Point 1

Proj. Pt. 2 (resultant vector scaled to 6 ch/h)



INDEPENDENCE FIRE EXERCISE

SCALE – 1: 24 000
CONTOURS = 40 FT

Paul Bunyan Fire – Huron National Forest of Michigan
(hypothetical fire to illustrate fire growth by successive periods through different fuels)

Situation:

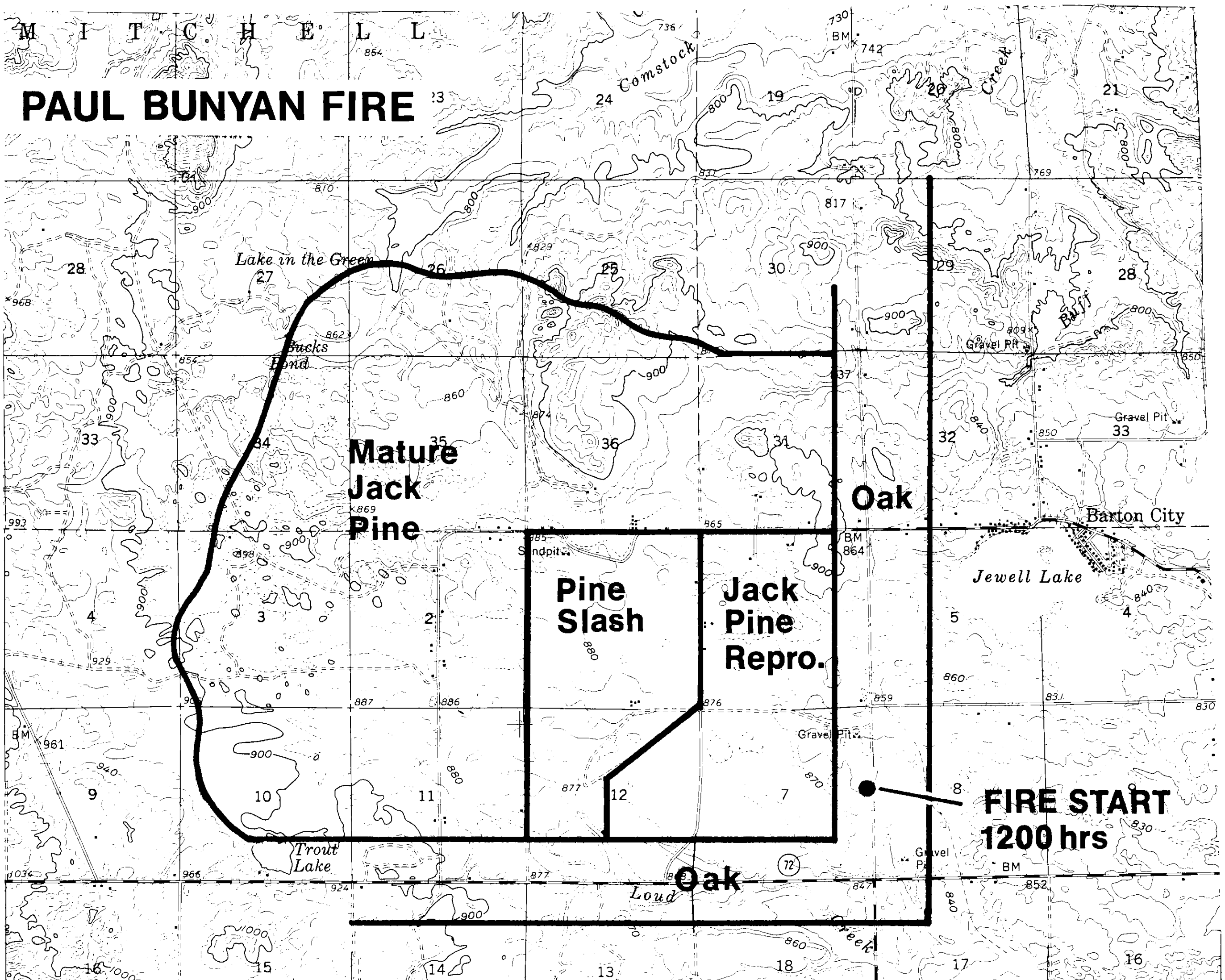
After a long, exceptionally dry summer, a fire is found to have started alongside a road in oak litter. The hardwood trees have lost most of their leaves. Beyond the oak stand lies jack pine reproduction 3 ft high interspersed with grass and weeds. The jack pine reproduction covers about 70 percent of the area. The grass and weeds are entering dormancy. The area also includes sparse stands of mature jack pine, with some logging slash from spring cutting (see fuel map). Jack pine is a shade-intolerant species, with needles 3/4 to 1-1/2 inches long. The slash is red and at about 25 tons per acre. The mature jack pine is in a closed stand, with compact needles forming the litter.

It is 1200 on October 27, temperature = 72° F, relative humidity = 33–45 percent, and there is 10 percent cloud cover. The wind is from the east at 18 to 22 miles per hour. After 1 hour it switches to the southeast and decreases to 15 to 20 miles per hour.

Show the probable fire location after 1, 2, and 3 hours. Plot fire behavior predictions on a fire characteristics chart.

Questions:

1. Does the fire burn into the slash by the end of 3 hours?
2. What is the probability of spot fire ignition in the slash?
3. What conclusions can you draw concerning fire suppression:
   a. in the oak?
   b. in the jack pine reproduction?
   c. in the pine slash?
   d. in the mature jack pine stand?
4. When the winds stop and the fire is contained, mopup must begin. What soils characteristic in some parts of the Lake States makes mopup particularly difficult?



FINE DEAD FUEL MOISTURE CALCULATIONS

a. Projection point	1	2	3	4
b. Day or night (D/N)	[✓ D]/N	D/N	D/N	D/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	72			
d. Relative humidity, %	45			
e. Reference fuel moisture, % (from table A)	7			
f. Month	Oct			
g. Exposed or shaded (E/S)	[✓ E]/S	E/S	E/S	E/[✓ S]
h. Time	1200	1300	1330	1400
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/[✓ L]/A	B/L/A	B/L/A	B/[✓ L]/A
j. Aspect	—			—
k. Slope	0			—
l. Fuel moisture correction, % (from table B, C, or D)	1			4
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	8	8	8	11
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists <u>and</u> a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location(from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 3

NAME OF FIRE Paul Bunyan FIRE BEHAVIOR OFFICER School Solution

DATE ______ TIME ______

PROJ. PERIOD DATE 10/27/79 PROJ. TIME FROM 1200 to 1300

INPUT DATA				First hour				TI-59 Reg. No.
1	Projection point			1				
2	Fuel model proportion, %			100				
3	Fuel model			9				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0				60
5	Dry bulb temperature, °F		DB	72				61
6	Relative humidity, %		RH	45				62
7	1 H TL FM, %		1H	8				28
8	10 H TL FM, %		10H	↓				63
9	100 H TL FM, %		100H	↓				30
10	Live fuel moisture, %		LIVE	—				33
11	20-foot windspeed, mi/h			(18-22)	( )	( )	( )	
12	Wind adjustment factor			(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	8				79
14	Maximum slope, %		PCT S	0				80
15	Projection time, h		PT	1				81
16	Map scale, in/mi		MS	1				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							
OUTPUT DATA								
19	Rate of spread, ch/h	[A]	ROS	16				88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	343				90
21	Fireline intensity, Btu/ft/s	[B]	INT	102				53
22	Flame length, ft	[R/S]	FL	4				54
23	Spread distance, ch	[C]	SD	16.1				42
24	Map distance, in	[R/S]	MD	0.2				43
25	Perimeter, ch	[D]	PER	44				40
26	Area, acres	[R/S]	AREA	11				89
27	Ignition component, %	[E]	IC	29				44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	2221				52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 3

NAME OF FIRE Paul Bunyan FIRE BEHAVIOR OFFICER School Solution

DATE ______ TIME ______

PROJ. PERIOD DATE 10/27/79 PROJ. TIME FROM 1300 to 1500

Next 2 hours

								TI-59 Reg. No.
	INPUT DATA							
1	Projection point			2	2	2		
2	Fuel model proportion, %			30	70	30/70		
3	Fuel model			2	6	2&6		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	0				60
5	Dry bulb temperature, °F		DB	72				61
6	Relative humidity, %		RH	45				62
7	1 H TL FM, %		1H	8				28
8	10 H TL FM, %		10H	{				63
9	100 H TL FM, %		100H	↓				30
10	Live fuel moisture, %		LIVE	50	–			33
11	20-foot windspeed, mi/h			(15-20)	( )	( )	( )	
12	Wind adjustment factor			(.4)	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	7				79
14	Maximum slope, %		PCT S	0				80
15	Projection time, h		PT	2		2		81
16	Map scale, in/mi		MS	1				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							
	OUTPUT DATA							
19	Rate of spread, ch/h	[A]	ROS	70	46	53		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	475	439			90
21	Fireline intensity, Btu/ft/s	[B]	INT	608	367			53
22	Flame length, ft	[R/S]	FL	9	7			54
23	Spread distance, ch	[C]	SD			106		42
24	Map distance, in	[R/S]	MD			1.4		43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 3 of 3

NAME OF FIRE Paul Bunyan FIRE BEHAVIOR OFFICER School Solution

DATE TIME

PROJ. PERIOD DATE 10/27/79 PROJ. TIME FROM to

INPUT DATA Check intensity in slash and burning conditions in mature jack pine.

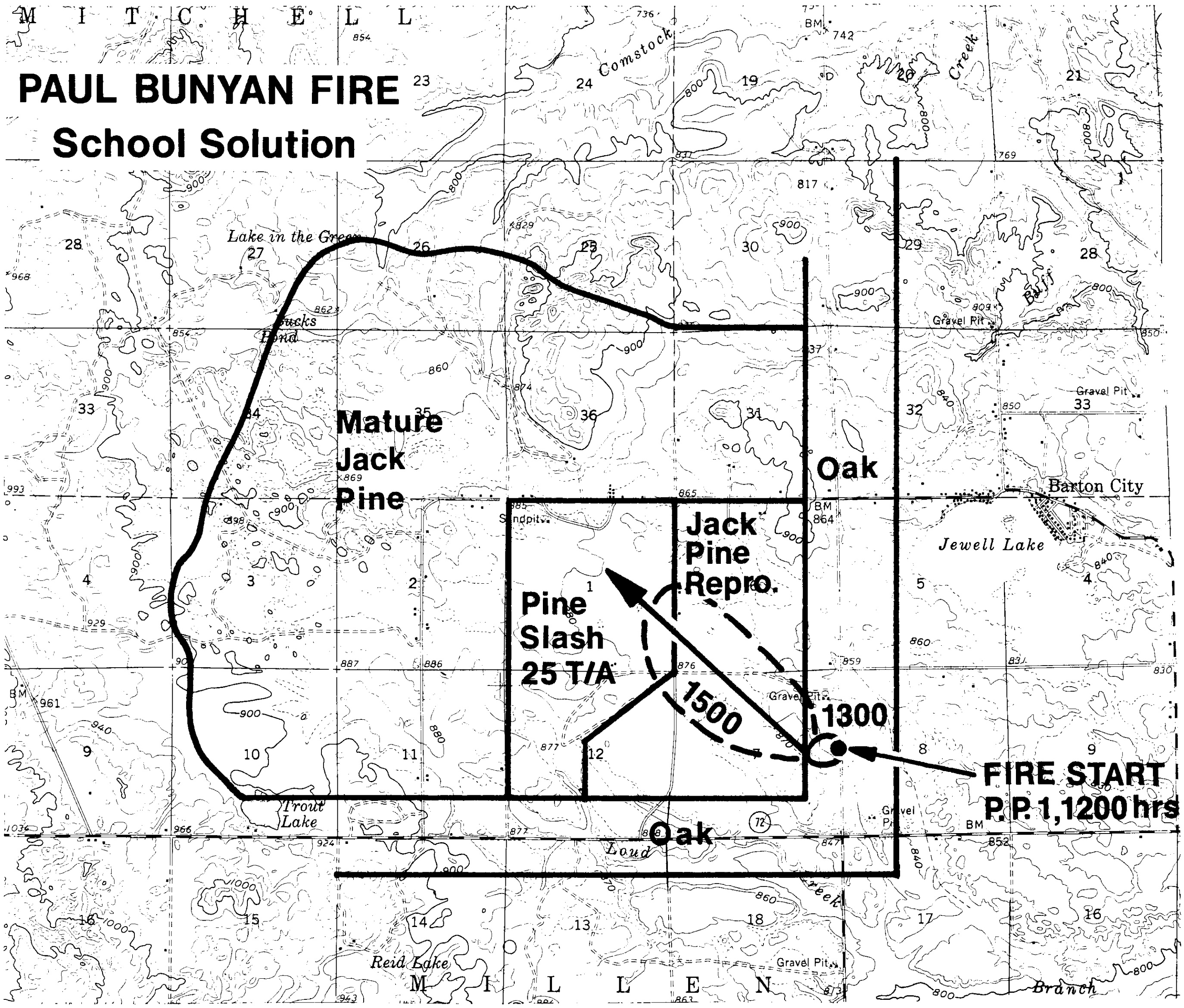
							TI-59 Reg. No.
1	Projection point		3		4		
2	Fuel model proportion, %	slash	100		100		mature pine
3	Fuel model		12		8		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	0		2		60
5	Dry bulb temperature, °F	DB	72		72		61
6	Relative humidity, %	RH	45		45		62
7	1 H TL FM, %	1H	8		11		28
8	10 H TL FM, %	10H					63
9	100 H TL FM, %	100H					30
10	Live fuel moisture, %	LIVE	—		—		33
11	20-foot windspeed, mi/h		(15-22)	( )	(15-20)	( )	
12	Wind adjustment factor		(.4)	( )	(.2)	( )	
13	Midflame windspeed, mi/h	M WS	7		4		79
14	Maximum slope, %	PCT S	0		0		80
15	Projection time, h	PT	—		1		81
16	Map scale, in/mi	MS	—		—		82
17	Map conversion factor, in/ch						
18	Effective windspeed, mi/h						

OUTPUT DATA

19	Rate of spread, ch/h	[A] ROS	17		1		88
20	Heat per unit area, Btu/ft^2	[R/S] H/A	2112		162		90
21	Fireline intensity, Btu/ft/s	[B] INT	654		3		53
22	Flame length, ft	[R/S] FL	9		1		54
23	Spread distance, ch	[C] SD			1.1		42
24	Map distance, in	[R/S] MD			—		43
25	Perimeter, ch	[D] PER			4		40
26	Area, acres	[R/S] AREA			< 1/2		89
27	Ignition component, %	[E] IC			9		44
28	Reaction intensity, Btu/ft^2/min	[R/S] IR			—		52
		Ignition probability	40%		20%		

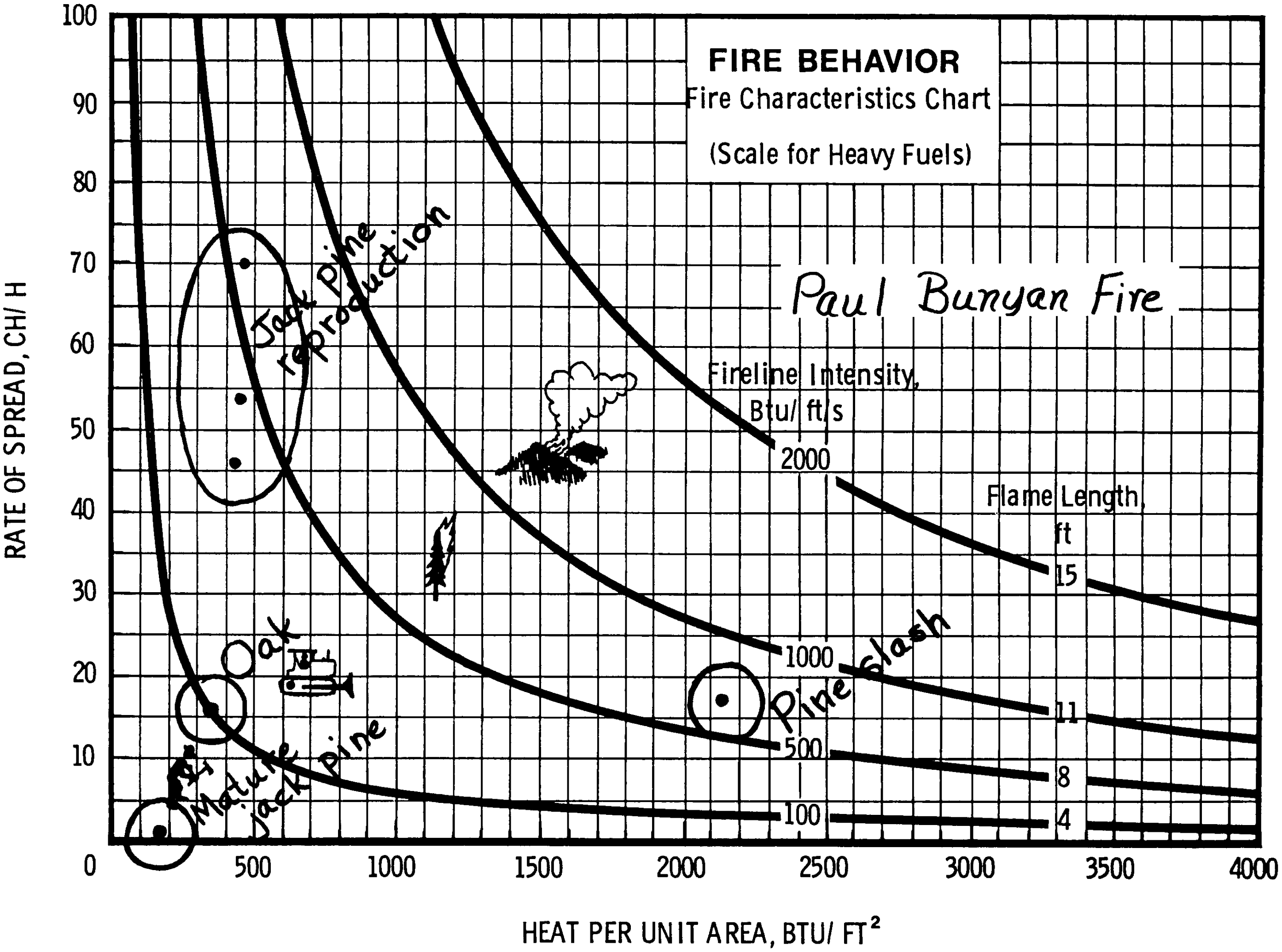
Paul Bunyan Fire - School Answers to Questions

1. Yes. The fire will reach the slash in about 2-1/2 hours.
2. Given: Dry bulb temperature = 72° F
   Cloud cover = 10%
   Fine fuel moisture = 8%
   Then: Fuel temperature = 92° F
   Ignition probability = 45%
3. Suppression interpretations:
   a. *In the oak*: Based on a fireline intensity of 102 Btu/ft/s, the fire is near the limit of direct attack with handtools. A hand line may not hold the fire. The road provides a firebreak on the east side of the fire. The fire will reach the jack pine reproduction in approximately 1 hour.
   b. *In the jack pine reproduction*: Since the area is best described by a mixture of two fuel models, the fire will exhibit a range of conditions as illustrated on the fire characteristics chart. The expected rate of spread is the weighted average of 53 ch/h. The fireline intensity will range between about 370 and 600 Btu/ft/s. Most of the area has a fireline intensity that indicates that equipment can be effective in controlling the fire, but that the fire may be potentially dangerous to personnel and equipment. The rest of the area will burn with an intensity that may present serious control problems. It will take about 1-1/2 more hours for the fire to burn through the reproduction and into the slash.
   c. *In the pine slash*: This fuel burns at a relatively low rate of spread but has a high heat per unit area. The fireline intensity indicates that spotting may occur and that control efforts at the fire head will probably be ineffective. According to the fuel model description, the fire will probably be sustained until a fuel break or change in fuels is encountered.
   d. *In the mature jack pine stand (PP #4)*: There is a chance that firebrands generated by the burning slash will reach the mature jack pine stand, but the probability of ignition within the stand is only 20 percent. Spot fires should be easily contained by persons using hand tools. In an hour, a spot fire would grow to an area of less than 0.5 acre, with a perimeter of 4 chains.



There is a better chance of the fire carrying into the stand from the slash. By this time, it will be later in the day and burning conditions will be poorer.

4. Peat is often found in this part of the country; fire continues to burn in the peat long after the surface fuels are consumed. The fire behavior models used in this manual were designed to describe the flaming edge of surface fires. They do not apply to the mopup problem.



Spotting and Crowning

INTRODUCTION

Table IV-1 indicates that when fireline intensity in surface fuels reaches 500 Btu/ft/s, severe fires can be expected. Flame lengths are about 8 ft, fire suppression techniques are becoming ineffective, and torching of tree crowns and spotting will begin. When fireline intensity reaches 1,000 Btu/ft/s, flame lengths could reach 11 ft and severe crown fire is very probable. If there is any chance of a fire reaching this stage, there is concern about whether the fire is going to spot beyond the firelines and whether it will crown and make a severe run. A large number of case studies have been written about severe fires and every region of the country has data on fuels, weather, and circumstances associated with severe fire. It is not the purpose of this manual to compile and condense these observations. Research in the United States, Canada and Australia is now concentrating on the study of severe fire so that predictive tools can be developed. This chapter covers a few techniques in spot fire distance, ignition of firebrands, and crowning that can be used in conjunction with the techniques developed for predicting surface fire behavior.

SPOTTING

A newcomer to an intense wildfire quickly learns the importance of spotting to the fire suppression team. A firebrand blown over established control lines can wipe out days of hard work by hundreds of firefighters.

The problem of spotting involves three factors:

1. The source of firebrands.
2. How far they travel.
3. The probability of ignition on landing.

The source of the firebrand can arise from several situations.

Short-range spotting.—Embers (often a shower of them) produced in the moving fire front are carried a short distance ahead of the fire where they may or may not start new fires before the main fire front overruns them. There are, at present, no techniques for accounting for the effect of short-range spotting on fire behavior. The deficiency does not appear to be a problem in predicting 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 fires. Further, the model assumes that fuels are uniform and continuous. Short-range spotting can actually compensate for the discontinuous nature of some fuels, giving extended usefulness of the model.

The difference between short-range and long-range spotting is not so much defined by distance as it is by whether or not the firebrands are being lofted by a convection column and carried beyond the immediate area that is being heated and that will soon be overrun by the fire.

Long-range spotting.—As the name implies, the embers are carried well beyond the fireline where new fires are started that for some time grow and spread independent of the originating fire. There are two ways that embers can travel beyond the fire front.

1. They can be carried aloft by strong convective currents where they are caught in the prevailing wind and begin to fall. Firebrands can be lofted by one or more trees torching out, by a concentration of ground fuels that produces enough vertical velocity to loft a firebrand, or by a fire whirl. Low density particles with high drag will travel the greatest distance, but may burn out before reaching the ground.

2. Firebrands, some very large, can be picked up and suspended in a fire whirl that then moves out of the fire area. On the Flambeau experimental fire in 1967 a firebrand 3 inches in diameter and 3 ft long that had been lifted by a strong fire whirl landed near the author. The flame within the whirl extinguishes, but the whirl continues to move downwind similar to a dust devil. The glowing firebrands are carried in a central core and are deposited as the whirl loses energy. This phenomenon was apparent on the Sundance Fire as reported by Anderson (1968), Berlad and Lee (1968), and Lee (1972).

There is no index for the onset of spotting other than its association with severe fire intensity, torching, crowning, and fire whirls. The conditions that favor the development of fire whirls are discussed in an excellent guide for field applications by Countryman (1971).

Spot fire distance.—Albini (1979) has developed a model for predicting the distance a firebrand will travel. It applies to firebrands originating from torching of a tree. It was not meant to apply to firebrands resulting from a running crown fire or conflagration, but may be considered as a first approximation in such situations. Methods for manually predicting spot fire distance are given below. More recently Albini (1981) has extended the model to include firebrands arising from piled fuel, a heavy concentration of surface fuels, or from several torching trees. Chase (1981) has developed a spot fire distance program for the TI-59 utilizing Albini's model.

On the Lily Lake Fire (Bear River Ranger District, Wasatch National Forest), frequent intermediate-range spotting from torching lodgepole pine afforded two opportunities to test the spotting model in its new form for the TI-59 calculator (letter by Frank Albini on file at the Northern Forest Fire Laboratory).

Test results for spotting distance (miles):

Case	Model high estimate	Model low estimate	Midrange of model estimate	Reconstruction of actual spotting distance
1	1.32	0.97	1.04	0.76
2	.91	.40	.64	.75

A simplified manual calculation is presented here.[5]

Limitations:

1. The source of firebrands is from a single torching tree (see footnote 6).
2. The terrain is level.
3. The firebrand is assumed to **travel over forested** terrain.
4. The method requires data about the branching structure of the torching tree's species. These data were used to construct the nomograms used to predict lofting height of the firebrand. Similarity between tree species can be used to extend the method to other species.

---

[5] These simplified procedures were originally developed from Albini's work by Hal Anderson and later improved by Pat Andrews at the Northern Forest Fire Laboratory. If you have a TI-59 calculator, obtain Chase's paper for a more comprehensive method. To obtain a copy of the program, send 7 blank magnetic strips for a TI-59 calculator to the Northern Forest Fire Laboratory, Drawer G, Missoula, MT 59806, and request the spotting distance program.

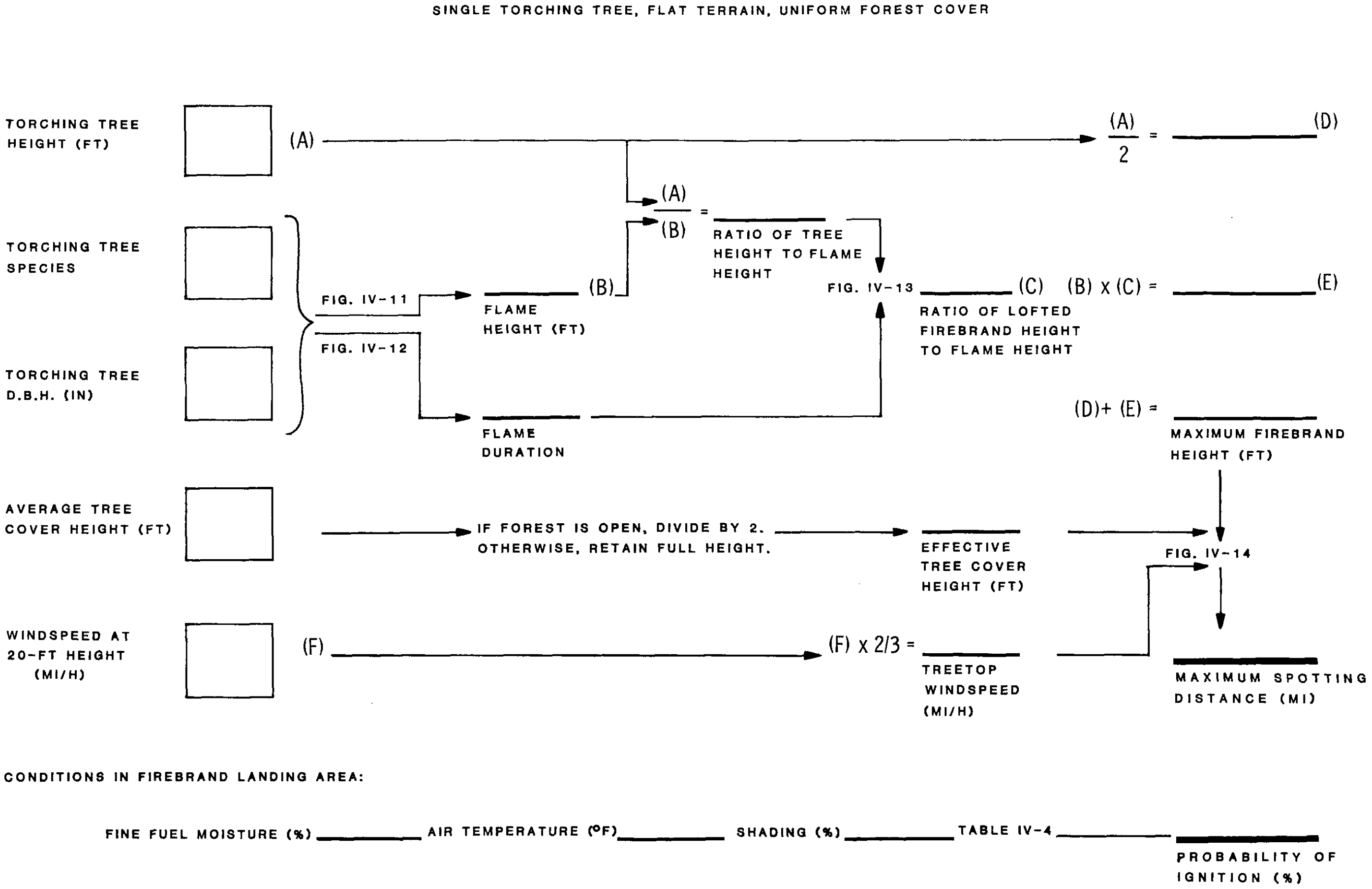
Procedures:

Calculation of spot fire distance requires the following information:

1. Name of tree species that is torching.
2. Height of torching tree (feet).
3. Diameter at breast height (d.b.h.) of torching trees (inches).
4. Average treetop height along the path of the firebrand (feet). The average treetop 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, use half the treetop height.
5. Windspeed as measured in an open area 20 ft above the vegetation (mi/h).

A worksheet for calculating maximum spotting distance is shown as exhibit IV-1. The inputs are entered in the boxes.

Exhibit IV-1.—Spotting worksheet.



The worksheet is completed by extracting data from figures IV-11 through IV-14 as you proceed across the worksheet from left to right.

After entering the inputs, obtain flame height from figure IV-11, using d.b.h. and torching tree species.[6] Enter flame height on the worksheet.

Obtain duration from figure IV-12, using d.b.h. and tree species and record on the data sheet.

Divide the tree height by the flame height and enter on the worksheet as the ratio of tree height to flame height.

Obtain the ratio of lofted firebrand height to flame height from figure IV-13, using flame duration and ratio of tree height to flame height as inputs.

Note that these entries are identified by a capital letter in parenthesis.

Divide (A) by 2 to obtain (D).

Multiply (B) by (C) to obtain (E).

Add (D) and (E) to obtain the maximum firebrand height, feet.

If the forest cover downwind from the torching tree is a relatively open stand, divide the average tree cover height by 2; otherwise use the full tree height.

Multiply the 20-ft windspeed (F) by two-thirds or 0.667 to obtain the treetop windspeed (mi/h).

On the lower right-hand edge of figure IV-14, locate the firebrand height. Proceed vertically to the effective tree cover height. Move left horizontally until you reach the treetop windspeed. Move vertically down to the bottom axis and read the maximum spot fire distance. Record this on the data sheet.

A worked example follows.

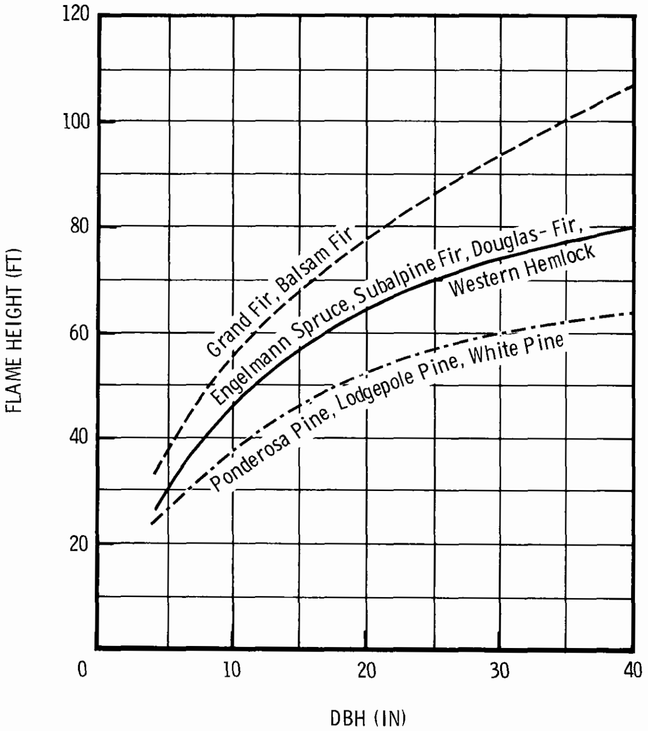


Figure IV-11.—Flame height produced by torching tree.

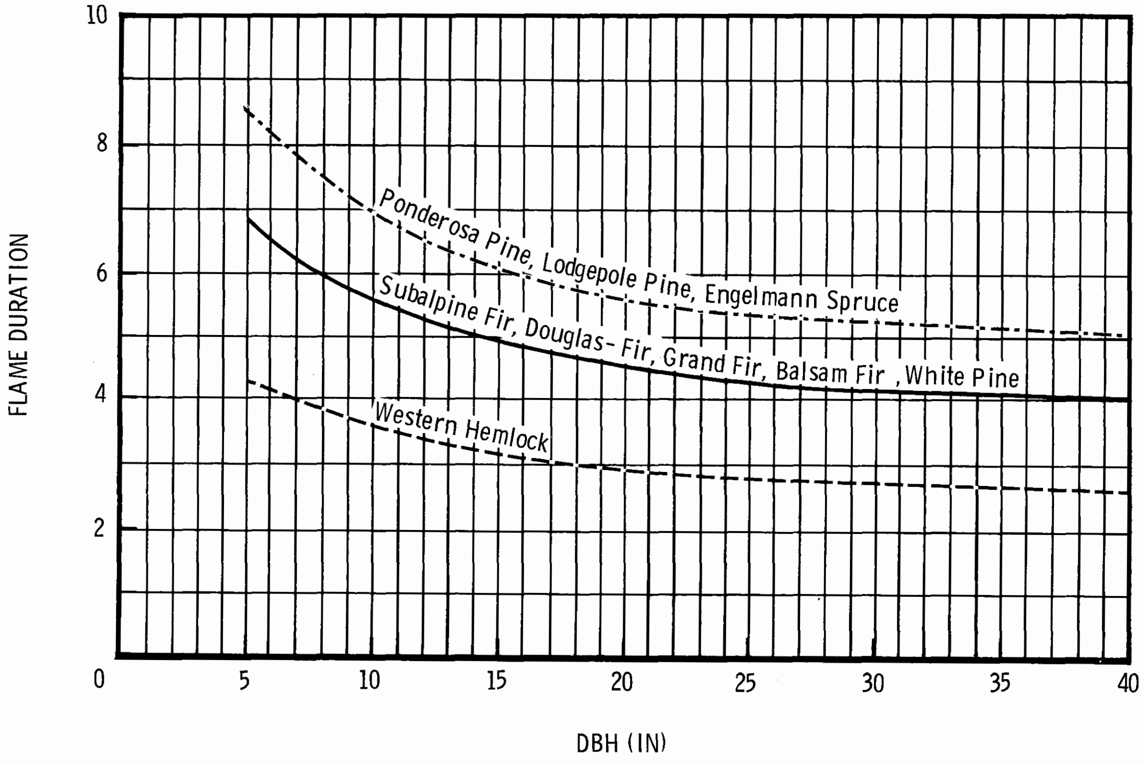


Figure IV-12.—Flame duration (dimensionless) of torching tree.

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[6] The TI-59 program (Chase 1981) corrects flame height and flame duration to account for the simultaneous torching of groups of trees.

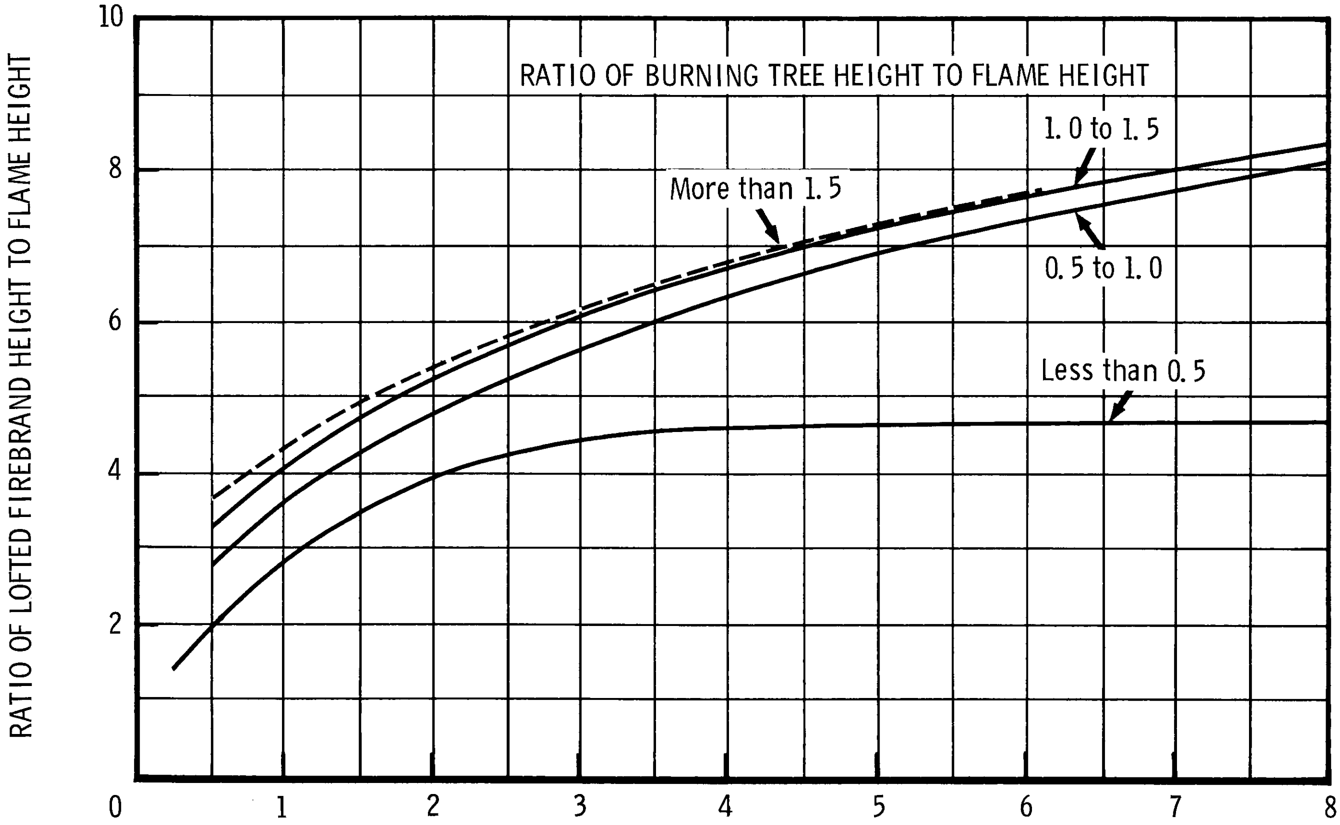


Figure IV-13.—Ratio of lofted firebrand height to flame height.

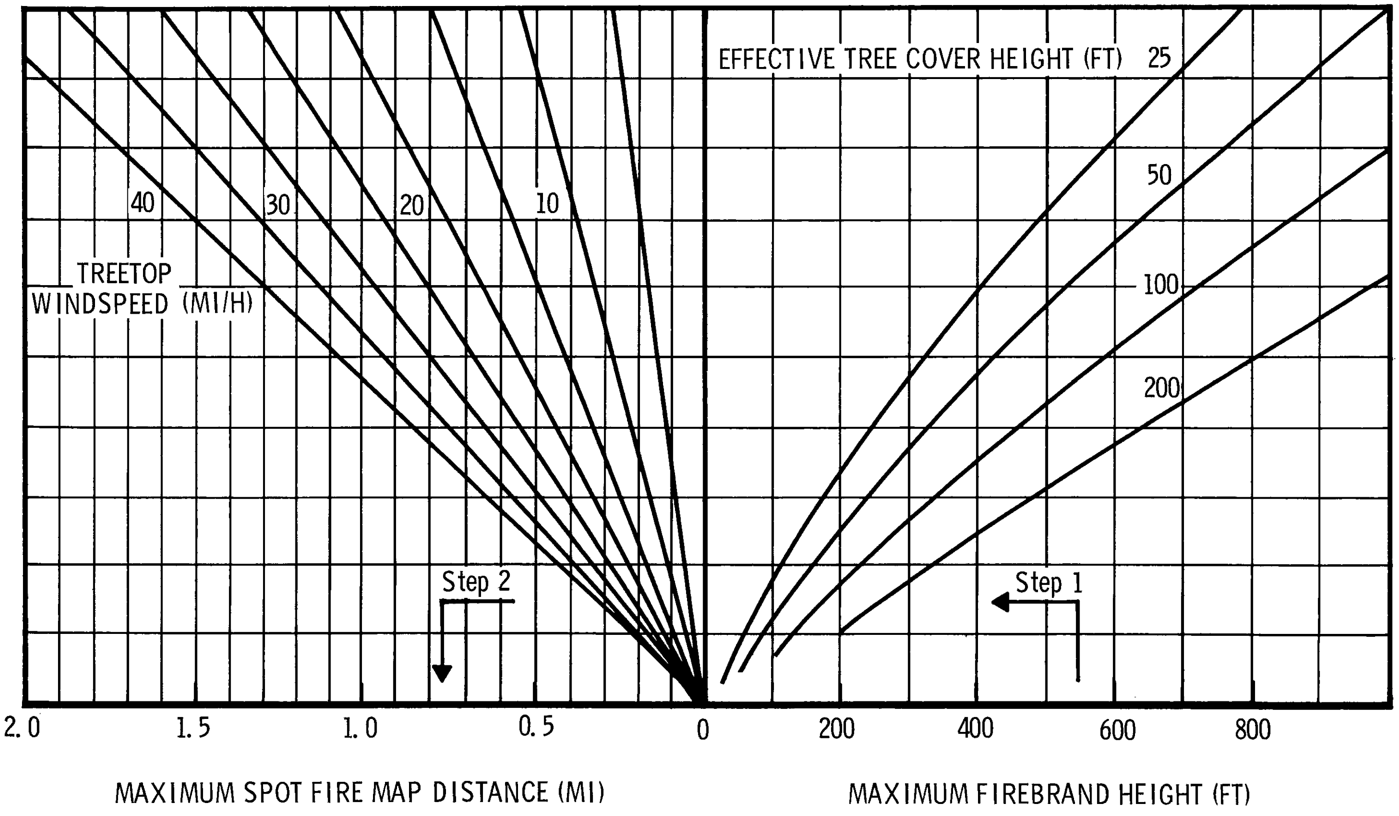
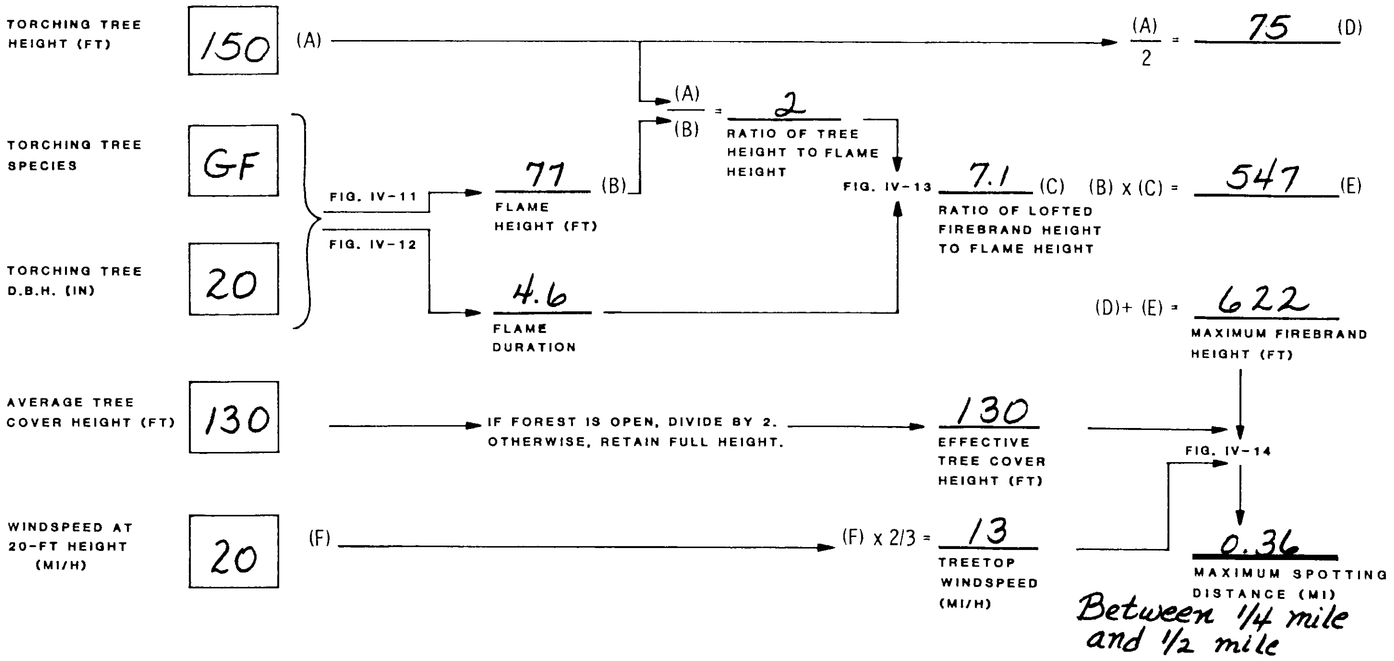


Figure IV-14.—Maximum spot fire distance nomogram.

SINGLE TORCHING TREE, FLAT TERRAIN, UNIFORM FOREST COVER



TORCHING TREE HEIGHT (FT) 150 (A)

TORCHING TREE SPECIES GF

TORCHING TREE D.B.H. (IN) 20

AVERAGE TREE COVER HEIGHT (FT) 130

WINDSPEED AT 20-FT HEIGHT (MI/H) 20 (F)

$\frac{(A)}{2}$ = 75 (D)

$\frac{(A)}{(B)}$ = 2 RATIO OF TREE HEIGHT TO FLAME HEIGHT

FIG. IV-11 → 77 (B) FLAME HEIGHT (FT)

FIG. IV-12 → 4.6 FLAME DURATION

FIG. IV-13 7.1 (C) RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT

(B) x (C) = 547 (E)

(D)+ (E) = 622 MAXIMUM FIREBRAND HEIGHT (FT)

IF FOREST IS OPEN, DIVIDE BY 2. OTHERWISE, RETAIN FULL HEIGHT. → 130 EFFECTIVE TREE COVER HEIGHT (FT)

(F) x 2/3 = 13 TREETOP WINDSPEED (MI/H)

FIG. IV-14 → 0.36 MAXIMUM SPOTTING DISTANCE (MI)

Between 1/4 mile and 1/2 mile

CONDITIONS IN FIREBRAND LANDING AREA:

FINE FUEL MOISTURE (%) 6 AIR TEMPERATURE (°F) 80 SHADING (%) 70 TABLE IV-4 60 PROBABILITY OF IGNITION (%)

PROBABILITY OF IGNITION

When spotting is possible, the probability of ignition where the firebrand lands must also be considered. The method presented here was developed by Mark J. Schroeder (unpublished office report 2106-1, August 13, 1969), and adapted for FBO's by Pat Andrews. It is based on the amount of heat required to bring the fuel to ignition temperature. It assumes that the firebrand lands on **fine** fuel. The probability of ignition does not consider whether or not the resulting ignition will be sustained and therefore is different from ignition component.

Probability of ignition is obtained from table IV-4. The inputs needed are:

- fine fuel moisture.
- air temperature.
- percent shading of ground fuels due to either cloud cover or tree canopy.

A place for recording this information is given on the bottom of the spotting worksheet, exhibit IV-1.

Example: fine dead fuel moisture = 6%
shading due to tree canopy = 100%
air temperature under canopy = 75° F
from table IV-4: probability of ignition = 50%

Table IV-4.— Probability of ignition (Percent)

		Fine dead fuel moisture (percent)															
Shading	**Dry bulb temp**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Percent	°*F*																
0-10	110+	100	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10
	100-109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	90- 99	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	80- 89	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	70- 79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	60- 69	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	50- 59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40- 49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30- 39	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
10-50	110+	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	100-109	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	90- 99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	80- 89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	70- 79	100	80	70	60	50	50	40	40	30	30	20	20	20	10	10	10
	60- 69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	50- 59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40- 49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30- 39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
60-90	110+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	90- 99	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	80- 89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	70- 79	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	60- 69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50- 59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40- 49	90	70	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	30- 39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
100	110+	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	90- 99	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	80- 89	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	70- 79	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	60- 69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50- 59	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
	40- 49	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
	30- 39	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10	10

CROWNING

An excellent source of background information on crown fires is given by Van Wagner (1977) who groups crown fires into 3 classes:

Passive crown fires; those in which trees torch as individuals, reinforcing the spread rate, but are not basically different from surface fires. **Active crown fires**; those in which a solid flame develops in the crowns, but the surface and crown phases advance as a linked unit dependent on each other. **Independent crown fires**; those in which the fire advances in the crowns alone.

The conditions under which crown fires are likely to occur were identified in table IV-1 as those that will produce fireline intensities in surface fires beginning in the 500 to 1,000 Btu/ft/s range. This usually requires hot and dry conditions with strong winds or steep slopes. It also requires an overstory that is conducive to carrying or sustaining a crown fire.

Following his attendance at the 1979 FBO course, Alexander[7] produced a set of graphs and tables that relate the critical surface intensity for crown combustion and flame length to the height of the live crown base and the crown foliar moisture content. Although I have no experience with these graphs, they appear to be reasonable, and one is presented in appendix F.

Fahnestock (1970) produced a key (exhibit IV-2) that identifies the nature of ladder fuels spacing and general tree crown characteristics that are inducive to crown fires. The key produces a value between 0 and 10. The output numbers indicate the **order** of likelihood of a sustained crown fire and are not to be construed as a proportionality nor as a probability (Fahnestock 1970).

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[7] Martin E. Alexander, fire research officer, Canadian Forestry Service, Northern Forest Research Centre, 5320 - 122 St., Edmonton, Alberta T6H 3S5 Canada.

Exhibit IV-2.—Fahnestock's Crowning Potential Key.

	Rating
A. Foliage present, trees living or dead—B	
B. Foliage living—C	
C. Leaves deciduous or, if evergreen, usually soft, pliant, and moist; never oily, waxy, or resinous (1)	0*
CC. Leaves evergreen, not as above—D	
D. Foliage resinous, waxy, or oily—E	
E. Crowns dense—F	
F. Ladder fuels plentiful—G	
G. Canopy closure > 75 percent (2)	9
GG. Canopy closure less (3)	7
FF. Ladder fuels sparse or absent—H	
H. Canopy closure > 75 percent (4)	7
HH. Canopy closure less (5)	5
EE. Crowns open—I	
I. Ladder fuel plentiful (6)	4
II. Ladder fuels sparse or absent (7)	2
DD. Foliage not resinous, waxy, or oily—J	
J. Crowns dense—K	
K. Ladder fuels plentiful—L	
L. Canopy closure > 75 percent (8)	7
LL. Canopy closure less (9)	4
KK. Ladder fuels sparse or absent—M	
M. Canopy closure > 75 percent (10)	5
MM. Canopy closure less (11)	3
JJ. Crowns open—N	
N. Ladder fuels plentiful (12)	3
NN. Ladder fuels sparse or absent (13)	1
BB. Foliage dead—O	
O. Crowns dense—P	
P. Ladder fuels plentiful—Q	
Q. Canopy closure > 75 percent (14)	10
QQ. Canopy closure less (15)	9
PP. Ladder fuels sparse or absent—R	
R. Canopy closure > 75 percent (16)	8
RR. Canopy closure less (17)	4
OO. Crowns open—S	
S. Ladder fuels plentiful (18)	6
SS. Ladder fuels sparse or absent (19)	2
AA. Foliage absent, trees dead—T	
T. Average distance between trees 33 feet or less—U	
U. Ladder fuels plentiful—V	
V. Trees with shaggy bark and/or abundant tinder (20)	10
VV. Trees not as above (21)	8
UU. Ladder fuels sparse or absent—W	
W. Trees with shaggy bark and/or abundant tinder (22)	10
WW. Trees not as above (23)	5
TT. Average distance between trees > 33 feet (24)	2

*Rare instances have been reported, resulting from extreme drought.

The discussion is directed to crown fires in timber canopies. Brush fields can also carry crown fires, but the fire behavior of brush fields is covered by the methods of this manual for surface fuels.

When conditions are favorable for crowning—strong winds or steep slope, with a closed canopy—fireline intensity should be estimated carefully. Fuel model 8, which represents short needle litter fuels, will never predict an intensity high enough to initiate crowning. Fuel models 9 and 10 can, if the windspeed is strong enough. Therefore, consider the choice of a wind adjustment factor carefully. Do not assume fully sheltered conditions without regard to openings, or ridgetops where the fuels may be fully exposed and the fireline intensity can flare up if only for a short time, but sufficient to induce a crown fire.

Similarly, if there are jackpots of dead and down fuel scattered under the canopy, these can induce flareups and crown fires. The jackpots of fuel may be better described by a slash model, such as 12 or 13, than a timber model. See the two-fuel-model concept for this calculation.

The rate of crown fire spread cannot be predicted directly from a model at this time. On the Sundance Fire it was measured by two men in a pickup truck driving parallel to the crown fire at 6 mi/h or 480 chains/h. The rate can be calibrated against spread in surface fuels. Comparison with fuel model 10 on level or gently rolling terrain (Pattee Canyon Fire 1977; Lily Lake Fire 1980)[8] has shown spread rate to be 2 to 4 times faster in the crowns than was calculated for fuel model 10 with the fuel considered to be fully exposed to the wind (wind correction factor 0.4). Short runs up steep slopes have produced faster runs, eight times the predicted rate with model 10.[9]

Crowning on the Lily Lake Fire

The Lily Lake Fire on the Wasatch National Forest made a strong initial run by crowning through lodgepole pine on the afternoon of June 23, 1980. The approximate time and location of the fire as well as the weather data from a nearby guard station provide an excellent chance to compare the crown fire rate of spread with a predicted rate of spread in surface fuels under the same conditions.

The fire started from an escaped campfire in the early afternoon of June 23, 1980. The fire made a short run to the top of a nearby ridge where it spotted across the East Fork of the Bear River, a distance of approximately 1 mile; at that point it began a run to the northeast corner of Section 33 near Christmas Tree Creek. It was generally paralleling the contours of nearby mountains, although it crossed three minor drainages and several low ridges during this period (see map). Minimum elevation of the fire is about 8,600 ft and the maximum about 9,500 ft.

Examination of the area from the air and on the ground reveals a very severe crown fire, with the trees completely bare

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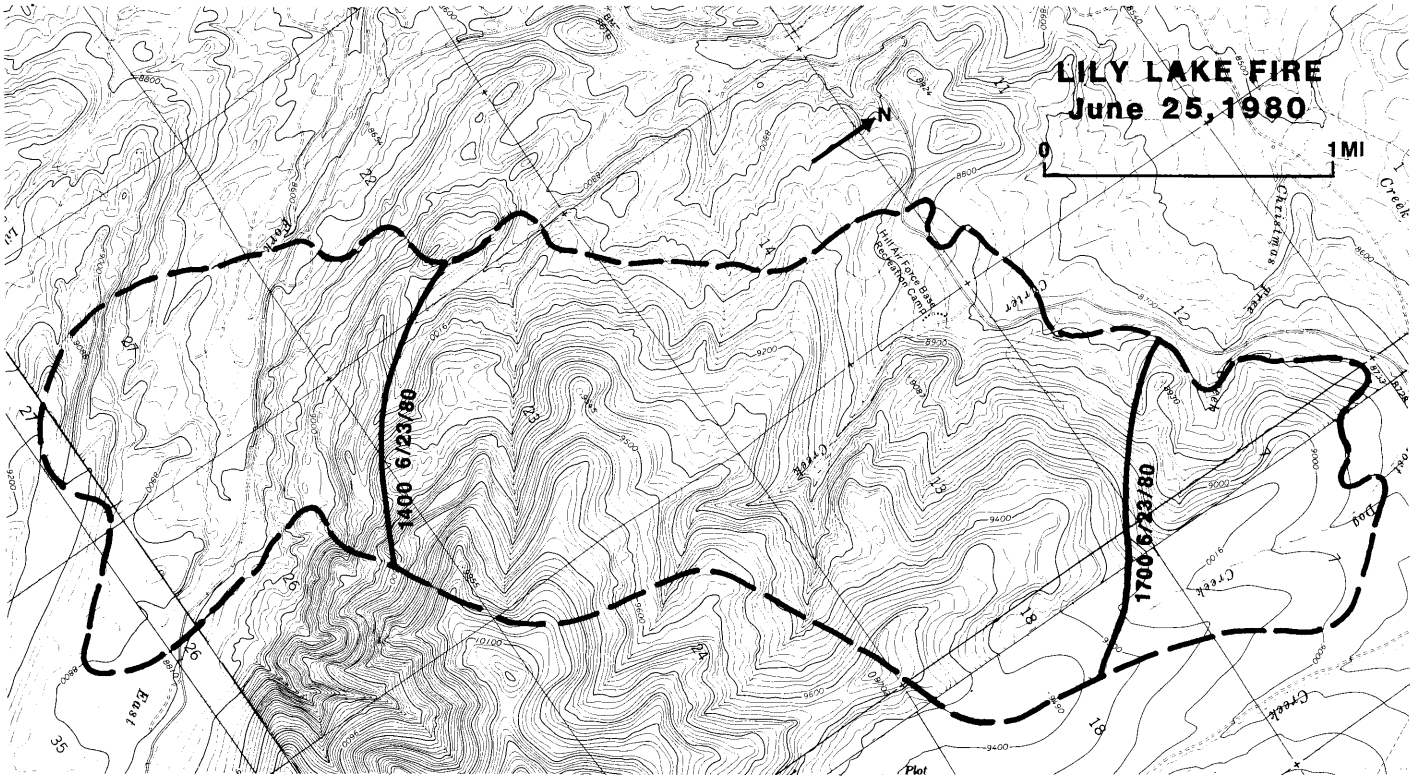
[8] Data on file, Northern Forest Fire Laboratory. See example at end of this section.

[9] Personal communication with George Rinehart, Ship Island Creek Fire, 1979.



of foliage. Surface fuels were consumed, but evidence indicated that the fire burned most intensely in the crowns.

There had been no rain in this part of the country since June 5. Strong southwesterly winds were blowing from 35 to 40 miles an hour across the ridges. Wind persisted for several days after the fire began.

Data from the fire weather station at the nearby Bear River Guard Station were as follows:

State of weather	1
Dew point temperature	21° F
Dry bulb temperature	69° F
Relative humidity	16%
Wind, south	20 mi/h
Fuel moisture sticks	4%
T_{max} for previous 24 hours	78° F
T_{min}	46° F
RH_{max}	48%
RH_{min}	12%

Inputs to the fire behavior worksheet were inferred as follows:

		Comments
Fuel model	10	
Shade factor	2	50%-90% shade due to crown cover
Dry bulb temperature	78° F	
Relative humidity	12%	
1-H fuel moisture	5%	obtained from tables for shade
10-H fuel moisture	6%	4 percent measured in open
100-H fuel moisture	7%	estimate
Live fuel moisture	100%	see later comment
20-ft windspeed across ridges	35-40 mi/h	estimate from meteorologist and helicopter pilot
Wind adjustment factor for midflame wind		0.3 on windward slope, 0.4 over ridges
Midflame windspeed	11 and 15 mi/h	
Slope	20%	

The choice of live fuel moisture is a bit of a quandary because of the early season that normally would indicate moist fuels. Snow along the upper edge of the fire indicated that some of the area had just melted free of snow. Examination of the live plants revealed that the dwarf whortleberry was barely leafing out; and the arnica was small and scattered. Since there was little live fuel in the lodgepole where the fire was, the live fuel moisture was set at a nominal value of 100 percent. If the live fuel had been lush and heavy in this area, it would have been set much higher at 200 to 300 percent.

The windspeed across this area was estimated to be 35 to 40 mi/h across the ridges. Wind adjustment factors were estimated for the windward side, going uphill as 0.3 and across the ridges as 0.4. Slopes on the windward side were about 20 percent. There appeared to be considerable dead and down material in unburned areas around the fire; consequently fuel model 10 was chosen.

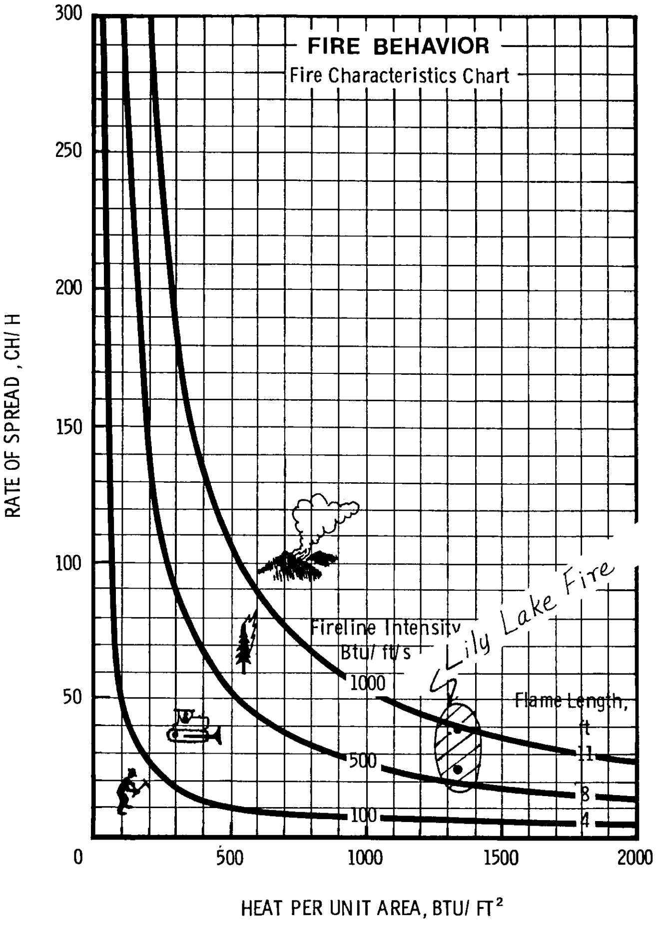
Using the TI-59 calculator, the following fire behavior in surface fuels was calculated:

	Windward slope	**Across ridges**
Spread rate	26 ch/h	40 ch/h
Heat per unit area	1,324 Btu/ft²	1,324 Btu/ft²
Fireline intensity	641 Btu/ft/s	966 Btu/ft/s
Flame length	9 ft	11 ft

These values are plotted on the accompanying fire characteristics chart.

The chart indicates that a surface fire beneath the crowns would be very intense, with moderate spread rates. Crown torching and spotting are very probable and a running crown fire is possible.

With these large flame lengths accompanied by 30 to 40 mi/h wind, the overstory would almost surely crown, which it did. The measured spread distance between 1400 and 1700 was 2.75 miles, which was covered in 3 hours giving a spread rate of 73.6 ch/h. Comparison of this with the calculated spread rate in the surface fuels (26 to 40 ch/h) shows that the crown fire spread from two to three times faster than what would be predicted in surface fuels (model 10) under the same conditions.



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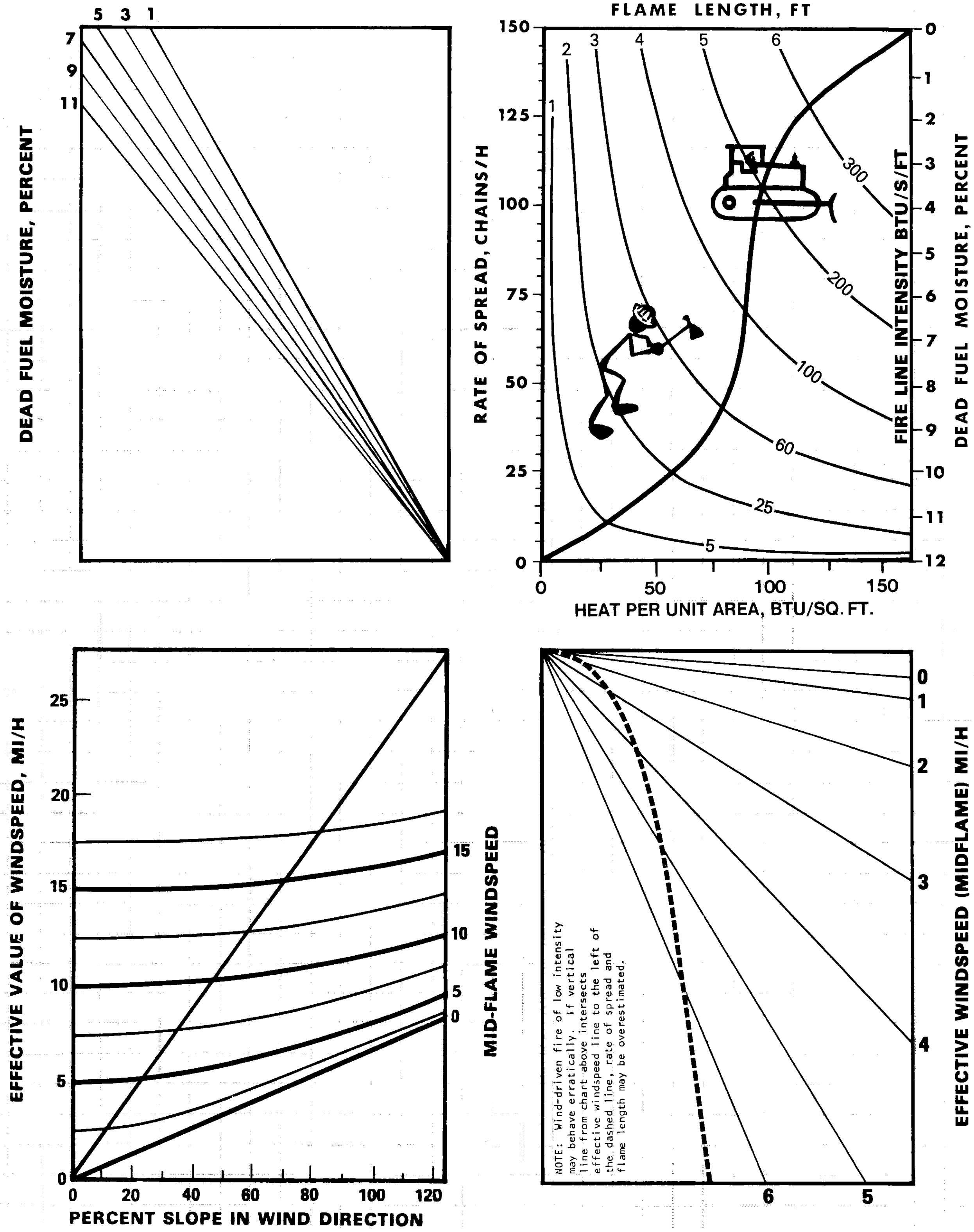
APPENDIX A
Nomograms

Fuel model 1 – low windspeeds

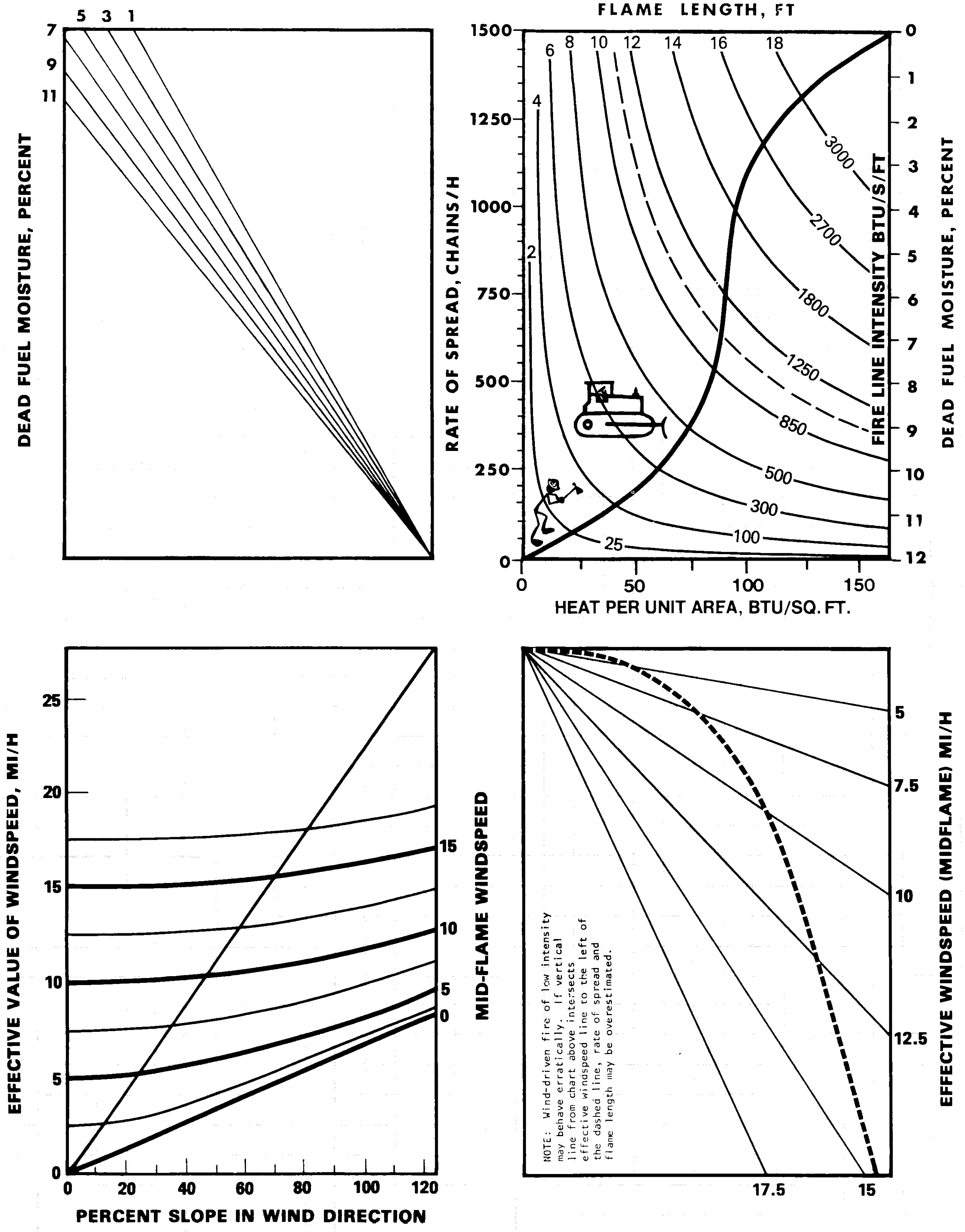
1. SHORT GRASS (1 FT) -LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

Fuel model 1 – high windspeeds

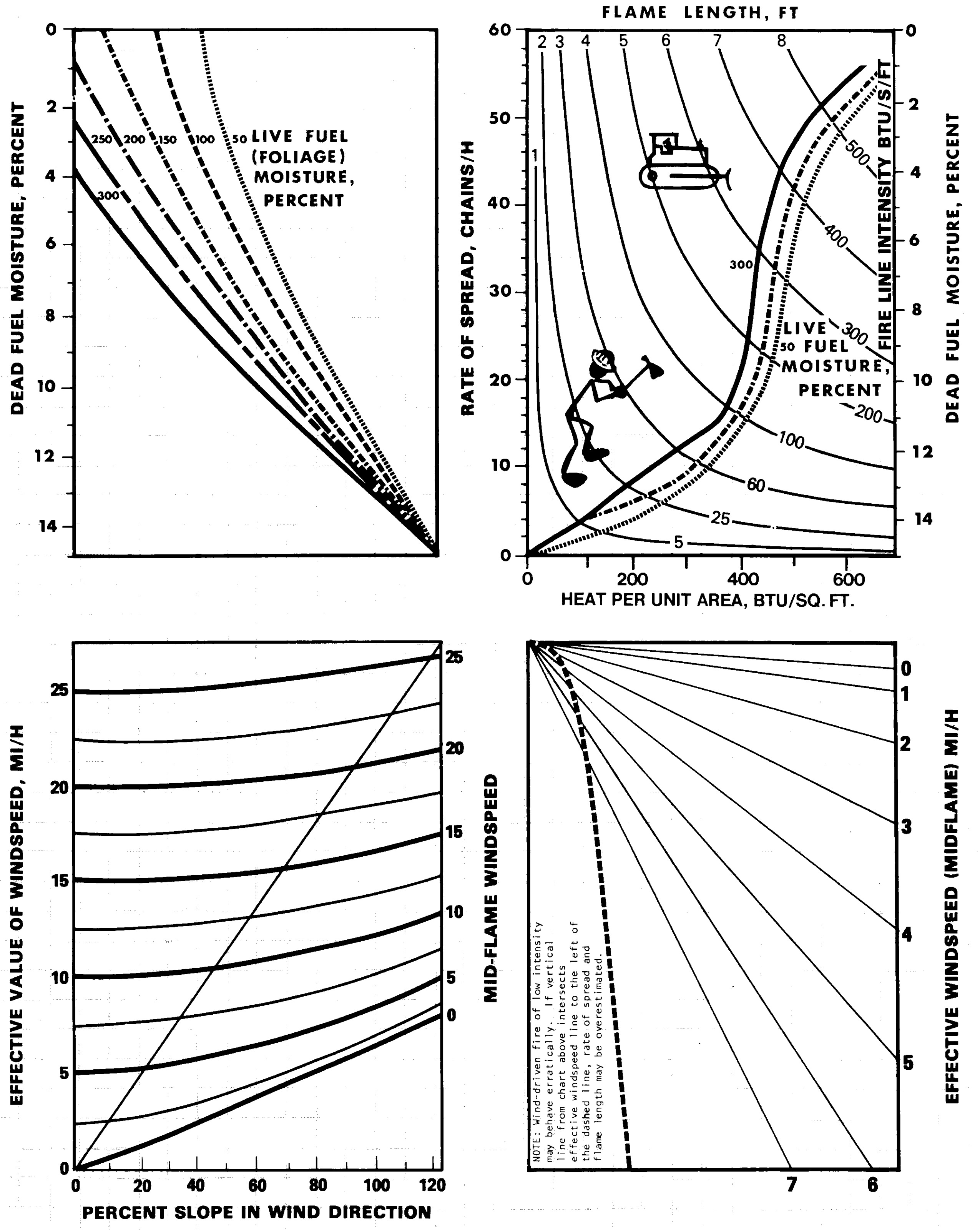
1. SHORT GRASS(1 FT) – HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

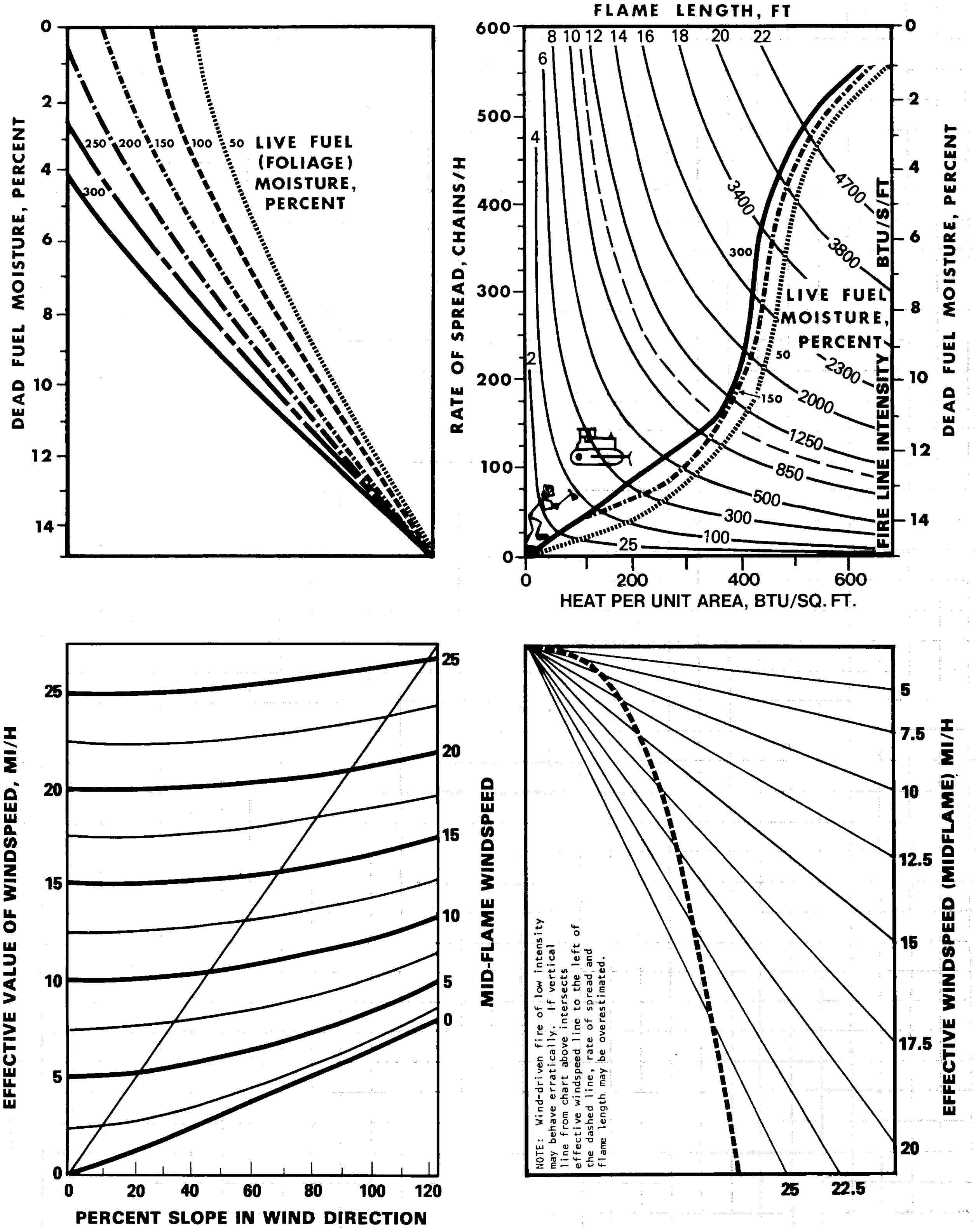
Fuel model 2 – low windspeeds

2. TIMBER (GRASS & UNDERSTORY) – LOW WINDSPEEDS



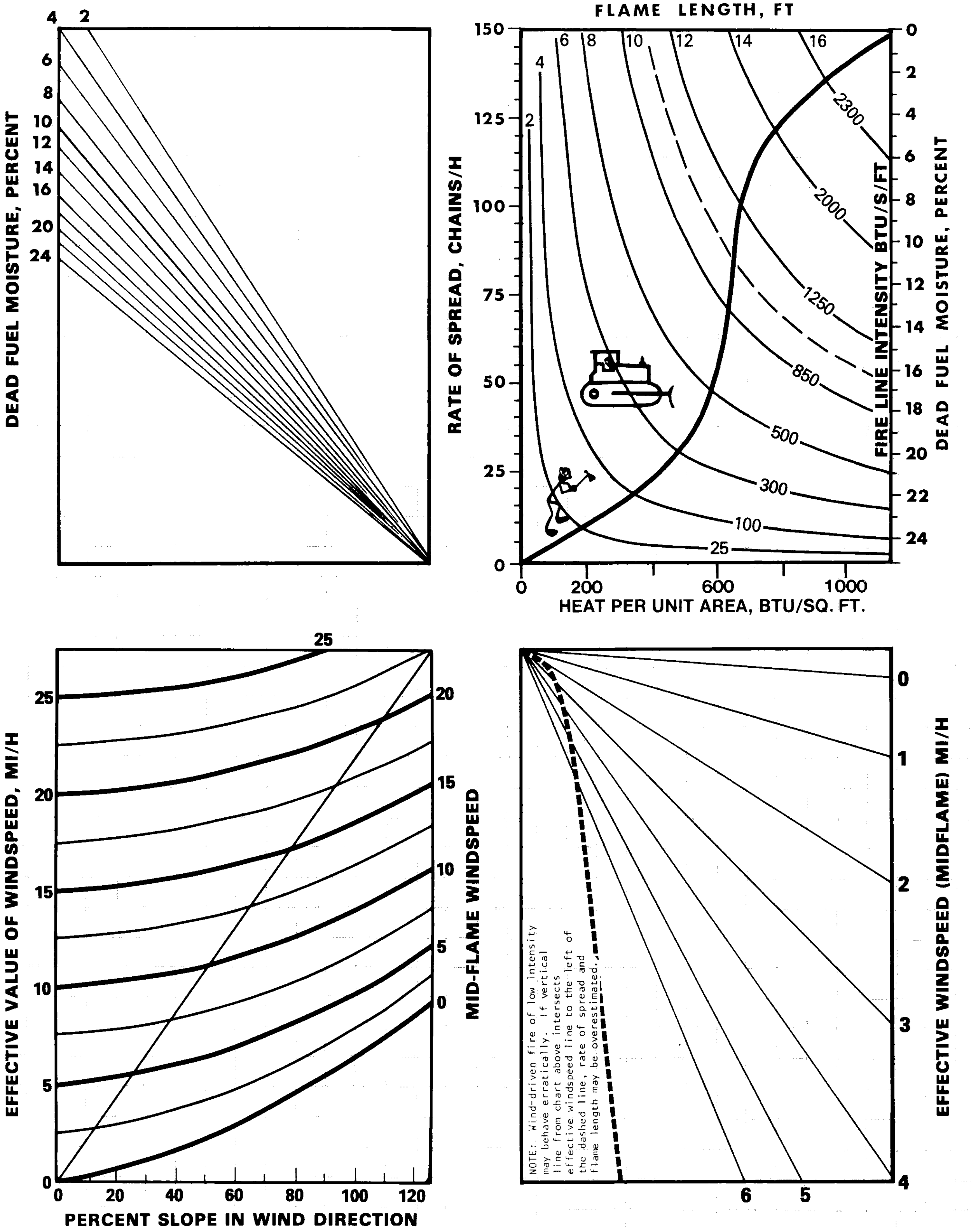
NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

2. TIMBER (GRASS & UNDERSTORY) - HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

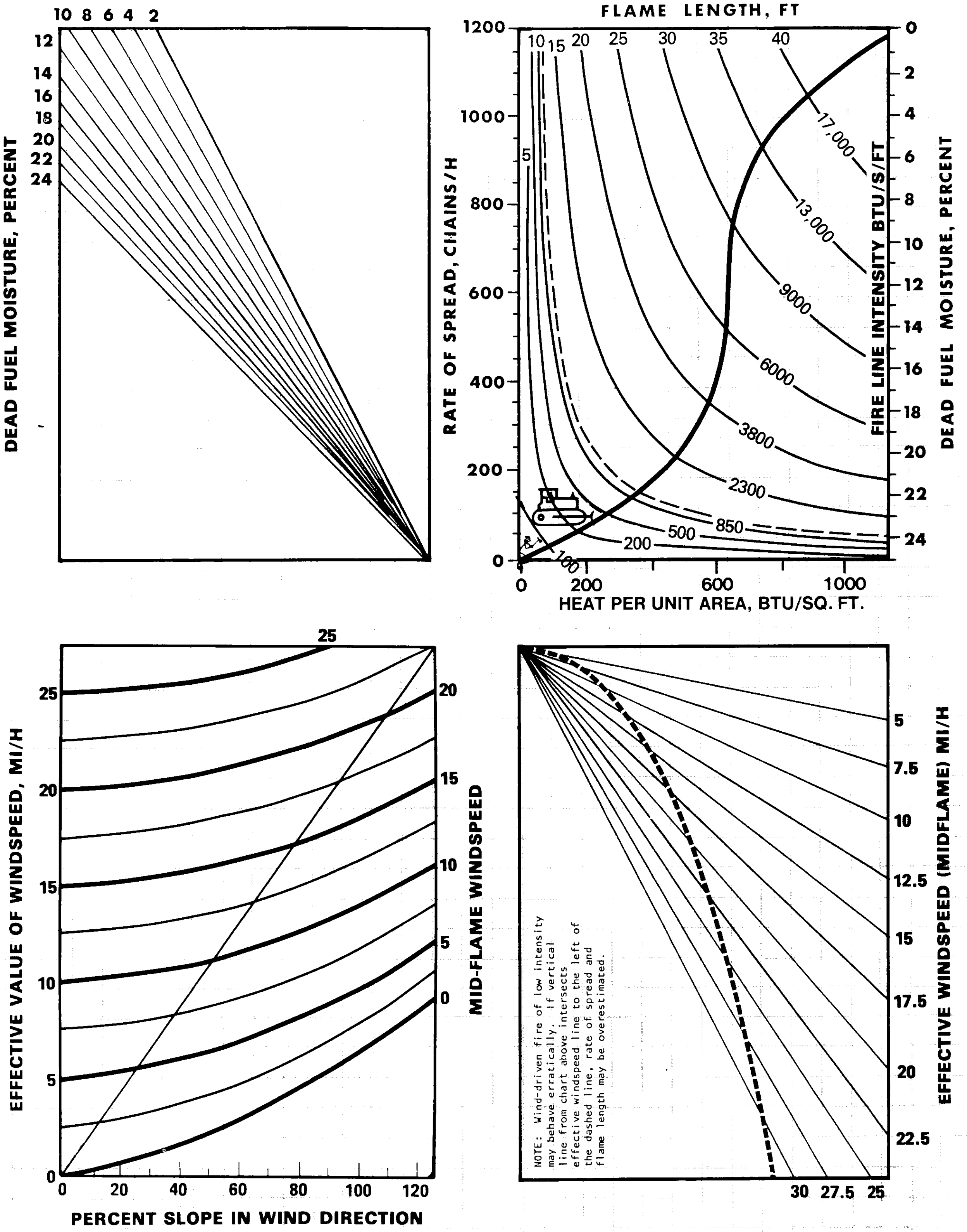
3. TALL GRASS (2.5 FT)-LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

Fuel model 3 – high windspeeds

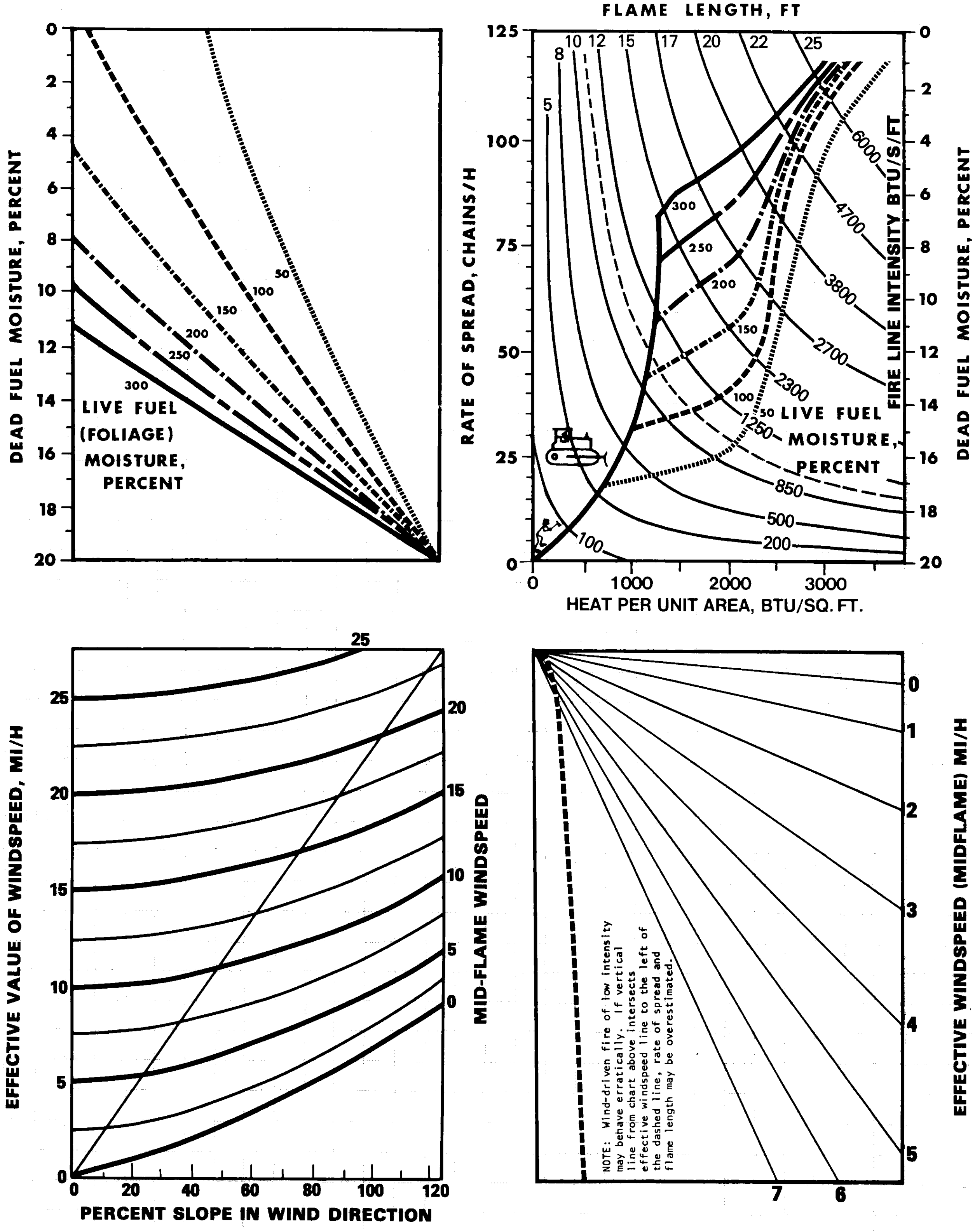
3. TALL GRASS (2.5 FT) - HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

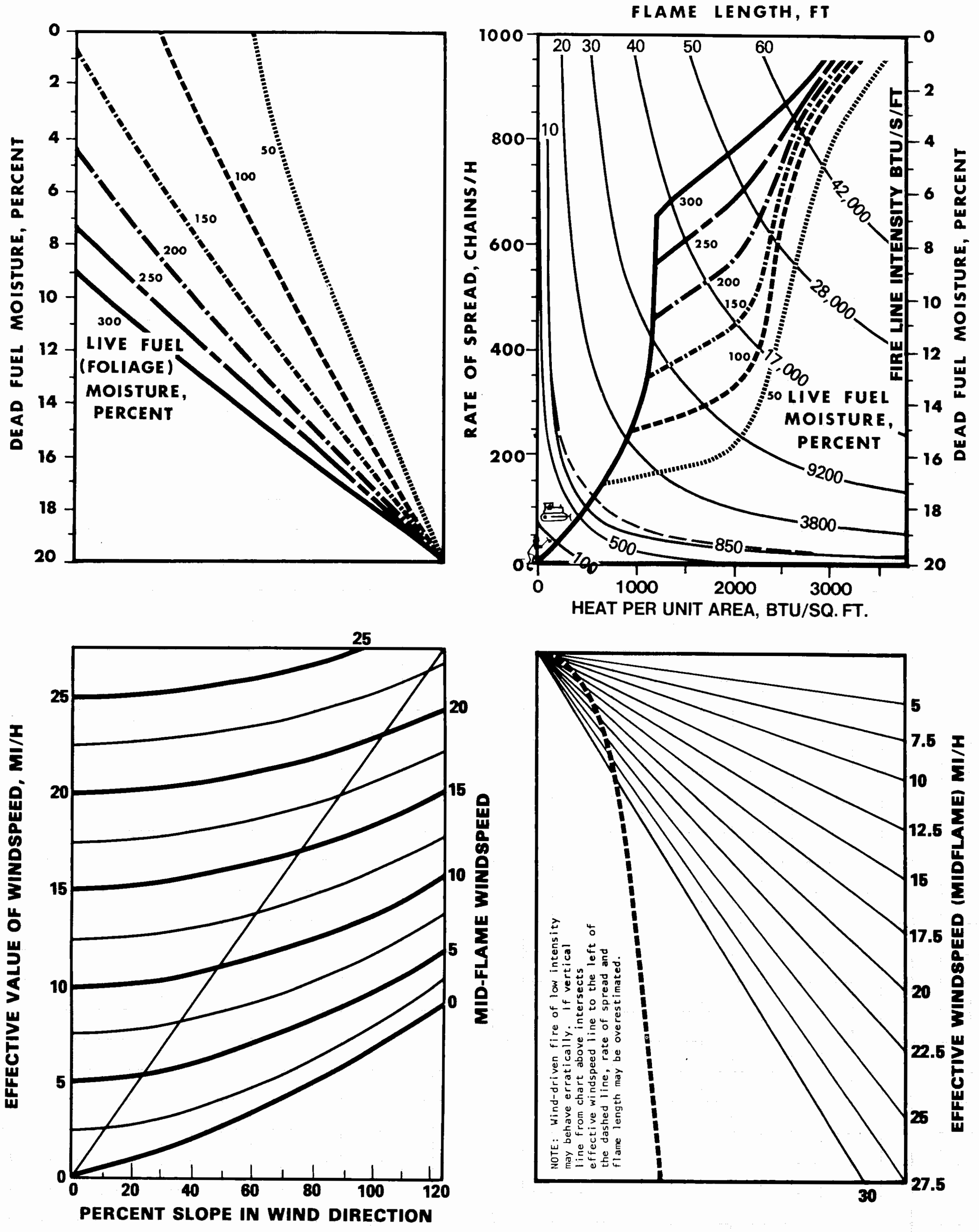
Fuel model 4 – low windspeeds

4. CHAPARRAL(6 FT) -LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

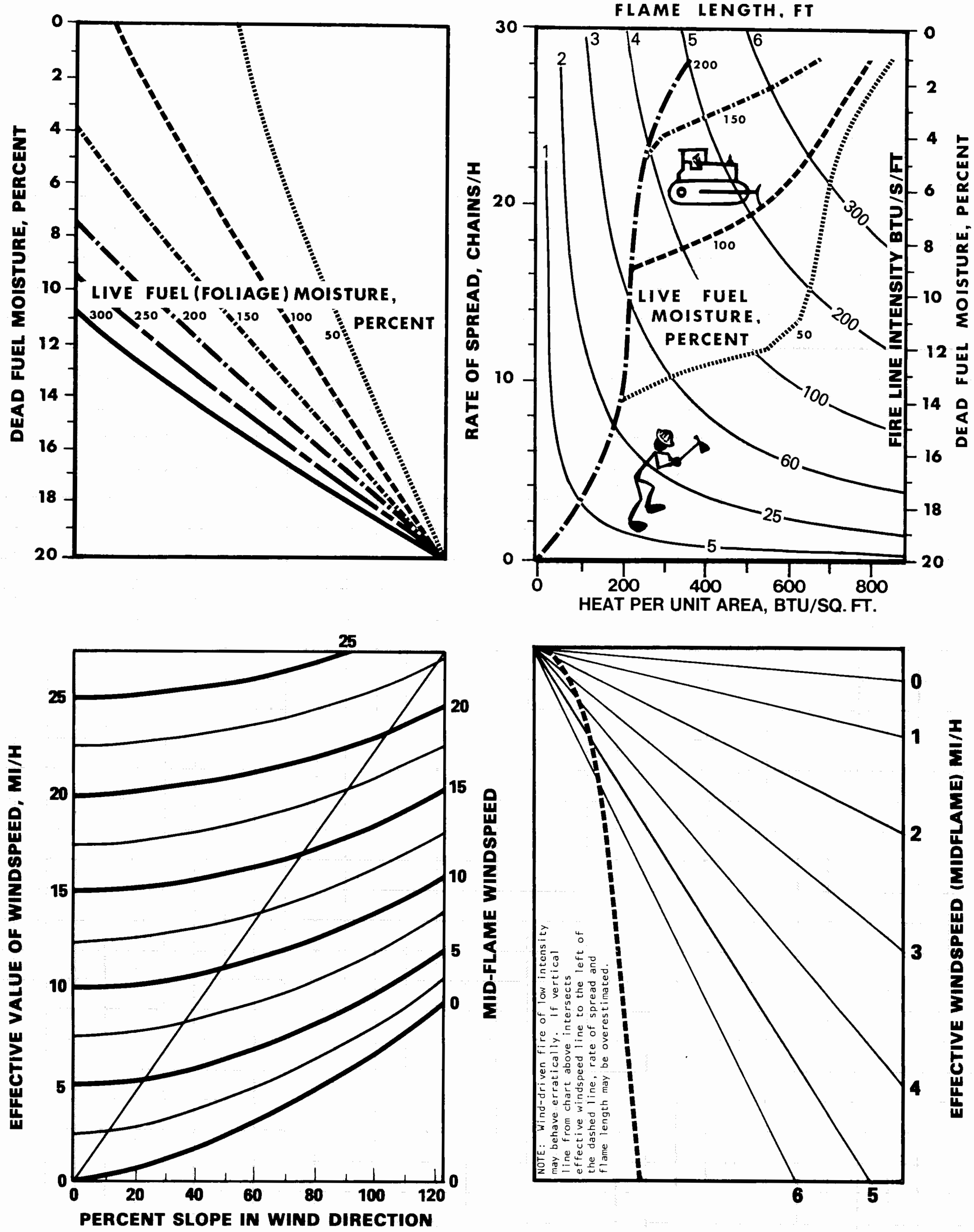
4. CHAPARRAL (6 FT)- HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

Fuel model 5 – low windspeeds

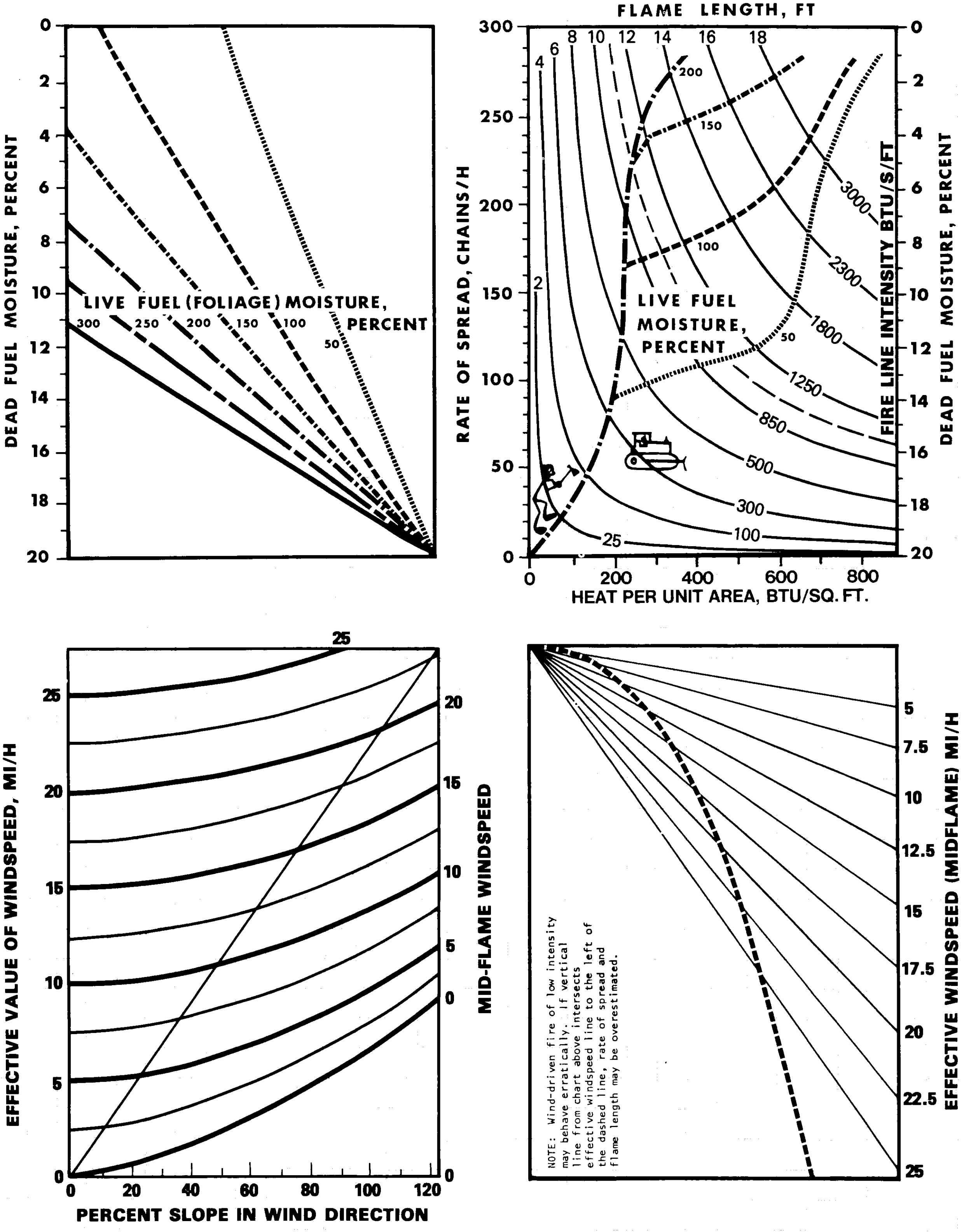
5. BRUSH (2 FT) - LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

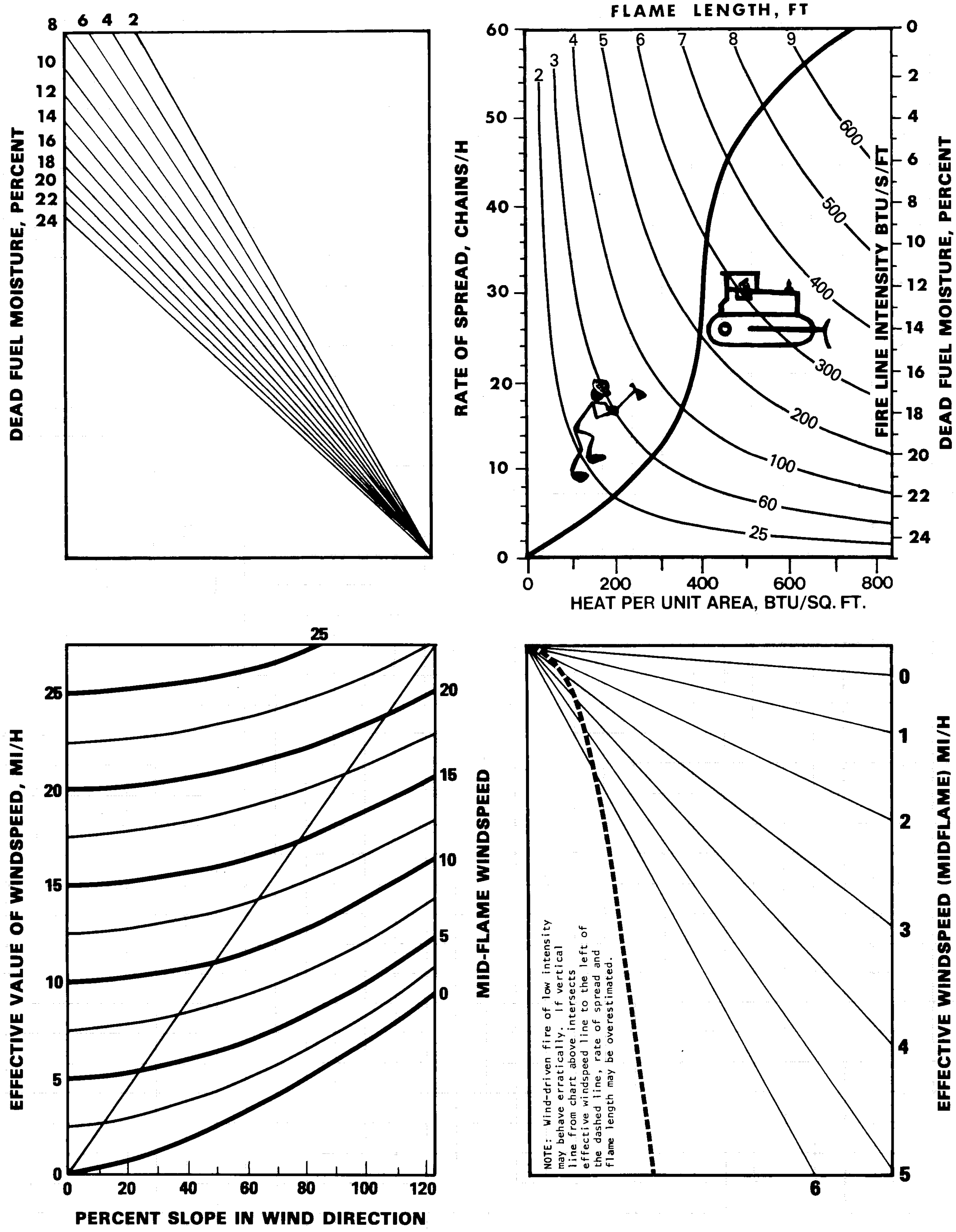
Fuel model 5 – high windspeeds

5. BRUSH (2 FT) - HIGH WINDSPEEDS



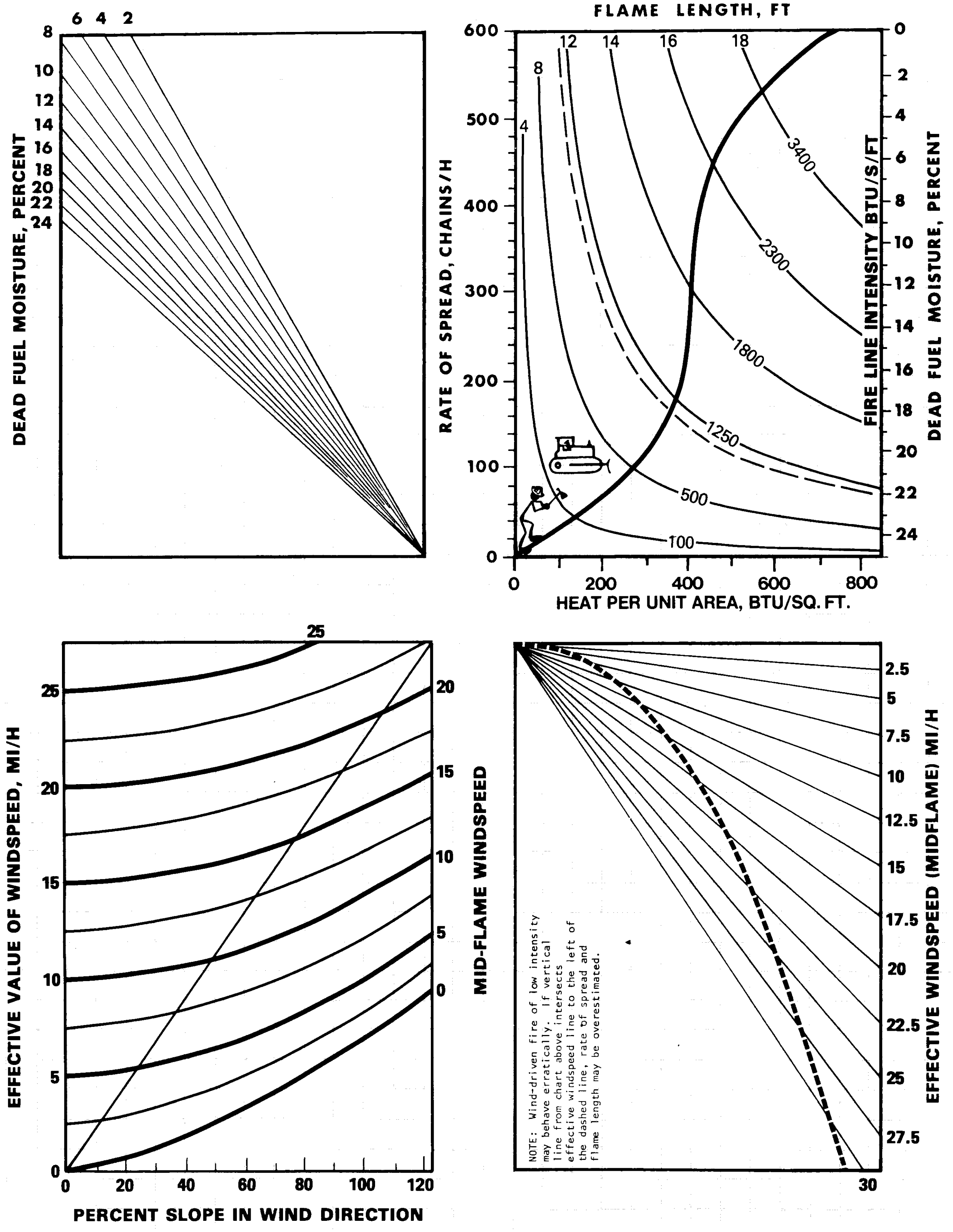
NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

6. DORMANT BRUSH, HARDWOOD SLASH – LOW WINDSPEEDS



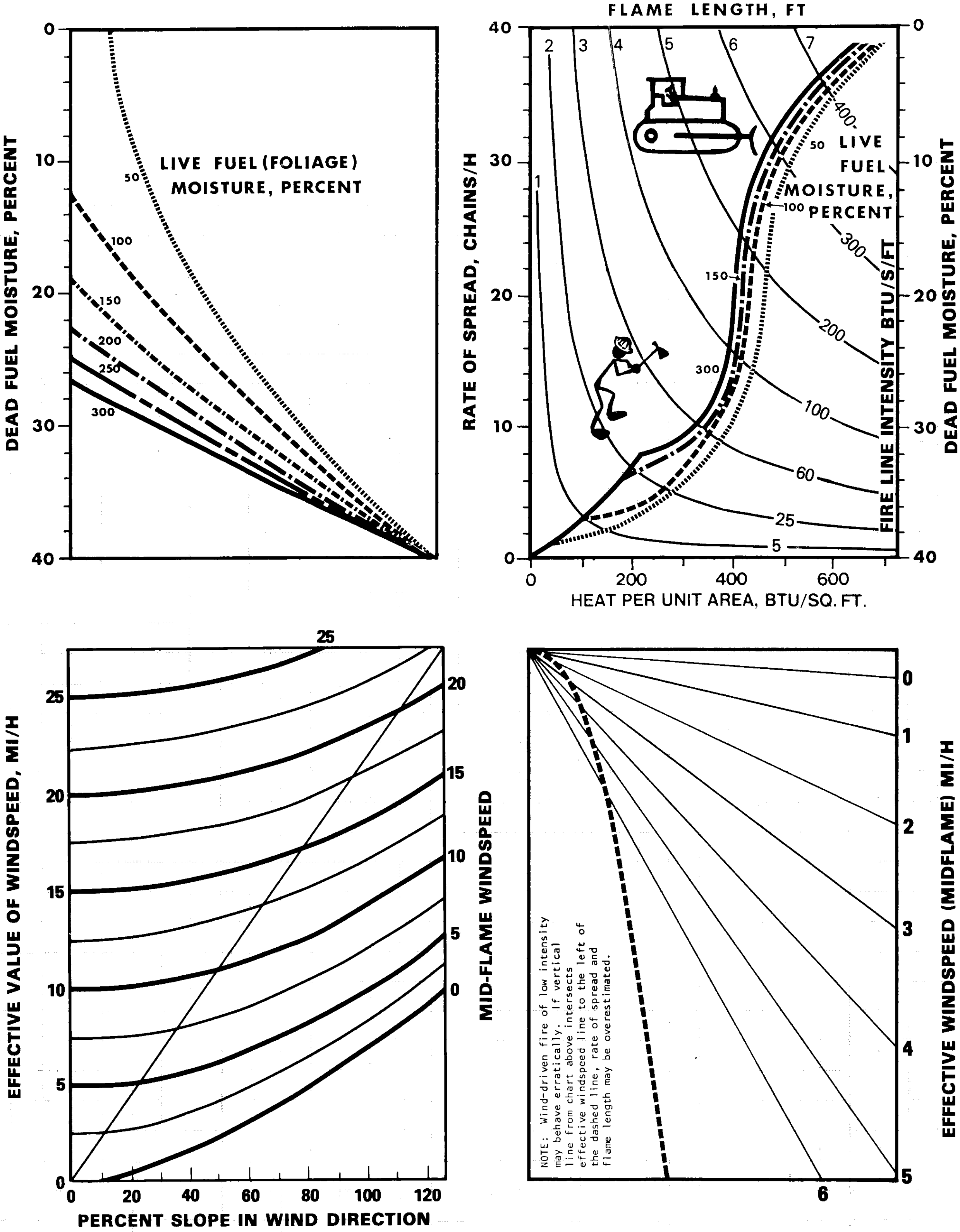
NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

6. DORMANT BRUSH, HARDWOOD SLASH–HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

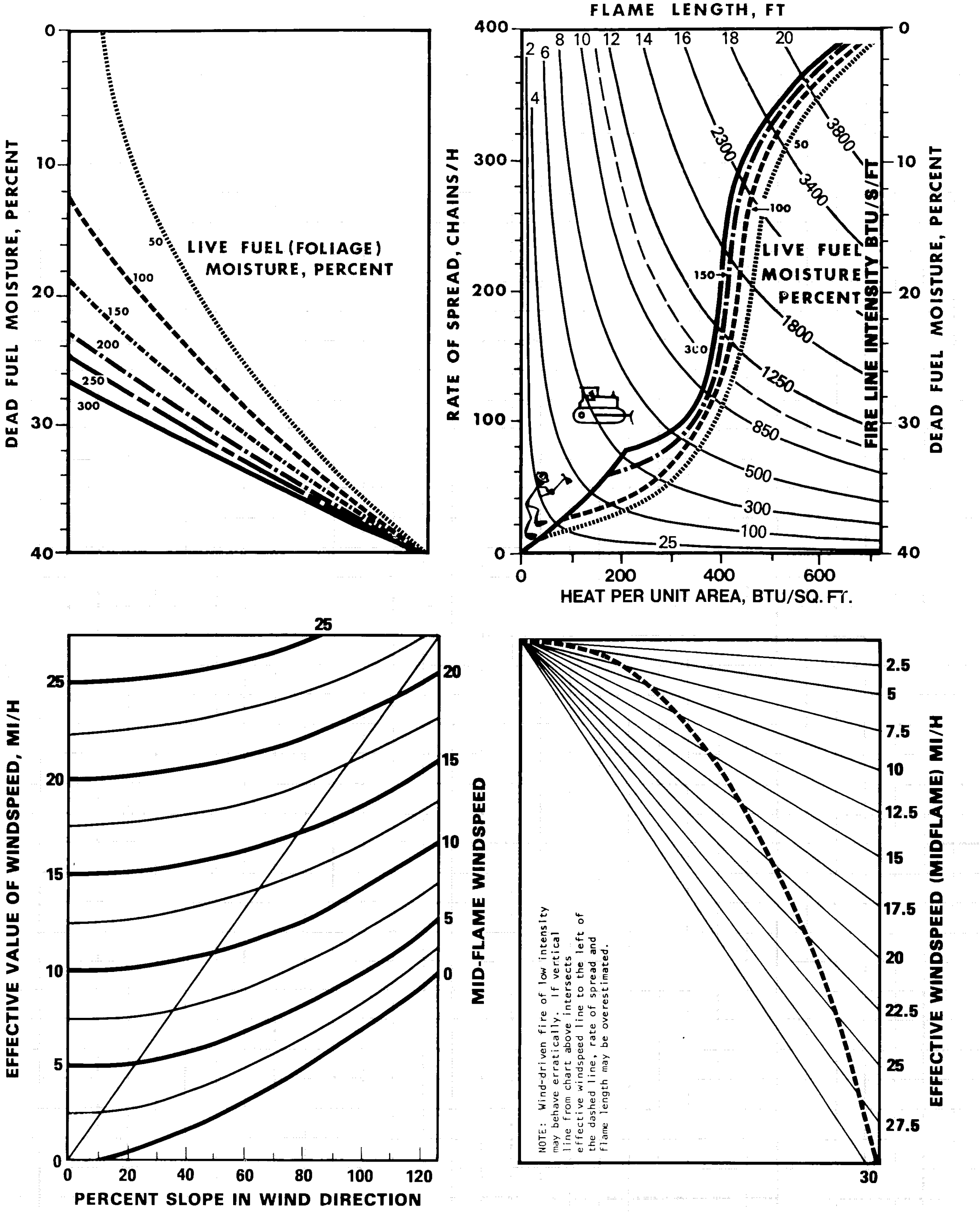
7. SOUTHERN ROUGH - LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

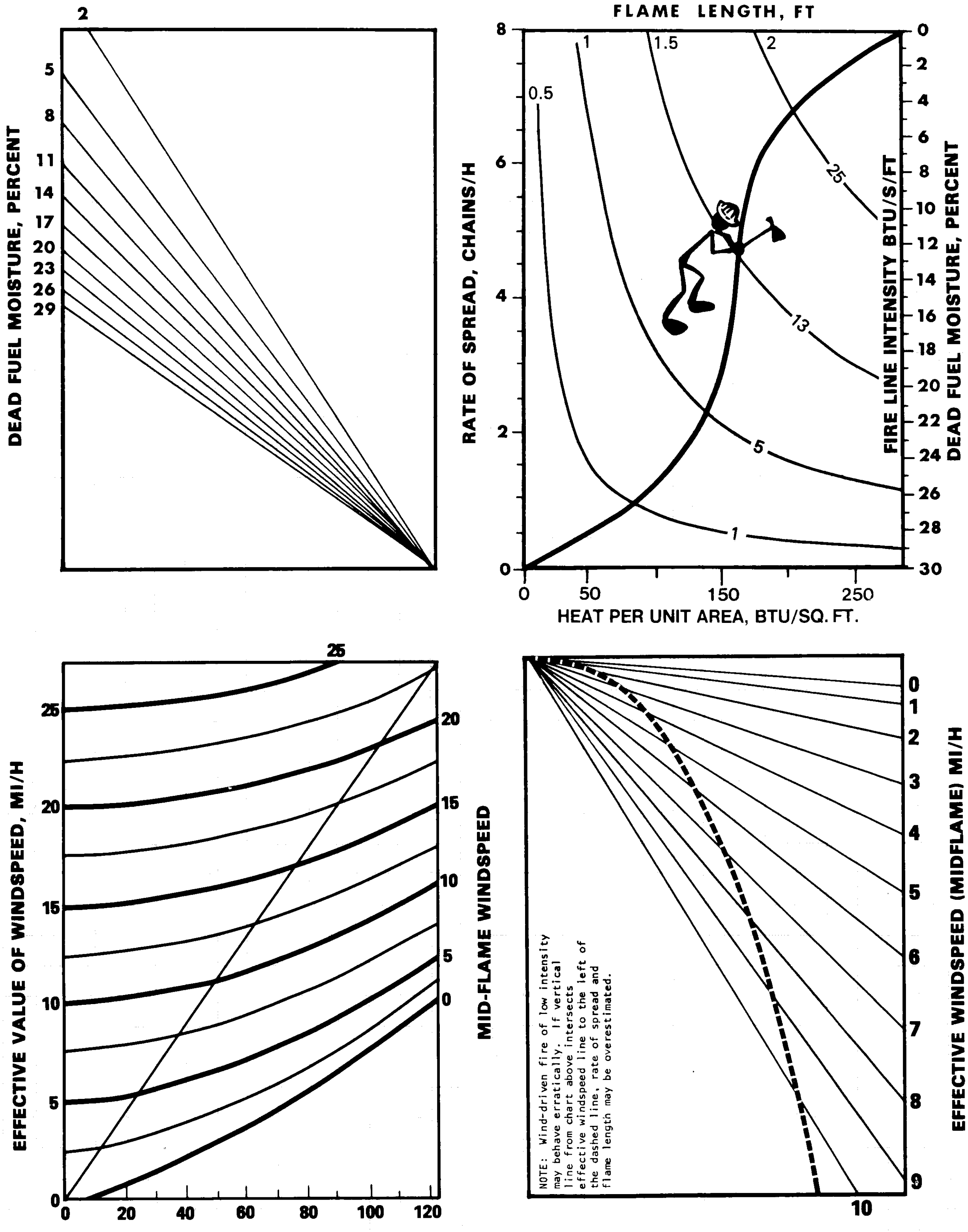
Fuel model 7 – high windspeeds

7. SOUTHERN ROUGH -HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

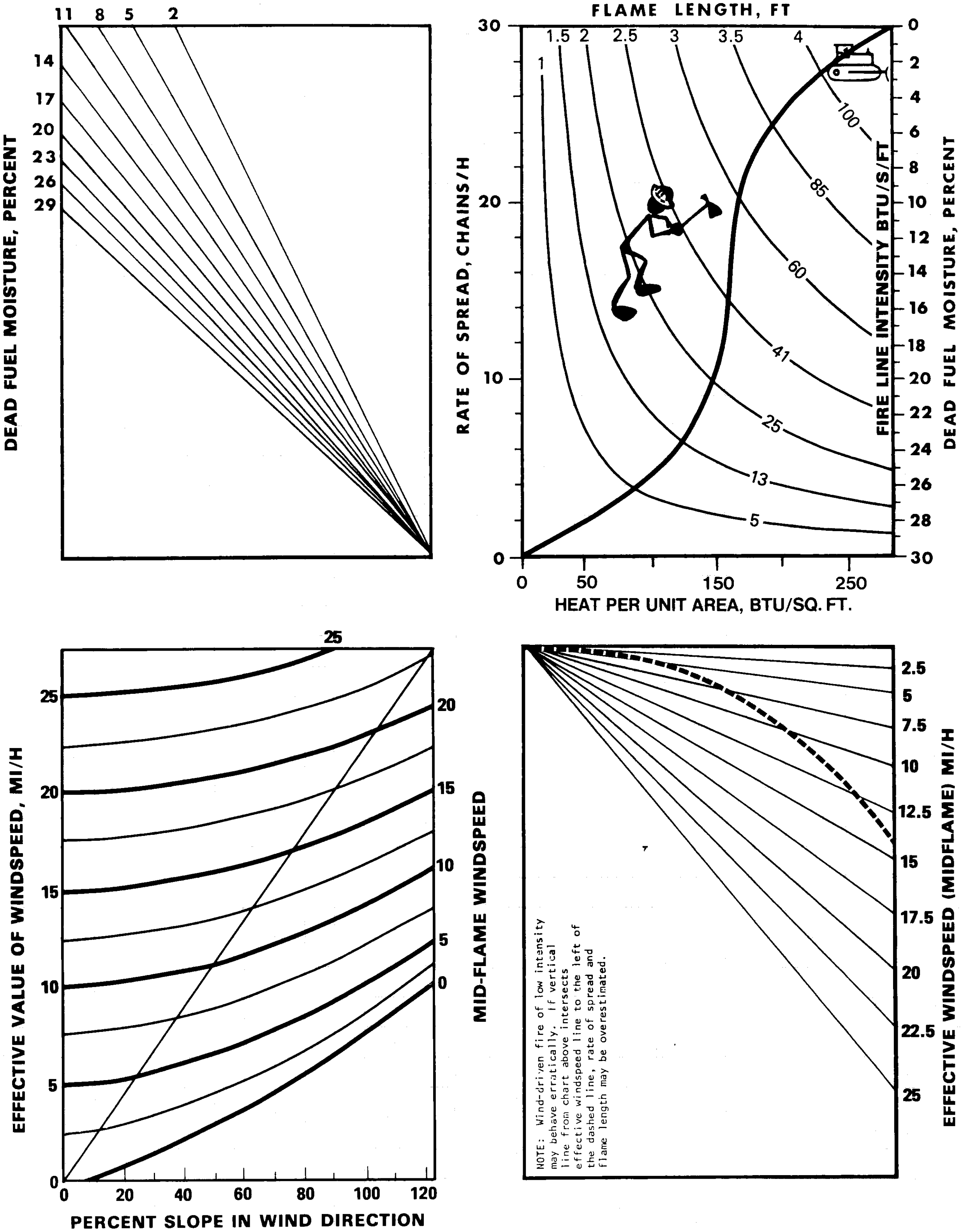
8. CLOSED TIMBER LITTER – LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

Fuel model 8 – high windspeeds

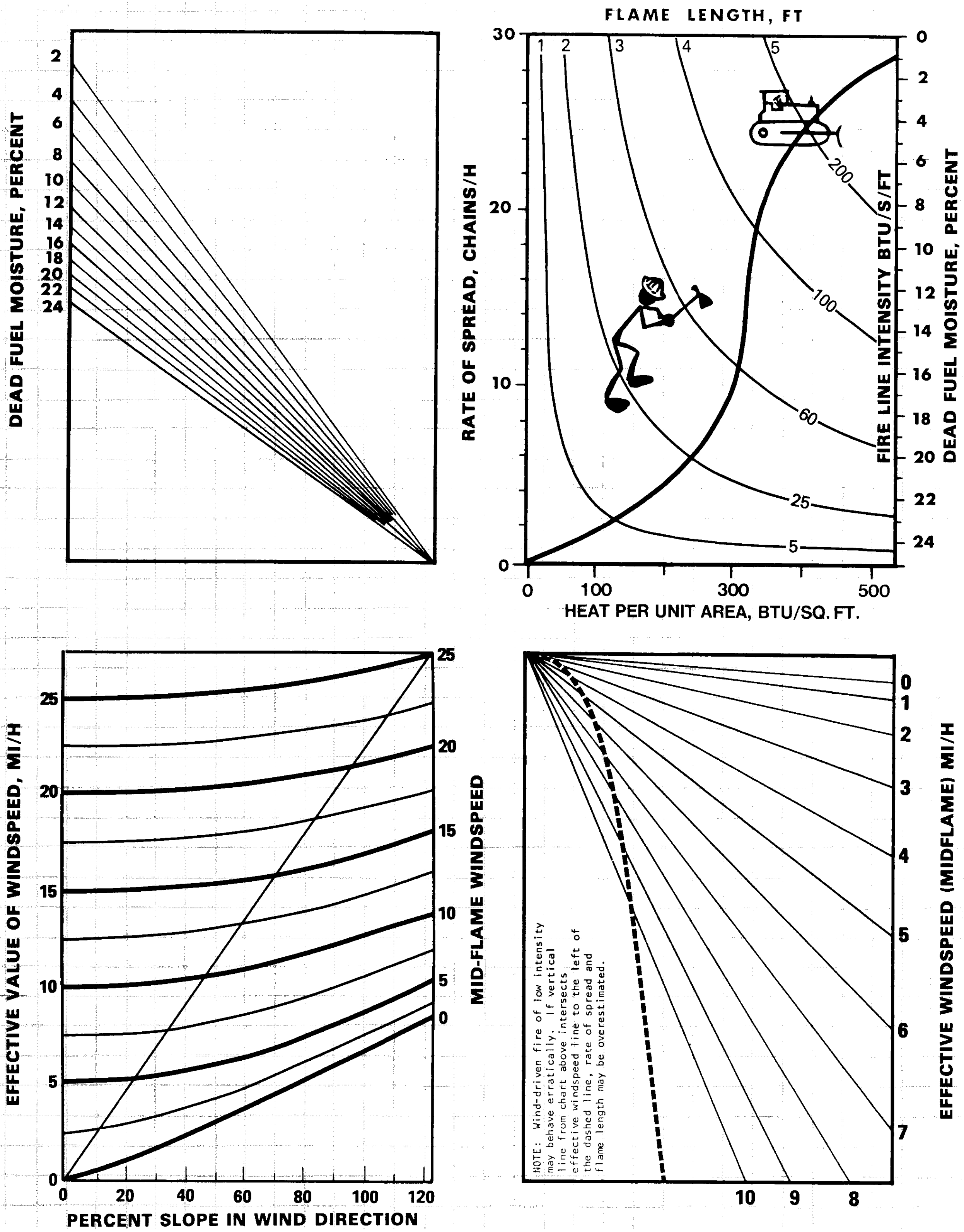
8. CLOSED TIMBER LITTER- HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

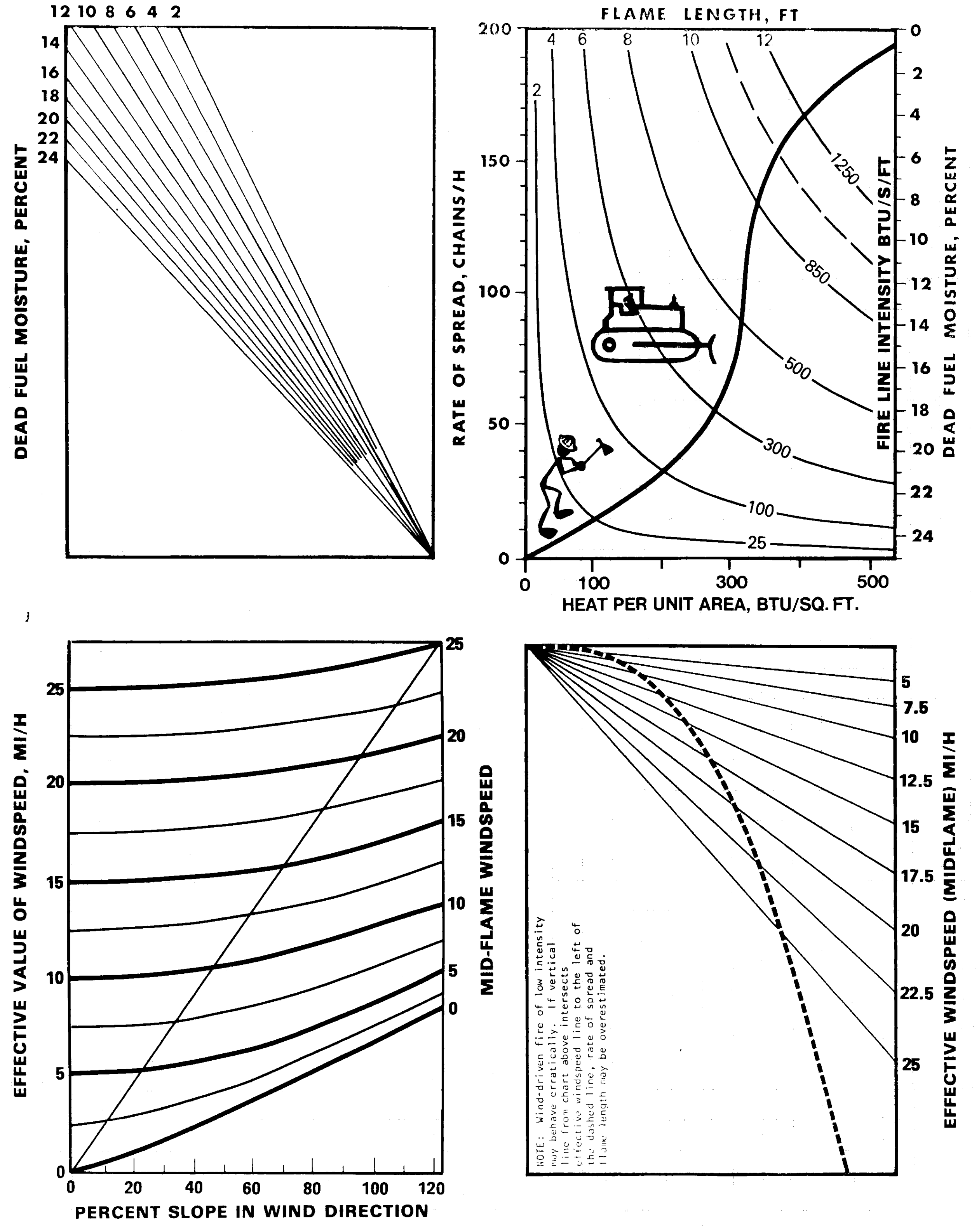
Fuel model 9 – low windspeeds

9. HARDWOOD LITTER – LOW WINDSPEEDS



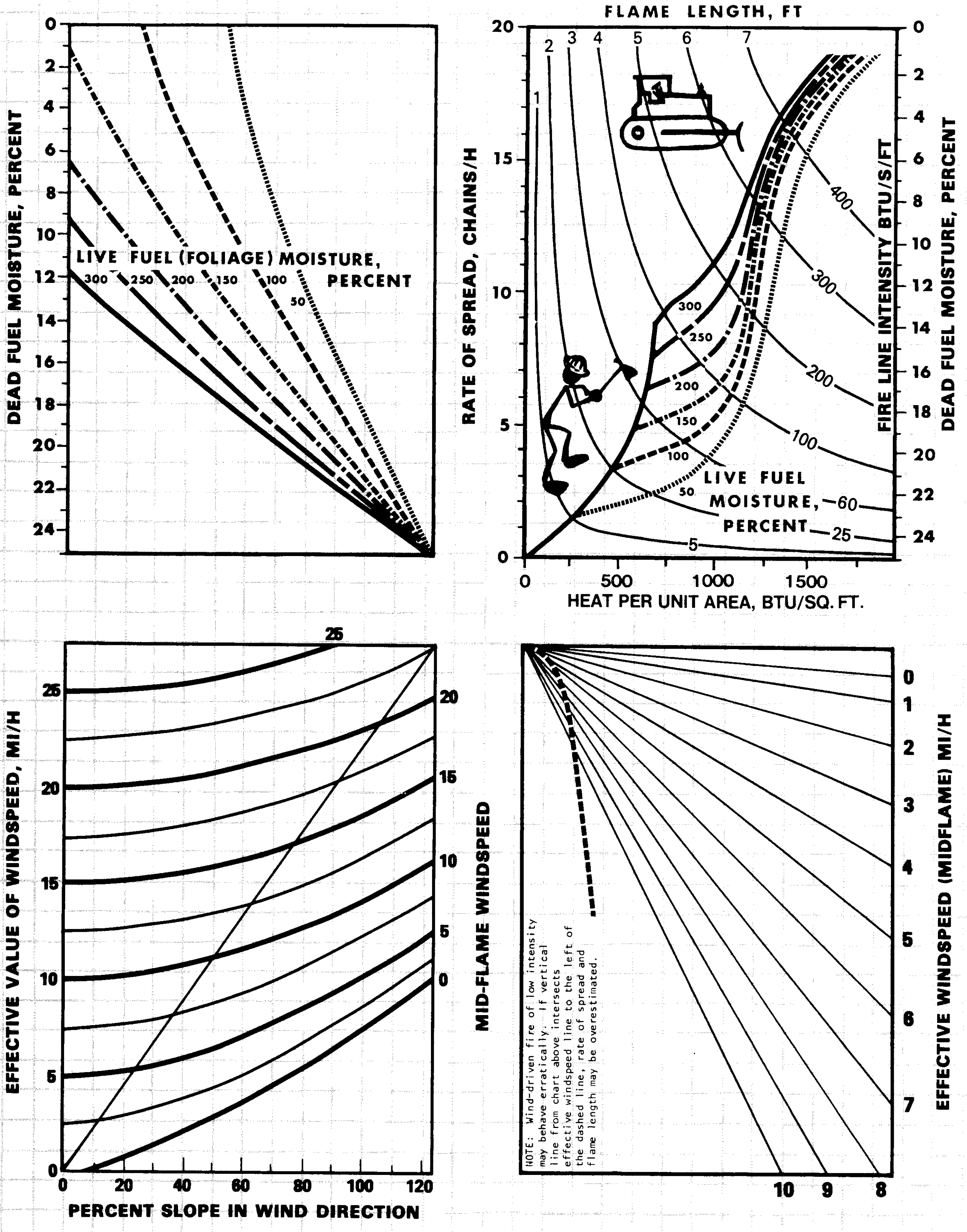
NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

9. HARDWOOD LITTER-HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

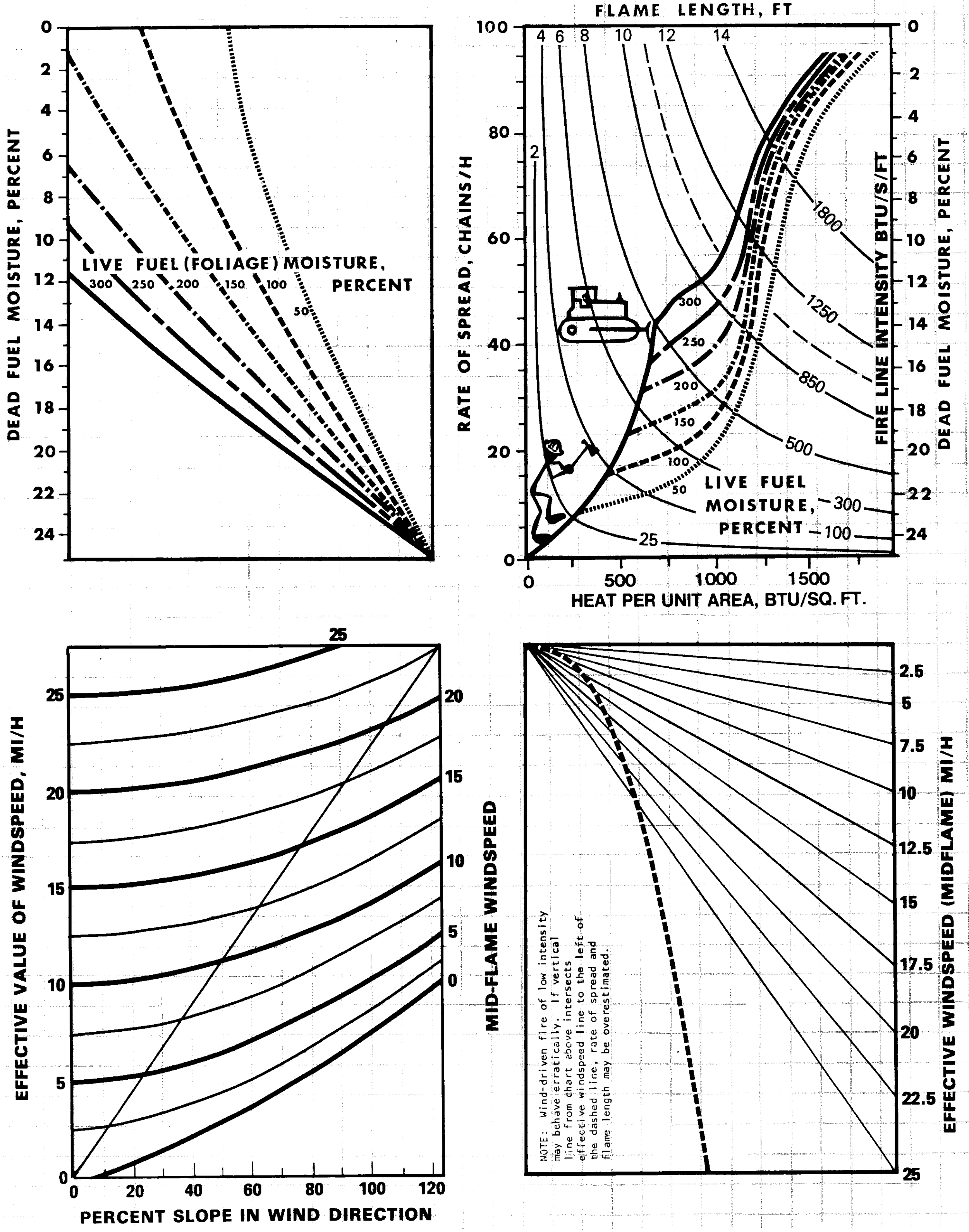
10. TIMBER (LITTER & UNDERSTORY)-LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

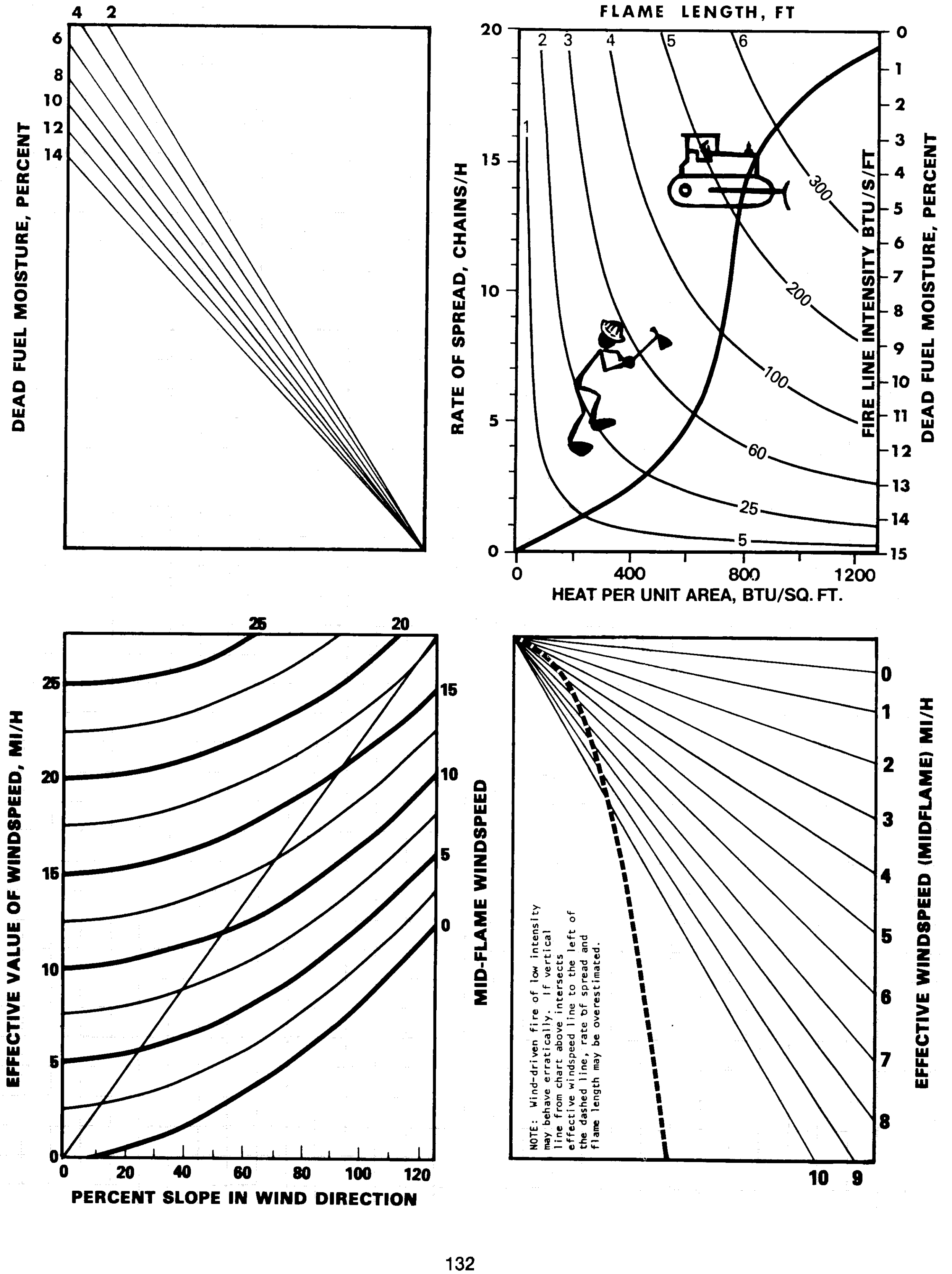
Fuel model 10 – high windspeeds

10. TIMBER (LITTER & UNDERSTORY)-HIGH WINDSPEEDS



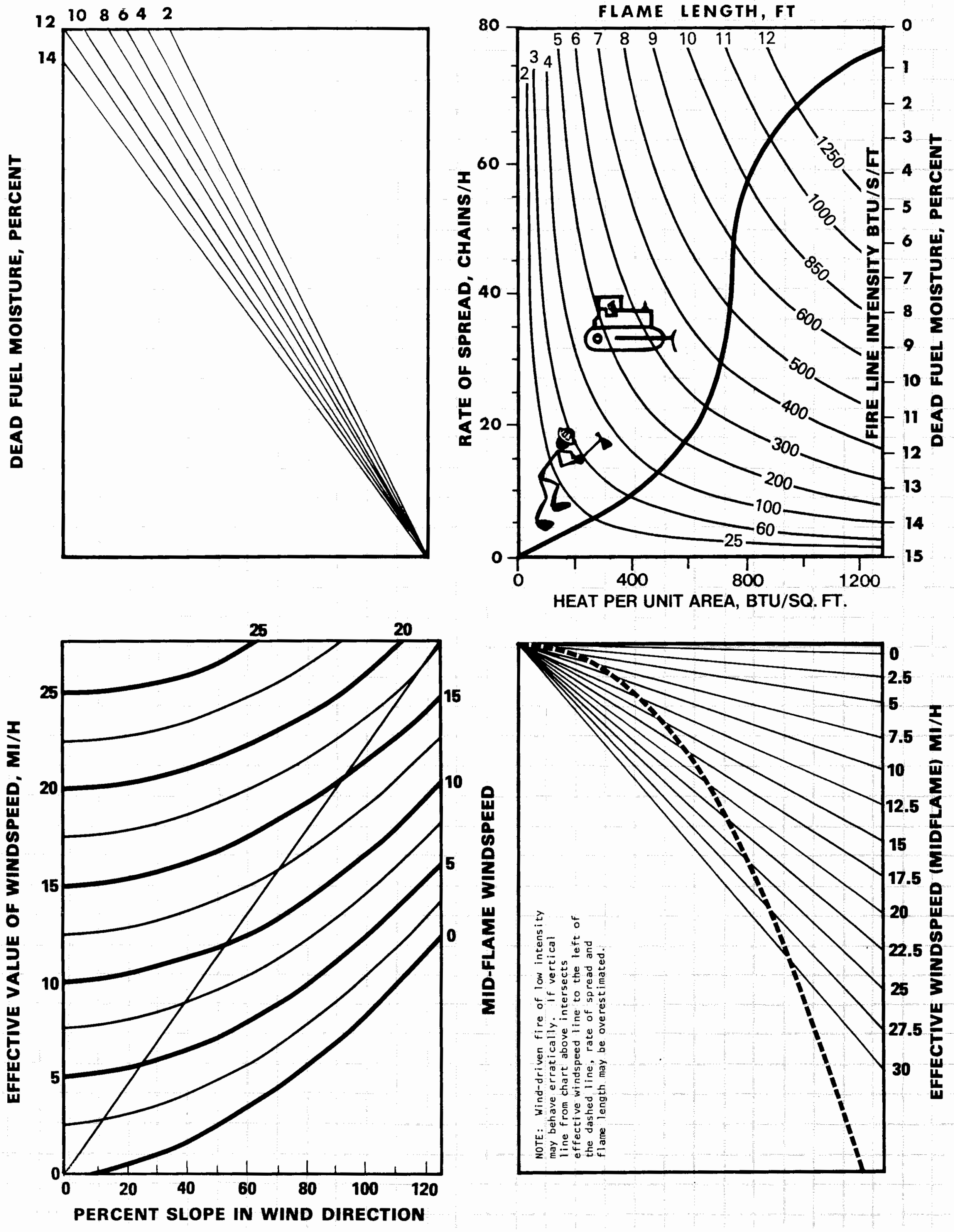
NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

11. LIGHT LOGGING SLASH-LOW WINDSPEEDS



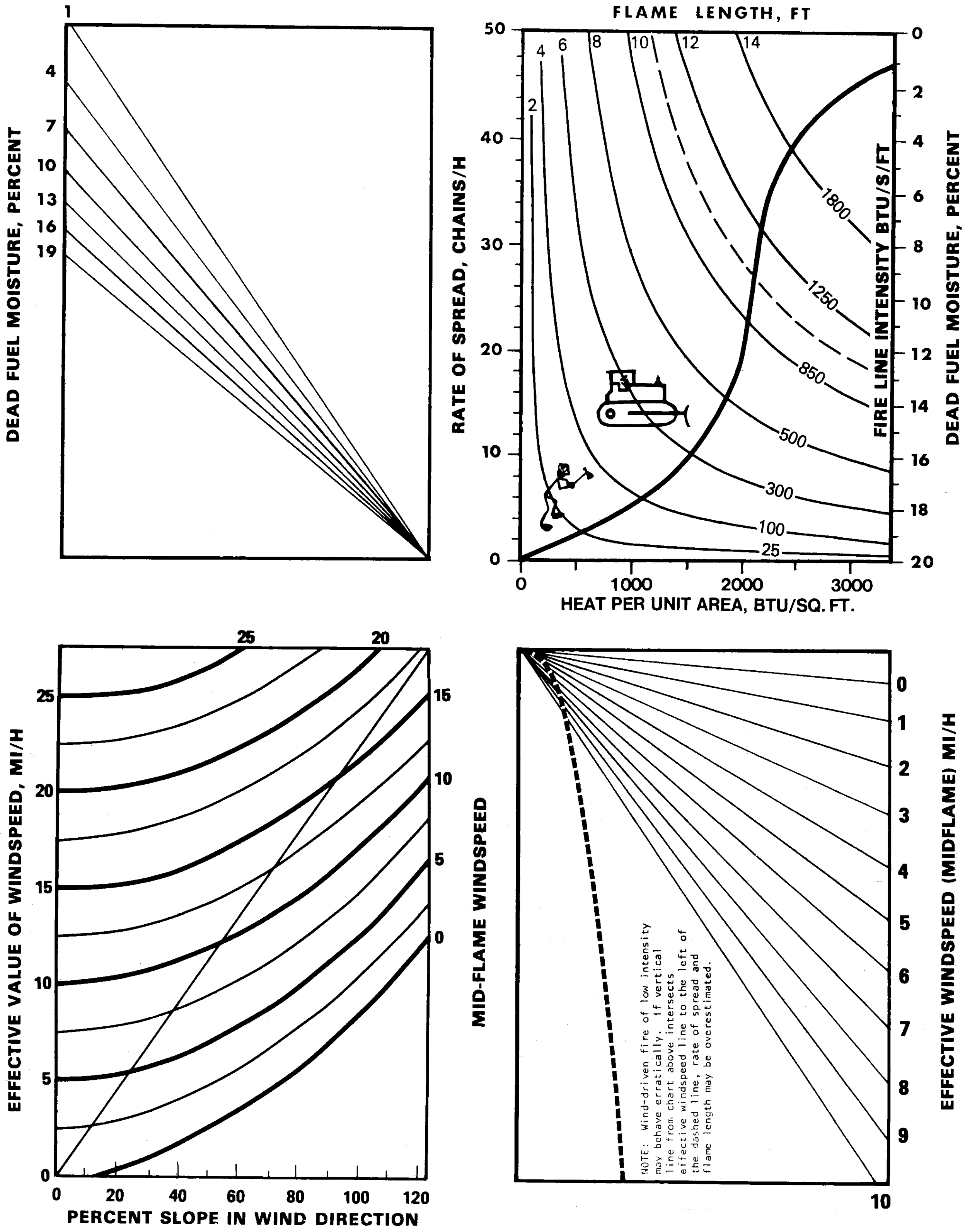
NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

11. LIGHT LOGGING SLASH-HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

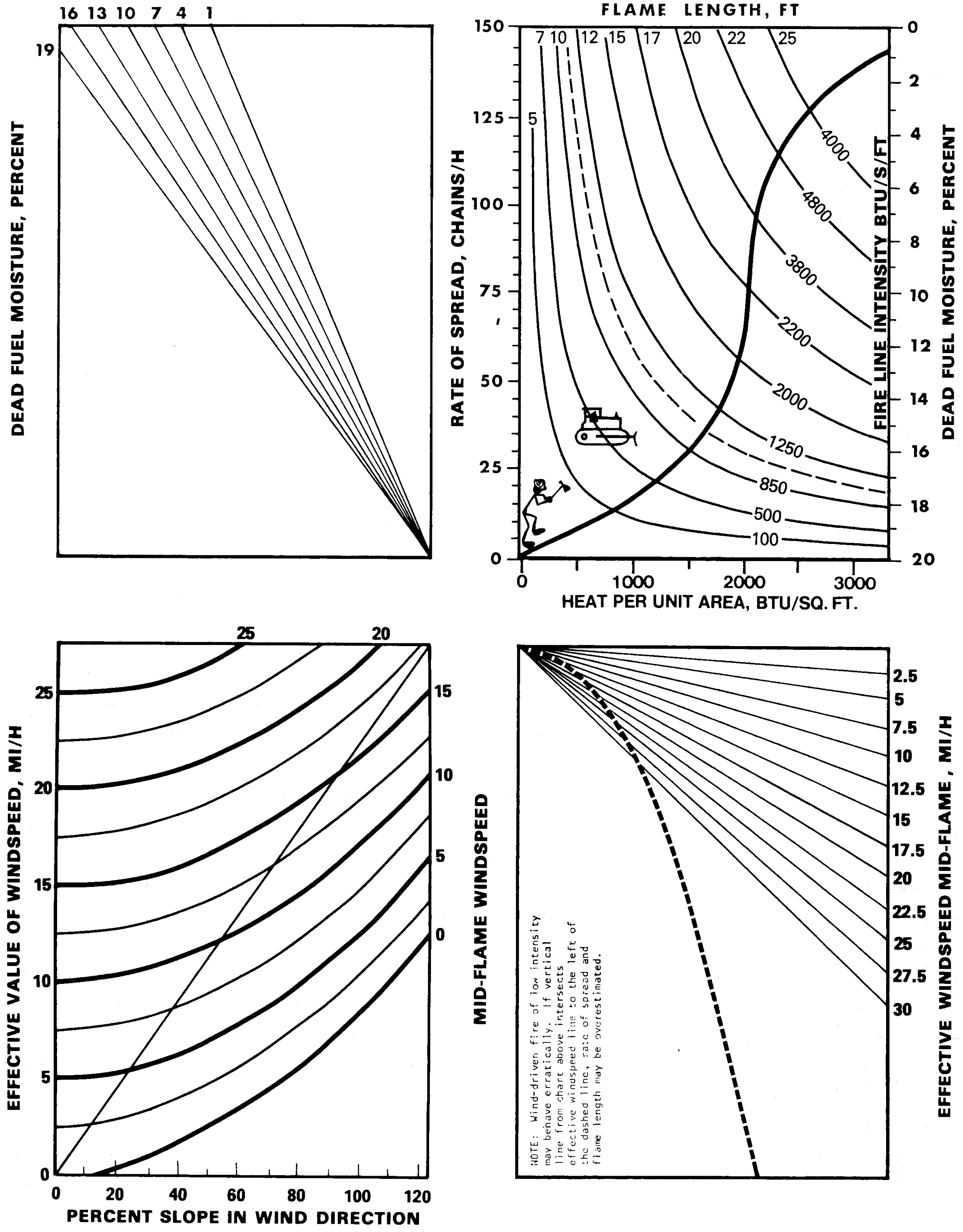
12. MEDIUM LOGGING SLASH –LOW WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

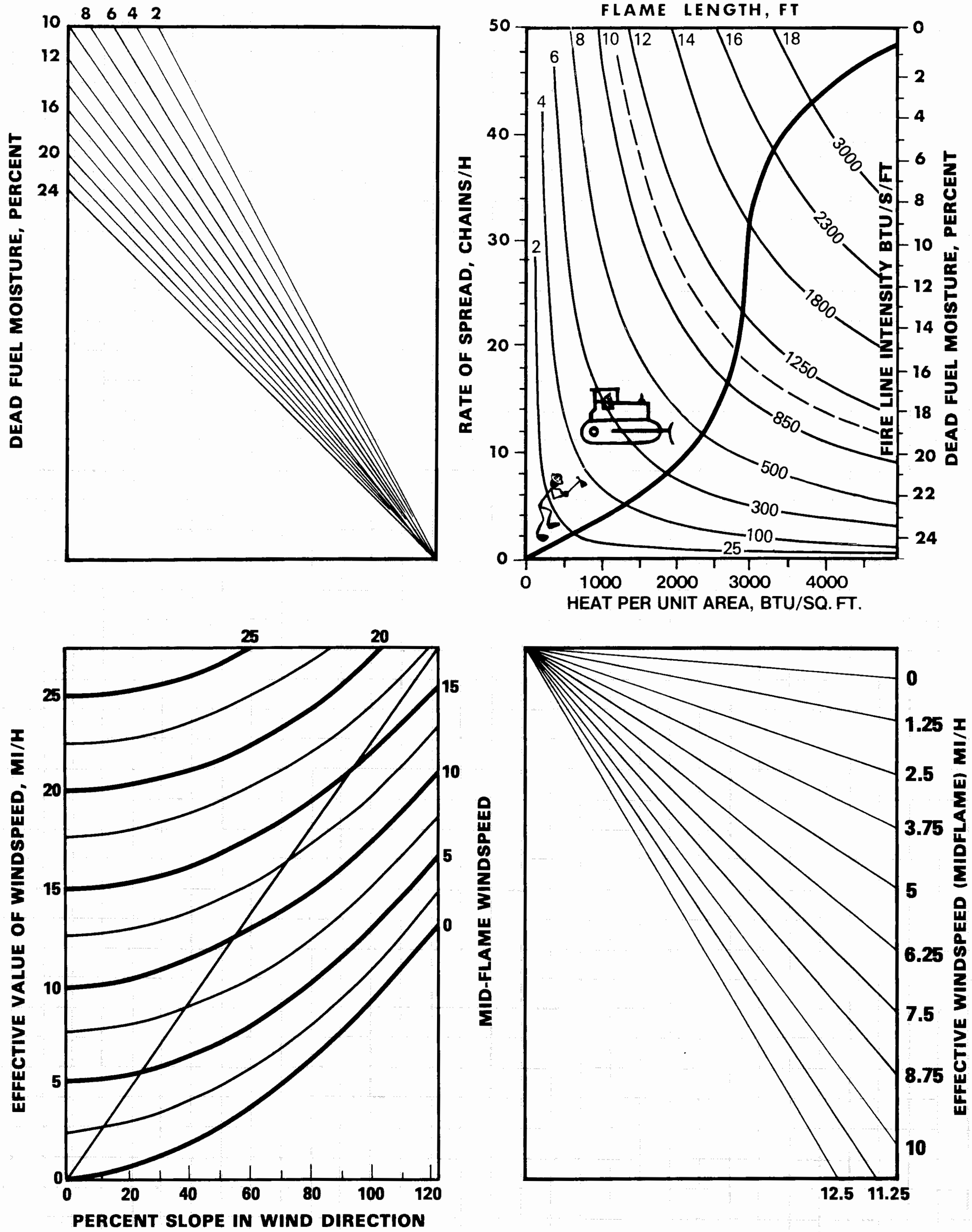
Fuel model 12 – high windspeeds

12. MEDIUM LOGGING SLASH-HIGH WINDSPEEDS



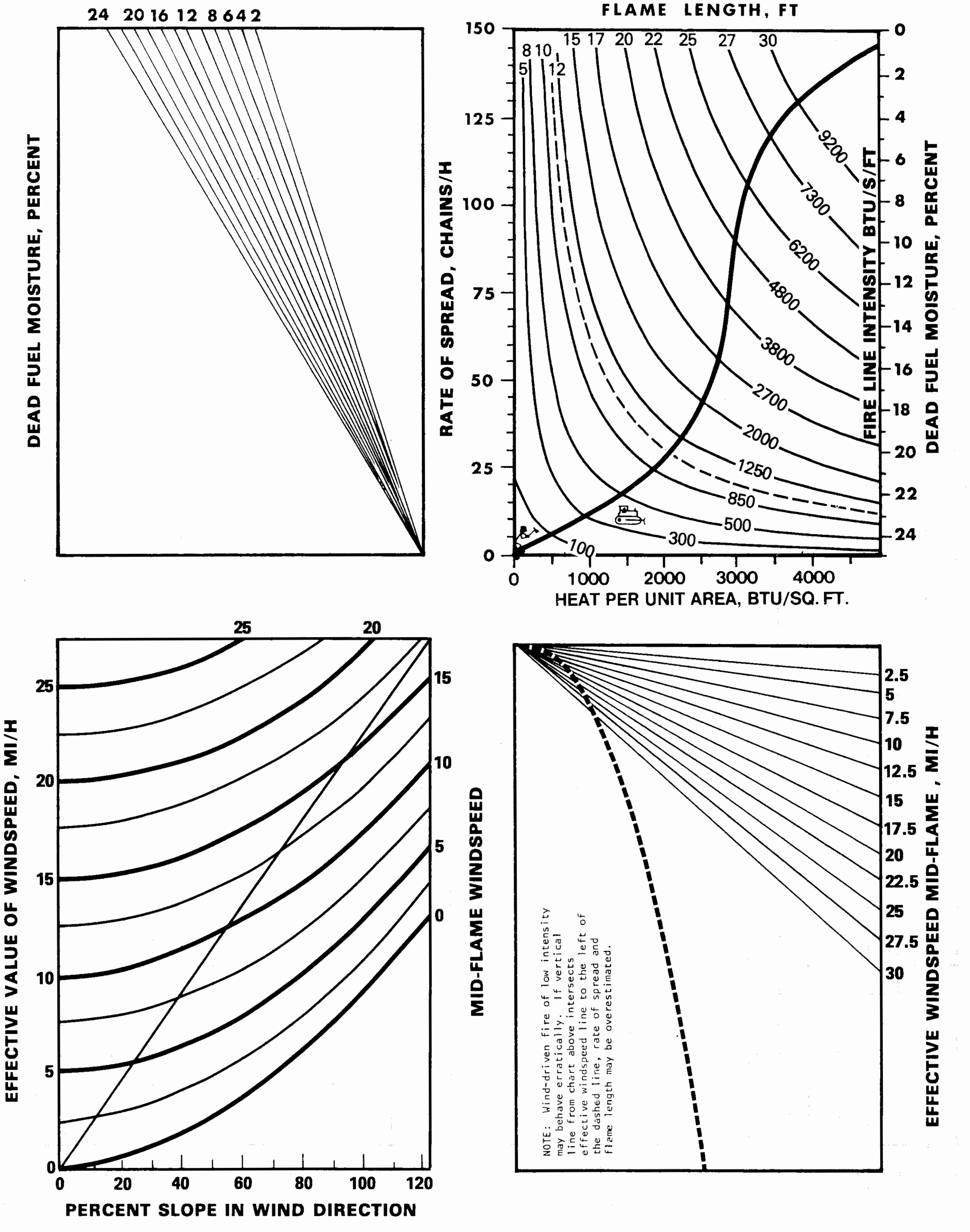
NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

13. HEAVY LOGGING SLASH–LOW WINDSPEEDS



Fuel model 13 – high windspeeds

13. HEAVY LOGGING SLASH-HIGH WINDSPEEDS



NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

APPENDIX B

Computation of Midflame Windspeed for the 13 Fire Behavior Fuel Models

Albini and Baughman (1979) provide the rationale for adjusting windspeed measured at 20 feet to the midflame height. Their method, and particularly their figure 2, which is reproduced here as figure B-1, was utilized to find a standard correction factor for each of the 13 fire behavior models. Without a standard, it would be necessary to calculate a midflame windspeed for every fire environment situation. It is recognized that some accuracy is lost in the process, but it is believed that this is not severe, and justified by the time saved for field work. We have found that even though flame length varies considerably with changes in windspeed, flame height is not as variable.

To use figure B-1, it is necessary to know the flame height and fuel bed depth for each fuel model. Calculation of flame height was made for dry, average, and moist conditions for each fuel model. The ratio of average midflame windspeed to 20-ft windspeed was not very different for the three conditions, so the average moisture condition, 8 percent dead, 100 percent live was used. Results are shown in table B-1.

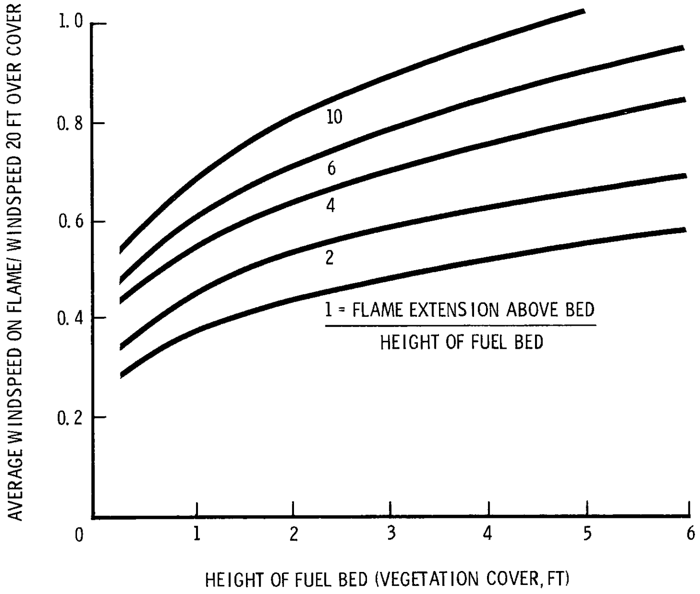


Figure B-1.—Average windspeed acting on a flame extending above a uniform surface fuelbed layer (vegetation cover), due to log windspeed variation.

Table B-1.— Data used in obtaining midflame windspeed adjustment factors for the 13 NFFL fuel models

Fuel model	Flame height[1] zero windspeed	Flame height divided by fuel depth	MWS/20′WS	Value used in wind adj table
1	0.99	0.99	0.36	0.4
2	1.6	1.6	.42	.4
3	2.7	1.1	.45	.4
4	4.9	.8	.55	.6
5	.92	.46	.35	.4
6	1.4	.56	.37	.4
7	1.4	.56	.38	.4
8	.37	1.8	.32	.4
9	.9	4.5	.44	.4
10	1.6	1.6	.41	.4
11	1.1	1.1	.37	.4
12	2.7	1.2	.45	.4
13	3.7	1.2	.48	.5

[1] Dead fuel moisture = 8 percent; living fuel moisture = 100 percent.

APPENDIX C
Calculation of Intensity Values

The three intensity values given as outputs by the TI-59 are interrelated and can be derived from each other.

I_R = reaction intensity, Btu/ft^2 · min
I = fireline intensity, Btu/ft · s
H_A = heat per unit area, Btu/ft^2
R = rate of spread,[1] ft/min
t = residence time, min

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

$$H_A = I_R t$$

where t is dependent upon the characteristic surface-area-to-volume ratio of the fuel bed, $\tilde{\sigma}$, ft^{-1} (Rothermel 1972). Thus H_A or I_R can be calculated from the other when the residence time is known.

Anderson (1969) shows how residence time is related to fuel particle size:

$$t = 8d, \text{ min}$$

where d is the fuel particle size (inches), but

$$d = 4/\sigma$$

hence

$$t = 384/\tilde{\sigma}, \text{ min.}$$

Table C-1 gives the characteristic fuel particle sizes and residence times for the 13 NFFL fuel models.

Table C-1.— Fuel particle sizes and residence times for 13 NFFL fuel models

Fuel model	$\tilde{\sigma}$	d	t
	Ft^{-1}	*Inches*	*Min*
1	3500	0.014	0.110
2	2784	.017	.138
3	1500	.032	.256
4	1739	.028	.221
5	1683	.029	.228
6	1564	.031	.246
7	1552	.031	.247
8	1889	.025	.203
9	2484	.019	.155
10	1764	.027	.218
11	1182	.041	.325
12	1145	.042	.335
13	1159	.041	.331

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[1] The output of both the TI-59 CROM and the nomograms is R in ch/h. To convert to ft/min, multiply by 1.1.

APPENDIX D
Correction 1-Hour Dead Fuel Moisture Beyond 2,000 Feet[1]

If the fire location is more than 2,000 ft in elevation above or below the location where weather conditions are known, the procedure described below can be used to calculate fine fuel moisture. It accounts for slope, aspect, and time of year as well as elevation. Caution: this procedure should be used only during the afternoon when there is good heating and no inversion.

Data needed for calculation:

Known weather site	**Projection point**
dry bulb temperature	elevation
1-hour fuel moisture	aspect
elevation	slope
aspect	amount of shade
slope	month
amount of shade	
month	

Procedure

1. Determine the 1-hour timelag fuel moisture at the known weather site using the dead fuel moisture tables in Chapt. II.
2. Use figure D-1 to determine dewpoint at the known weather site.
3. Calculate the dry bulb temperature at the projection point with the following equation. Note that when estimating temperature at a higher elevation, the difference in elevation produces a negative correction and a lower temperature. When estimating temperature at a lower elevation, the difference in elevation produces a positive correction and a warmer temperature. Adherence to the subscript notation produces the correct adjustment.

$$DB_{pp} = DB_s + \left(3.5 \times \frac{E_s - E_{pp}}{1000}\right)$$

where

DB_{pp} = dry bulb temperature at the projection point
DB_s = dry bulb temperature at the known weather site
E_s = elevation at the known weather site
E_{pp} = elevation at the projection point.

4. Calculate dewpoint at the projection point with the following equation. Adherence to the subscript notation produces the correct adjustment just as it does for temperature.

$$DP_{pp} = DP_s + \left(1.1 \times \frac{E_s - E_{pp}}{1000}\right)$$

where

DP_{pp} = dewpoint at the projection point
DP_s = dewpoint at the known weather site
E_s = elevation at the known weather site
E_{pp} = elevation at the projection point.

5. Use figure D-1 to determine 1-hour timelag fuel moisture at the projection point (uncorrected for effect of solar radiation). See example following.
6. Use table D-1 to correct for solar radiation by determining the fuel moisture correction value at the projection point. Add this correction to the uncorrected 1-hour TL FM obtained in step 4.

Enter the final value on the fire behavior worksheet, line 7.

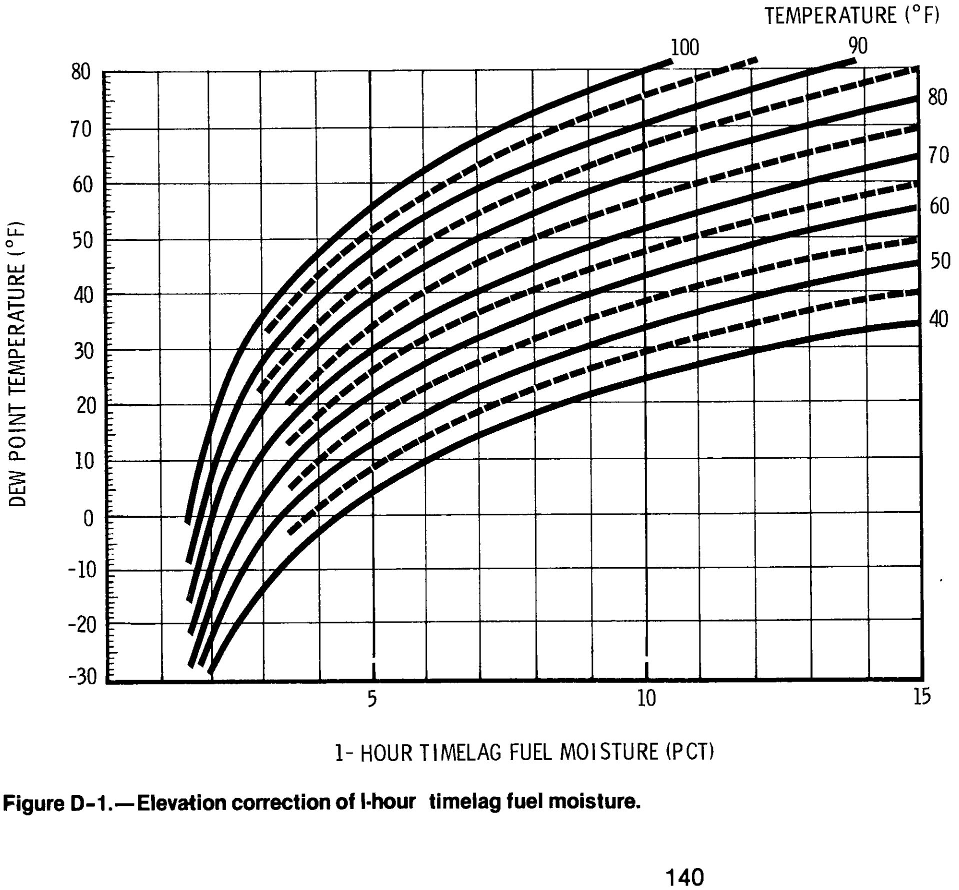

Figure D-1.—Elevation correction of l-hour timelag fuel moisture.

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[1] These procedures are cumbersome for field use, but are included for the serious student of fire behavior. The method was developed by Jack Cohen while working at the Northern Forest Fire Laboratory.

Table D-1.— Fuel moisture correction for aspect, slope, time of year, and canopy cover

Aspect	Slope	May June July	Feb Mar Apr Aug Sept Oct	Nov Dec Jan
		Canopy Less than 50 Percent		
N	0 – 30%	1	2	4
	31% plus	2	3	5
E	0 – 30%	1	2	4
	31% plus	3	4	5
S	0 – 30%	1	2	4
	31% plus	1	2	3
W	0 – 30%	1	2	4
	31% plus	0	1	3
		Canopy 50 Percent or More		
N		4	5	5
E		4	5	5
S		4	4	5
W		4	4	5

Example

Determine the 1-hour timelag fuel moisture on a fire given the data at the lookout tower on a warm afternoon with good atmospheric mixing.

Known weather site		**Projection point**	
1-hour TL FM	= 11%	elevation	= 3,500 ft
dry bulb temp.	= 60° F	aspect	= north
elevation	= 7,000 ft	amount of shade	= shaded
aspect	= south	slope	= 30%
slope	= 30%	month	= July
amount of shade	= exposed		
month	= July		

1. $DP_s = 44° F$

2. $$DB_{pp} = 60 + \left(3.5 \times \frac{7000\text{–}3500}{1000}\right)$$

$$= 60 + (3.5 \times 3.5)$$

$$= 72° F$$

3. $$DP_{pp} = 44 + \left(1.1 \times \frac{7000\text{–}3500}{1000}\right)$$

$$= 44 + (1.1 \times 3.5)$$

$$= 48° F$$

4. Uncorrected 1-hour TL FM at projection point is 9%.
5. Correction for the projection point = 4.
6. 9 + 4 = 13 (enter on line 7 of worksheet). In this case the fuel moisture decreased 2% due to elevation correction but increased 4% due to shading.

APPENDIX E
Ignition Component[1]

Many ignitions do not survive to become detectable fires. The ignition component of the National Fire Danger Rating System (Deeming and others 1977) was developed to identify fuel and weather conditions that would cause a fire to sustain itself long enough to be detectable. As conditions promote an increasing rate of spread, the ignition component increases until every ignition survives to become a detectable fire. Ignition component (IC) is always less than or equal to the probability of ignition (P(I)). Ignition component is an output of the fire behavior program of the TI-59 equipped with an NFDR/Fire Behavior CROM. Consider ignition component to be the probability, expressed as a percentage, that a firebrand will cause a detectable fire. To obtain maximum confidence, ignition component should be calibrated to the fuels and conditions of an area. Although IC does not include a factor to account for the number of ignition sources (firebrands), it generally relates to fire occurrence. A cross plot between number of detected fires and ignition component for a particular fuel model will provide the calibration. This should be done with historical data. Ignition component is more suited for planning purposes. It is recommended that probability of ignition be used during operations on wildfires and prescribed fires where the production of firebrands is probable and ignitions may hold over for a period of time before conditions change and cause them to become detectable fires.

APPENDIX F
Fire Intensity Required to Cause Crown Combustion

Martin E. Alexander developed the enclosed graph (fig. F-1), which identifies the surface fireline intensity necessary to cause tree crown combustion based upon the height to the live crown base and the foliar moisture content of the tree crowns. This is as yet unpublished. Foliar moisture content of conifers is obtainable from the literature.

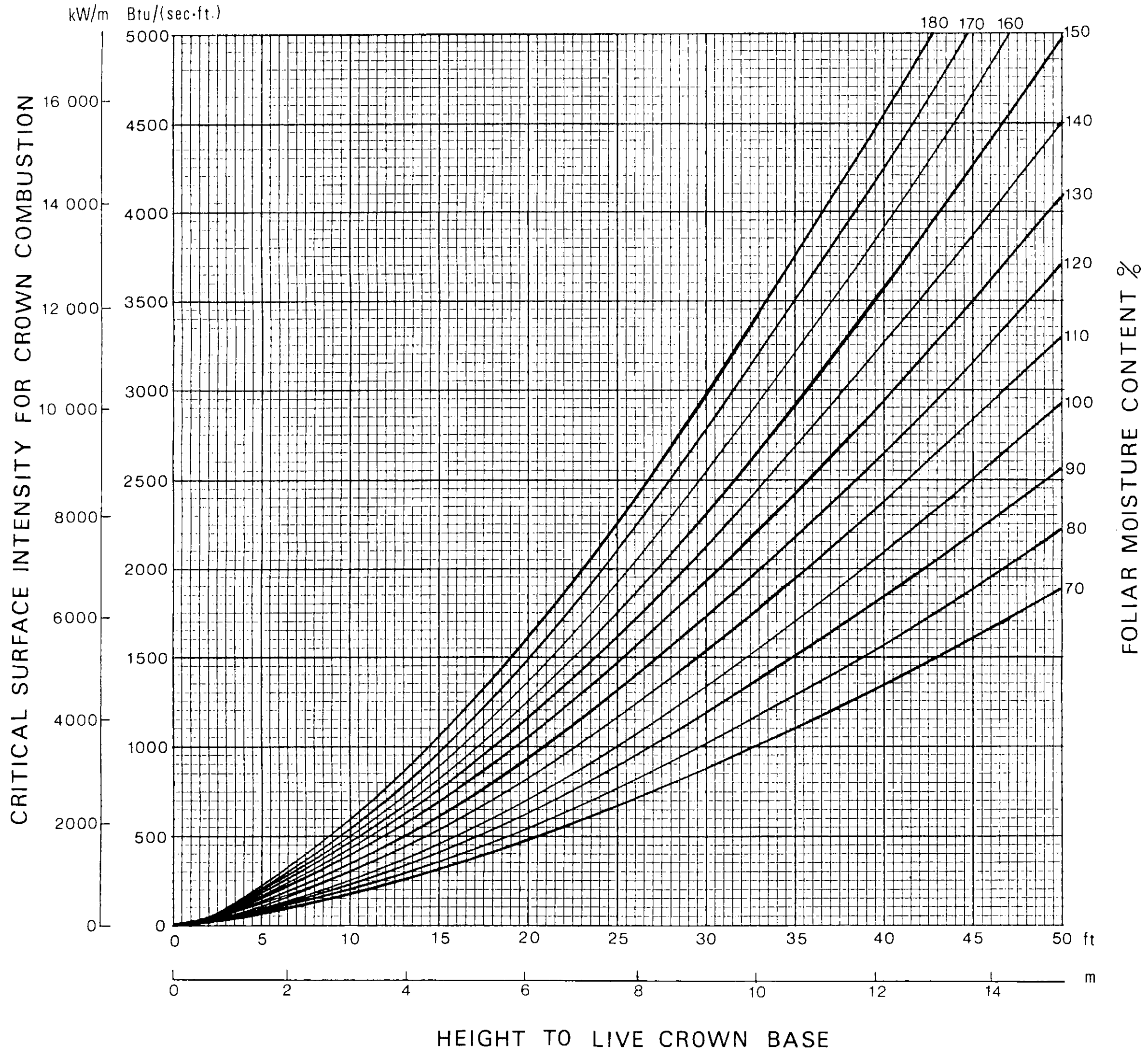

Figure F-1.—Surface intensity required for crown combustion.

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[1] Explanation of ignition component from lesson plan material developed by Pat Andrews.

APPENDIX G
Fire Example - Blackfoot Fire

This example is based on the Cabin Fire which burned in the Scapegoat Wilderness Area in northwestern Montana in August 1979. It has been adapted from a simulated fire exercise taught during FBO training by Ron Prichard. (Ron is an FBO on a Class I team in Region 1.) The purpose of this example is to illustrate how an FBO operates in a fire situation, and how the predictions are used by the fire staff. Examples of briefings and fire behavior forecasts are given along with strategy briefings prepared by other fire staff officers.

Blackfoot Fire - Exercises
EXERCISE 1
Mobilization, August 5, 1979

Situation

You have been called to the Missoula Aerial Fire Depot, arriving at 2100 hours on Saturday, August 4, 1979, to await the arrival of the remainder of the fire overhead team to which you are assigned. All members are expected to arrive in Missoula by 2330 hours, then transportation has been arranged to bus your team to a staging area near the fire. Missoula Aerial Fire Depot is headquarters of the regional fire coordinator and a smokejumper base. Missoula also is headquarters for the Lolo National Forest, on which this fire is burning. The National Weather Service office is located at the Missoula airport, and fire weather meteorologists are available at this facility. You are able to learn the location of the fire (approximately 60 air miles northwest of Missoula) and that it started earlier today from an abandoned campfire. The fire is burning in the Scapegoat Wilderness Area, and the nearest road is approximately 10 miles by trail. Eight smokejumpers were dispatched to the fire after discovery, but were unable to jump because of strong winds in the area. They reported that the fire was burning very hot in mature timber and ground fuels. It appeared to be 125 to 150 acres in size at 1600 hours when the jumpers departed the fire area. A 20-person district crew was dispatched to the fire at 1545 hours, but no word has been received of their arrival or effectiveness on the fire.

Assignment

You are an FBO with the overhead team assigned to this fire.

1. What will you do, if anything, while waiting arrival of your team members in Missoula? In brief outline form, write the actions you would take to prepare for your assignment.

Solution Example

1. Locate fire from best information available, using whatever map can be found. If possible determine forest, district, legal description, physical features, elevation, etc.
2. Try to determine location and manning status of lookouts in the area. (May be able to contact lookouts by radio.)
3. Call Weather Service for local general weather conditions and forecasts. Talk with person on duty. Identify yourself, explain your need for information, pass along fire location and elevation (as accurately as possible), and let him know you will be requesting spot weather forecasts for the fire area. Ask what time daily general fire weather forecasts are available.
4. If possible, secure a topographic map of the area and mark fire's location using best intelligence available. Slopes may be calculated for terrain around the fire's location.
5. Discuss local wind and weather patterns with people familiar with that area. Determine if local fire management officer or other knowledgeable person is available to interview regarding the area. Learn as much as possible about the fuels.
6. Determine availability of mobile or portable fire weather station and meteorologist. Ask for assignment to your fire if you can determine need without first visiting fire.
7. Take the opportunity to charge the batteries in your TI-59 calculator and any other calculator you normally use.
8. If you have access to accurate map or photo plot of fire, and are able to determine how long fire has been active, you may determine rate of spread exhibited by the fire and perhaps direction of run.
9. Try to secure a copy of the NFDRS form D9b from the weather station closest to, or most representative of, the fire.

EXERCISE 2
First day on fire, August 5, 1979

Situation

It is now 0930 on August 5, 1979, and you and your complete fire team have arrived in fire camp and are scheduled to receive a briefing from the initial attack fire boss in about 10 minutes. In addition, the fire weather meteorologist who has been assigned to the fire arrived about an hour ago and will brief you on the weather. Your team is assuming command of the fire at 1030 hours today (1 hour from now) and the plans chief has asked you to determine what the fire is likely to do the remainder of today, until 2000 hours when winds and heating should subside. There is a strategy session scheduled for 1400 hours today that you will be expected to attend and for which you will be expected to provide fire behavior information.

Assignment

After attending the initial briefing:

1. Prepare a brief but complete outline of your actions necessary to provide the needed fire behavior information for today's fire growth and the 1400 hour strategy session.
2. Make a projection of fire growth for the remainder of today (from 1000 hours until 2000 hours). Map the expected fire perimeter. Use the manual (nomogram) process for projecting fire growth. Remember that time is short and work with only those projection points you actually need!

BLACKFOOT FIRE
EXERCISE 2
Briefing Material

1. Fire Statistics
   a. Name of fire Blackfoot Fire
   b. Approximate size of fire 400 ac. @ 0600 8/5/79
   Location of fire E. Fork Blackfoot River T23N R10W S34 (provide map)
   c. Time of fire start Est. 1400 hours 8/4/79
   d. General weather Hot, dry; highs mid 80's - R.H. lows 15%; winds WSW with upslope to 15-18 mi/h, erratic at times. Temperature inversion in valleys below 6,000 ft until 1000 hours each day.
   e. Fuels at fire Mature conifer w/brush and ladder fuels on east flank
   ahead of fire same; fuel moisture from Lincoln D9b
   (1400 8/4/79) 10 hr TL = 10% 100 hr TL = 14%
   f. Fire behavior and spread Rapid downwind spread w/crowning and spotting up to 1/4 mile. Fire has burned into brush and ladder fuels on the east flank.
   g. Weather forecast Continued hot and dry with westerly winds to 15 mi/h daily. Temperature inversion below 6000 ft until 1000 hours.
   h. Is it a tanker show? Ground No Air Yes
   i. Is it a helicopter show? Yes
   j. Anchor points West flank at river near point of origin.
   k. Line held Approx. 20 chains constructed and held.
   l. Natural barriers None present to stop fire.
   m. Camp location 1/2 mi NW of origin in Sec. 28 (see map) elev. 5660 ft.
   n. Other fires on forest 2 lightning starts on 8/4—both contained.
   o. Present priority of this fire No. 1 on Forest, high Regional priority
2. Delegations and Assignments
   a. Initial attack fire boss Smokey Burns
   b. Forest Supervisor Rep. Sam Brown
   c. District Ranger Rep. Larry Fellows
   d. Resource advisor(s) Sharon Biggs
3. Local Fire Policy Standard policy, minimum use of mechanical equipment due to Wilderness. Least cost control appropriate with resource values at risk.
4. Resource and Development Values Main line trail up valley is heavily used by stock and hikers. Six native timber bridges on trail in vicinity of fire with estimated replacement value of $120,000.00
5. Control Objectives Prevent spread north into main Blackfoot River drainage. Limit eastward spread to avoid burning valuable wildlife habitat in the upper East Fork drainage.
6. Legal Considerations Private land SW of fire in Sec. 5 (approx. 1 mile) Investigation presently underway into cause of fire.
7. Pre-attack plans? Yes No X
8. Local Hazards Occasional grizzly bear, moose with calves, some steep terrain with rolling rocks.
9. Local Political Considerations Classified wilderness area. Minimum of mechanized equipment use and site alteration. Area is frequented by many national conservation/preservation groups.
10. Other agencies assigned None at present. National Guard requested for air support. (cargo drops)
11. Manpower on Fire 20 person District crew. 14 organized crews ordered, ETA 1400 hours 8/5/79
12. Equipment on Fire 1 - 206 helicopter, handtools. (2 short strings mules ordered, ETA 1400 hours 8/5/79)
13. Land Status All National Forest lands
14. Rehabilitation Policies Waterbar all control lines, seed disturbed areas with mixture provided by District, lop and scatter limbs and other slash created outside firelines.
15. Communications Fire net (Tach 2). Forest radio for outside communications. (ch1 direct - ch2 repeater)
16. Other:

At time of discovery, winds of 40 mi/h were estimated on the fire, caused by passage of weak low pressure system. Winds began to subside near 1800 hours last night and have returned to normal daily patterns common for this time of year. During initial run of fire, crowns were consumed in some areas, spotting was observed for an estimated 1/2 mile, and rates of spread were estimated at near 40 chains per hour through the mature timber stands. Fire remained on the ground and has traveled at much slower rate during the hours of darkness last night. Islands of unburned fuel remain in the area where fire missed or didn't enter the crowns as ground fuels were consumed.

Morrell Lookout, located 24 miles west of the fire at 7,700 feet, has been providing weather observations during the day on a 2-hour schedule. He can be reached by Forest net radio.

Summary of Fuel Conditions

In the old burn (see fuels map), 75 percent of the area is covered with brush approximately 2 ft in height, with very little dead material present. Foliage is not highly flammable. Twenty-five percent of the area is covered by short needle conifer reproduction thickets up to 25 ft in height, with branches near to the ground. These closed areas of reproduction have shaded out the brush from the understory, leaving a needle layer and a sparse herbaceous component which is carrying the fire. Thickets vary in size from a few feet across to a quarter of an acre, with occasional single trees surrounded by brush. Occasionally, fire will enter crowns of conifer reproduction, causing torching and spotting. A few veteran Douglas-fir trees that survived the earlier fire are scattered throughout the area.

In the grassy parks on the ridges and upper slopes (see fuels map), cover is short grass up to 18 inches in height growing under a sparse tree cover. Grass fuels are less than 30 percent shaded by the overstory trees. Some litter and short brush is present in areas, but is not heavy.

The remainder of the area is covered by a mixed stand of conifers that are mature to overmature. Species include DF, L, LPP, and AF, S at higher elevations. Medium to heavy loadings of dead and down fuels are present under the overstory trees. The dominant trees (DF and L) are generally 90 to 120 ft tall and up to 24 inches in diameter.

Summary of Weather Observations from Morrell Lookout

Date	Time	D.B. temp. (°F)	R.H. (%)	Winds (mi/h)
Aug. 4, 1979	1400	81	19	SW @ 30 with gusts to 45
	1600	81	18	SW @ 35 with gusts to near 50
	1800	79	22	SW @ 22 with occasional stronger gusts
	2200	72	26	WSW @ 8
Aug. 5, 1979	0600	46	44	Calm

WEATHER FORECAST

NOAA WEATHER SERVICE
Missoula Portable Weather Unit
Forecaster: Dave Goens

FORECAST #1
Blackfoot Fire Camp
0930 m.s.t. 8/5/79

DISCUSSION:

Weak pressure field over the Pacific Northwest. Weather pattern is very stable with no important changes foreseen. Temperature inversions will occur in valleys below 6,000 ft until 1000 hours daily.

DAY SHIFT, Monday, Aug. 5

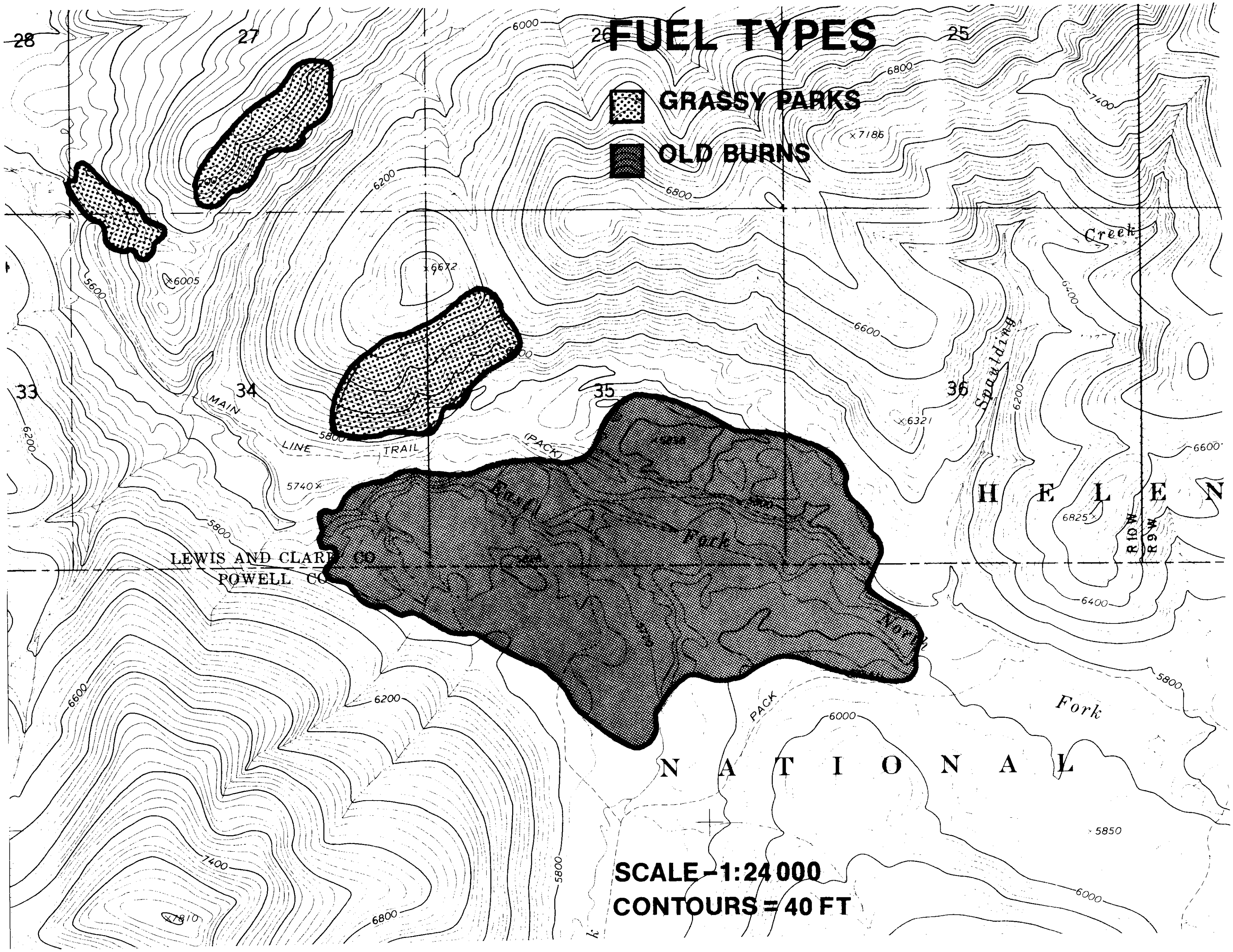
Little change today. High temperature 88° F at fire camp and along the lower slopes, 80° F near the ridgeline, minimum humidity 15 percent lower slopes, 20 percent upper slopes. Winds SW with up-canyon/upslope 5 to 10 mi/h by 1100, increasing to 10 to 15 mi/h and gusty by midafternoon.

OUTLOOK:

Tuesday and Wednesday - Little change from very warm and dry.

NIGHT SHIFT, Monday, Aug. 5

Up-canyon/upslope winds decreasing after 1930. Winds light downslope/down-canyon by 2100. Temperatures cooling into upper 30's at fire camp by sunrise and into mid to upper 40's on the mid and upper slopes. Humidity recovery to 70 percent in drainage bottom and to 45 percent on mid to upper slopes.



FUEL TYPES
▨ GRASSY PARKS
■ OLD BURNS
SCALE-1:24 000
CONTOURS = 40 FT
28
27
26
25
33
34
35
36
6000
6200
6400
6600
6800
7400
5600
5800
5740
6005
6672
7186
6321
6825
5850
7810
MAIN LINE TRAIL
(PACK)
PACK
North Fork
Spaulding Creek
Fork
LEWIS AND CLARK CO
POWELL CO
HELEN
NATIONAL
R10W
R9W

Solution Examples

Assignment 1. Action outline.

1. Try to get aerial reconnaissance of fire, fuels, and terrain in advance of the fire front. Ground reconnaissance of potential trouble spots would be extremely helpful if time permits.
2. Gather as much intelligence as possible from line personnel who have been on the fire (previous winds, fuels, temperatures, behavior, spotting, etc.).
3. Get belt weather kits into hands of line scouts, intelligence officers, or others who can provide observations from the line. (Be sure they know how to use the kit.)
4. Determine need and location of weather watchers and make operational.
5. Put together best possible fire status map from which to make projections.
6. Investigate availability and desirability of infrared mapping flight.
7. Determine location of various fuel types and slopes ahead of fire and select projection points.
8. Determine input variables (values) for projection to be made from 1000 hours to 2000 hours.
9. Prepare briefing for overhead strategy meeting using information developed by use of intelligence at hand.
10. Convert fire behavior terminology into terms that are easily understood by overhead team.
11. Check one more time with meteorologist for any late weather changes just prior to making projections.
12. Make any adjustments in projections, predictions, or briefing made necessary by late changes or added intelligence.
13. Check with the safety officer and the resource coordinator to determine if any special conditions must be stressed in your forecast or briefings.

FINE DEAD FUEL MOISTURE CALCULATIONS

		FM-8	FM-5	
a. Projection point	1	2	2	3
b. Day or night (D/N)	[✓ D]/N	[✓ D]/N	[✓ D]/N	[✓ D]/N
DAY TIME CALCULATIONS				
c. Dry bulb temperature, °F	84	85	88	82
d. Relative humidity, %	17	17	15	20
e. Reference fuel moisture, % (from table A)	2	2	2	3
f. Month	Aug	Aug	Aug	Aug
g. Exposed or shaded (E/S)	E/[✓ S]	E/[✓ S]	[✓ E]/S	E/[✓ S]
h. Time	1400	1400	1400	1400
i. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/[✓ L]/A	B/[✓ L]/A	B/[✓ L]/A	B/[✓ L]/A
j. Aspect	S	-	-	N
k. Slope	31	0	0	31
l. Fuel moisture correction, % (from table B, C, or D)	4	4	1	4
m. Fine dead fuel moisture, % (line e + line l) (to line 7, other side)	6	6	3	7
NIGHT TIME CALCULATIONS				
n. Dry bulb temperature, °F				
o. Relative humidity, %				
p. Reference fuel moisture, % (from table E)				
Use table F only if a strong inversion exists and a correction must be made for elevation or aspect change.				
q. Aspect of projection point				
r. Aspect of site location				
s. Time				
t. Elevation change B = 1000'-2000' below site L = ±1000' of site location A = 1000'-2000' above site	B/L/A	B/L/A	B/L/A	B/L/A
u. Correction for projection point location (from table F)				
v. Correction for site location (L) (from table F)				
w. Fuel moisture correction, % (line u - line v)				
x. Fine dead fuel moisture, % (line p + line w) (to line 7, other side)				

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 2

NAME OF FIRE Blackfoot FIRE BEHAVIOR OFFICER Ron Prichard
DATE 8/5/79 TIME 0930
PROJ. PERIOD DATE 8/5/79 PROJ. TIME FROM 1000 to 2000

Two-fuel-model concept

	INPUT DATA						TI-59 Reg. No.
1	Projection point		1	2	2		
2	Fuel model proportion, %		100	25	75		
3	Fuel model		10	8	5	8&5	
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	2	2	0		60
5	Dry bulb temperature, °F	DB	84	85	88		61
6	Relative humidity, %	RH	17	17	15		62
7	1 H TL FM, % Nomogram use	1H	6	6	3		28
8	10 H TL FM, %	10H	\	\	\		63
9	100 H TL FM, %	100H					30
10	Live fuel moisture, %	LIVE	100	-	100		33
11	20-foot windspeed, mi/h		(12)	(10)	(10)	( )	
12	Wind adjustment factor		(.2)	(.2)	(.25)	( )	
13	Midflame windspeed, mi/h	M WS	2.4	2	2.5		79
14	Maximum slope, %	PCT S	38	0	0		80
15	Projection time, h	PT	10	10	10	10	81
16	Map scale, in/mi	MS					82
17	Map conversion factor, in/ch		.033	.033	.033	.033	
18	Effective windspeed, mi/h		3	2	2.5		

	OUTPUT DATA							
19	Rate of spread, ch/h	[A]	ROS	4.3	.5	12	9.1	88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1350	190	720		90
21	Fireline intensity, Btu/ft/s	[B]	INT	90	1	160		53
22	Flame length, ft	[R/S]	FL	3.8	0.5	4.5		54
23	Spread distance, ch	[C]	SD	43			91	42
24	Map distance, in	[R/S]	MD	1.4			3	43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 2

NAME OF FIRE Blackfoot FIRE BEHAVIOR OFFICER Ron Prichard

DATE 8/5/79 TIME 0930

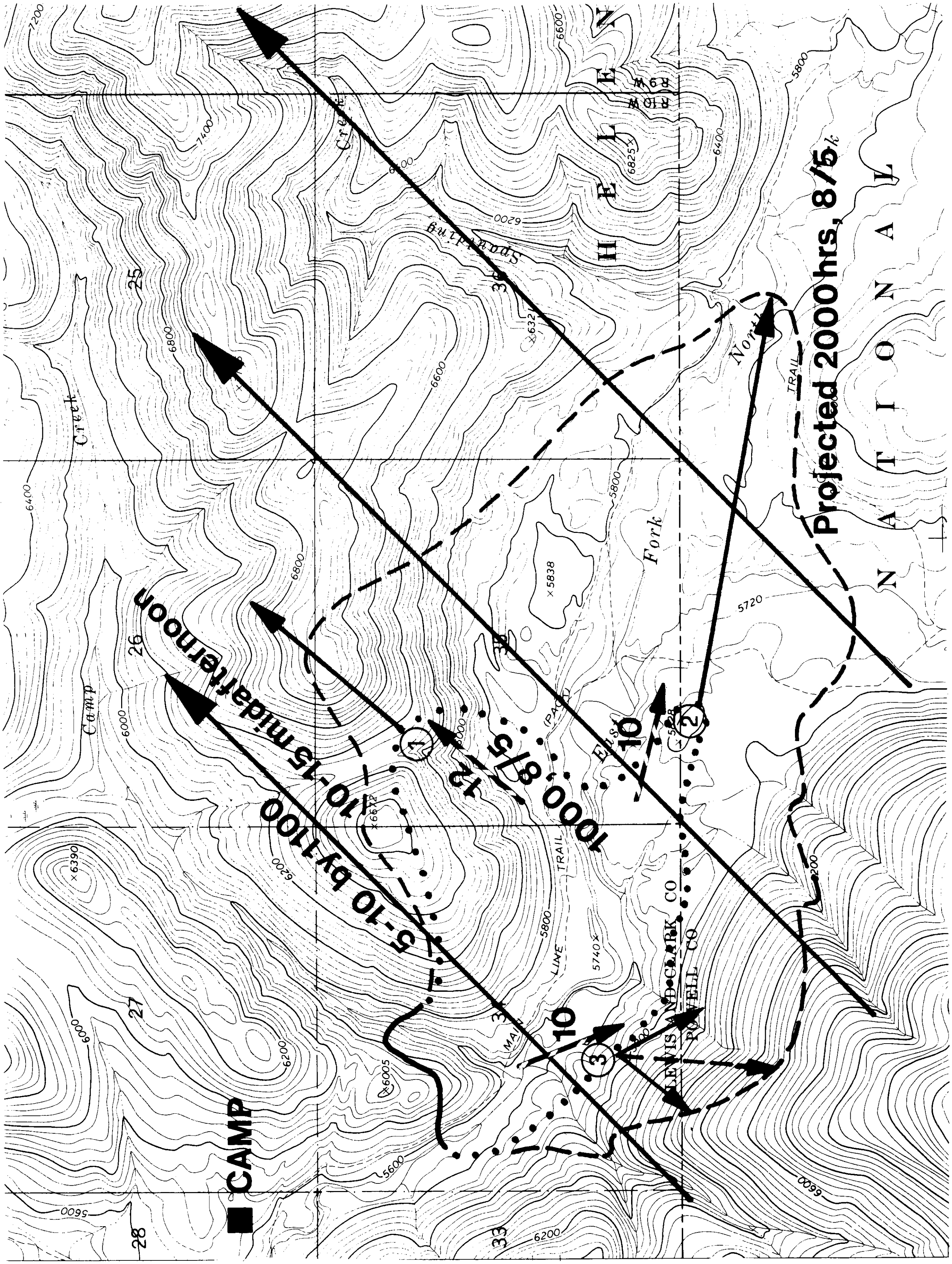
PROJ. PERIOD DATE 8/5/79 PROJ. TIME FROM 1000 to 2000

INPUT DATA

								TI-59 Reg. No.
1	Projection point			3	3			
2	Fuel model proportion, %			100				
3	Fuel model			10				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	2				60
5	Dry bulb temperature, °F		DB	82	Ditto			61
6	Relative humidity, %		RH	20				62
7	1 H TL FM, %	Nomogram use	1H	7				28
8	10 H TL FM, %		10H					63
9	100 H TL FM, %		100H					30
10	Live fuel moisture, %		LIVE	100				33
11	20-foot windspeed, mi/h			(10)	( )	( )	( )	
12	Wind adjustment factor			(.2)	( )	( )	( )	
13	Midflame windspeed, mi/h		M WS	2	0			79
14	Maximum slope, %		PCT S	0	40			80
15	Projection time, h		PT	10				81
16	Map scale, in/mi		MS	.033				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h			2	2			

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	2	2			88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1300	1300			90
21	Fireline intensity, Btu/ft/s	[B]	INT	50	50			53
22	Flame length, ft	[R/S]	FL	2.7	2.7			54
23	Spread distance, ch	[C]	SD	20	20			42
24	Map distance, in	[R/S]	MD	.7	.7			43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52


CAMP
5-10 by 1100
10-15 midafternoon
1000, 8/5
12
10
10
Projected 2000hrs, 8/5
①
②
③
Camp
Creek
Spaulding
North
Fork
TRAIL
MAIN LINE TRAIL
(PACK)
LEWIS AND CLARK CO
POWELL CO
H E L E N A
N A T I O N A L
25
26
27
28
33
35
36

Briefing Example

Overhead Team Briefing Notes 1400 Hours, August 5, 1979

1. *Previous Weather*

Hot, dry, with clear skies. Daytime temperature highs to mid-80's on upper slopes, near 80 in drainage bottoms. Humidities down to 15 percent in valley bottom, near 20 percent on upper slopes. Winds upslope/up-canyon at 10 to 15 mi/h during heat of day, shifting to light downslope by 2100 hours. No change in sight for next several days. Near normal temperature and humidities have prevailed for the past 10 days, with no measurable precipitation. Daily inversion until approximately 1000 hours below 6,000 ft.

2. *Previous Fire Behavior*

A. Fuels.—East flank of fire is advancing through an old burn (25 years old), which contains low brush up to 3 ft tall and patches of reproduction up to 20 ft tall, with branches near the ground to carry fire into crowns. The remainder of the fire is in mature timber, with medium to heavy loading of dead and down timber, which has varying amounts of live green understory containing about 100 percent moisture. Dead fine fuels are near 4 to 6 percent moisture content.

B. Topography.—Broad valley bottom is flat to gently rising in an easterly direction. Slopes above the valley range from 25 to 70 percent, with average slope near 40 to 50 percent. Elevation of the valley bottom is approximately 5,600 ft and top of fire is near 6,800 ft.

C. Weather.—Winds at time of origin (yesterday) were estimated at near 40 mi/h due to passage of a weak low-pressure system. Winds have generally been upslope/up-canyon during the day at speeds of 10 to 15 mi/h, changing to downslope 3 to 8 mi/h after 2100 hours daily.

D. Behavior.—From start of fire until approximately 1800 hours last evening, the fire was very active, being pushed by winds near 40 mi/h. Crowning and spotting to one-half mile was common when fire entered crowns. Fire returned to the ground as winds slackened and evening conditions set in.

3. *Present Fire Status*

Approximately 20 chains of control line has been constructed and held along the northwest flank. Remainder of fire is free to run, and will become active during heat of day. East side of fire will be most active as up-canyon winds blow against the lines.

4. *Predicted Fire Behavior*

A. Fuel.—The fire has entered an old burn (25 years old) on the east flank where brush and ladder fuels are present. Remainder of fire is in mature conifer timber. Fuel moisture will range from 4 to 6 percent for fine dead fuels. Heavy loadings of down dead fuels are present throughout north and south flank areas ahead of fire.

B. Topography.—Most active portion of the fire is in the flats along the river in the old burn. North side of fire is burning on slopes near 50 percent, while south flank is on slopes approximately 40 percent.

C. Weather.—Present most recent weather forecast to overhead team.

D. Behavior (v/s time).—

Intensity - During heat of day intensity will be in a range that is marginal for direct attack with handtools (over 100 Btu/s/ft), especially in the old burn along east side of fire and on south-facing slopes. Flame lengths in these areas will be between 3 and 5 ft. North slopes will experience intensities of approximately 50 Btu/s/ft and flame lengths of 2 to 3 ft during the same period.

Rate of spread - south slopes = 4 chains per hour
old burn = 9 chains per hour
north slopes = 2 chains per hour

Extreme fire behavior - Whirls may develop on lee sides of ridges or at canyon junctions. Expect whirlwinds in the burned area during heat of day. Individual trees or clumps will occasionally torch out where ladder fuels or heavy fuel loadings on the ground allow fire to enter crowns. Spotting may result up to one-fourth mile.

Perimeter - Will continue to increase at a moderate rate until control lines are completed and held.

5. *Strategy Implications (v/s time)*

A. Method of attack.—Direct attack with hand tools should be effective, with some possible difficulties along east flank in old burn. Careful use of retardant or timing attack to quiet periods of activity will be necessary. This portion of the perimeter will be most effectively worked at night when burning conditions are most favorable to control and down-canyon winds are blowing into burn area.

B. Burnout/backfire.—Where unburned fuels remain inside control lines, burnout operations should proceed as quickly as possible to reinforce the narrow hand line. Winds will push fire against lines along the entire eastern flank during the day from 1000 hours until 2000 hours, making burnout very risky in that area; however, favorable winds blowing into the burn will persist along the western flank during this same period.

Wind patterns will change near sunset permitting favorable burnout conditions on all areas of the fire except the western edge from 2100 hours until approximately 0900 hours next day.

Temperature inversion will maintain favorable moisture/temperature conditions on upper slopes throughout the night. Humidities may hamper nighttime burnout in valley bottom.

C. Fireline location.—Would recommend that control lines generally be positioned directly along edge of burn. Across steep draws or chutes, the line should be pulled back to safe and defensible terrain and the intervening fuels burned out as soon as conditions are favorable. Position control lines on backside of ridgecrests where fire is threatening ridgetops. Avoid sharp hooks in line or underslung line.

D. Line standards.—Recommend well-constructed handline 2 to 3 ft in width. Such line should be effective in control if fuels on inside of line are burned out as line progresses or as quickly as favorable conditions exist. Where line is located through ladder fuels, prune low branches from trees as high as can be reached and within 100 ft of line. Avoid placing line through such fuels where practical.

E. Success probability of manpower/equipment.—Good probability of success with ground forces along most of perimeter. May experience difficulty along east flank due to higher intensities and potential for spotting.

F. Air operations.—Nighttime inversion will hold smoke in valleys until 1000 hours each morning, making air operations doubtful prior to 1000 hours. Ridgetop winds will be brisk during day and caution must be exercised at exposed helispots due to low level turbulence.

6. *Safety*

A. Reburn potential.—Areas of unburned fuels inside control lines have been scorched and dried and potential for reburn is moderate to high.

B. Risk locations.—East flank is an old burn. There is a potential for rapid spread, high intensities, and spotting. Know your escape routes!

C. High smoke concentrations.—Smoke will limit visibility to 300–500 yards in valley bottoms below 6,000 ft until 1000 hours each day. East flank of fire will likely remain smoky during day from active fire advance.

D. Reinforcement confidence level.—Feel that crews presently ordered or on the line should be sufficient to complete and hold lines by late tomorrow if present weather remains stable as predicted.

E. Air operations.—See 5-F.

EXERCISE 3

Day shift, August 6, 1979

Situation

It is now 2000 hours on August 5 and the night crews have departed for the line. The day crews being relieved will begin arriving in camp shortly. The fire weather meteorologist has given you an updated forecast for tomorrow, which indicates a possibility of cumulus buildup over the fire by early afternoon tomorrow, along with slightly warmer temperatures. Nighttime temperature inversion will hold smoke in the valleys below 6,000 ft until approximately 1000 hours daily. Line construction has progressed well today and night crews are hopeful of completing burnout in division I and most of division II as well as continuing construction of line along both flanks of the fire.

You have just returned from a helicopter reconnaissance of the fire with the plans chief and the meteorologist, and have helped to update the fire status map to accurately position the fire at 2000 hours. The fire has remained active throughout the day; however, it has not moved as far as earlier projected, due to effective use of helicopter water drops along fire front and on spots ahead of fire.

You must now project the spread of the fire along open portions of the line for tomorrow's day shift plans, working from the position you expect the fire at by tomorrow morning at 0600. The line overhead will be briefed at 0530 in the morning prior to shift change at 0600. You will be expected to present your fire behavior briefing. You must also prepare your fire behavior forecast for tomorrow's day shift plans and turn it in to the plans section by 2130, about 1-1/2 hours from now.

Three divisions of three sectors each are to be manned tomorrow, with divisions I and III lined and improvement and holding actions in progress. Division II will remain open through tonight, and crews will attempt to close that remaining portion of line as early as possible tomorrow.

As was determined in today's strategy session, it will be necessary to accomplish burnout and line improvement as early as possible if hand lines are to hold.

A spot fire was located during your helicopter reconnaissance about 1,000 ft ahead of the main fire on the east flank. It was estimated at less than one-quarter acre and did not appear to be rapidly spreading. It is inside and near the edge of the old burn in brushy fuels. There are no crews in the vicinity and it is doubtful that any could arrive at the spot before darkness sets in. The line boss is aware of the spot and has ordered helicopter water drops to be made as needed until darkness falls.

Assignment

1. Using your TI-59 calculator and fire behavior CROM, as well as all other information available to you, project the fire's spread during tomorrow's day shift from 0600 until 1800 hours. Prepare a map on which you have plotted fire spread. CAUTION: Have you used all the aids or intelligence available to you?
2. Prepare a fire behavior forecast for tomorrow's day shift (August 6), paying particular attention to strategies formulated by the overhead team.
3. Prepare a line briefing summary to be presented to line overhead before going on shift at 0530 in the morning. Pay particular attention to strategy implications. You may wish to use the fire characteristics chart to help make your points.

Summary of Weather Observations from Morrell Lookout

Date	Time	D.B. temp. (°F)	R.H. (%)	Winds (mi/h)
Aug. 5, 1979	1200	72	22	SW @ 8
	1400	82	18	SW @ 10 to 12
	1600	85	16	WSW @ 12 to 15 with gusts to 18
	1800	80	21	SW @10

WEATHER FORECAST

Day shift, August 6, 1979

NATIONAL WEATHER SERVICE, Missoula, Mont.
FORECASTER: Dave Goens
DATE AND TIME: August 5, 1979, 2100 (Tuesday)

FIRE: Blackfoot
LOCATION: Scapegoat Wilderness, Mont.
FORECAST NO.: 2

DISCUSSION: Upper level disturbance has passed east of the fire area. Pressures are building, winds are lighter, and conditions stabililizing. Look for fair skies and a little lighter winds. Daily inversion below 6,000 ft will persist until 1000 hours.

DAY SHIFT: August 6

WEATHER: Fair, with scattered cumulus buildup in vicinity of fire during the afternoon.

TEMPERATURE: Lower slopes near 90° F
Upper slopes near 85° F

HUMIDITY: Minimum near 12 to 15%

RIDGETOP WIND: SW 10 to 15 mi/h

SLOPE WINDS: Upslope by 1030 hours, 5 to 8 mi/h, chance of some gusts to near 15 to 18 mi/h mid- to late afternoon.

OUTLOOK FOR NEXT SHIFT: Night shift August 6
Clear with light winds and fair to good humidity recovery.

FURTHER OUTLOOK: (36 to 48 hours) Dry with above normal temperatures.

Summary of Strategy Session, August 5, 1979

Following are key points agreed to by the fire overhead team at the August 5, 1979, strategy session:

1. Continue to drive line rapidly in both directions from anchor point near the fire's origin. Work a pincer attack to cut off head of fire as flanking lines are completed.
2. Use direct attack in all cases where it is safe and effective.
3. Only hand lines will be used due to wilderness designation. Lines will be dug to bare soil and must be 2 to 3 ft in width.
4. Line improvement, particularly burnout, *must* proceed as quickly as possible after line is constructed. Take advantage of most favorable conditions to line and burnout difficult areas of the fire.
5. Plans section must analyze crew capabilities and condition to use most experienced and rested crews to drive line and burnout. Other crews will be used to hold constructed line.
6. Retardant will be used sparingly because of cost involved; however, it is available if needed.
7. Aerial and ground reconnaissance of a secondary control line location on the east side of the fire will be made immediately. This location, if satisfactory, will be used if fire overcomes initial containment efforts.
8. Avoid placing line through ladder fuels; however, if necessary, prune lower limbs from trees as high as reachable within 100 ft of the fireline. Do not concentrate pruned branches near fireline.
9. Crews will hike from base camp to the fireline and return using the main line trail through cooled portions of the fire, or along existing fireline. Night shift crews should relieve day shift in time to permit return to camp during daylight.
10. Fire behavior officer must keep a close watch on burnout conditions and keep line people advised of timing and locations where burnout may proceed.

FIRE BEHAVIOR WORKSHEET

Sheet 1 of 3

NAME OF FIRE Blackfoot FIRE BEHAVIOR OFFICER Ron Prichard

DATE 8/5/79 TIME 2000

PROJ. PERIOD DATE 8/6/79 PROJ. TIME FROM 0600 to 1100

				Two-fuel-model concept				TI-59 Reg. No.
	INPUT DATA							
1	Projection point			1	1			
2	Fuel model proportion, %			25	75			
3	Fuel model			8	5	8&5		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE*	3				60
5	Dry bulb temperature, °F		DB	60				61
6	Relative humidity, %		RH	50	Ditto			62
7	1 H TL FM, % from TI-59		1H	9.6				28
8	10 H TL FM, % 1.5% wetter than afternoon		10H	5				63
9	100 H TL FM, %		100H	6				30
10	Live fuel moisture, %		LIVE	–	100			33
11	20-foot windspeed, mi/h			(0)	(0)	( )	( )	
12	Wind adjustment factor			(–)	(–)	( )	( )	
13	Midflame windspeed, mi/h		M WS	0				79
14	Maximum slope, %		PCT S	0				80
15	Projection time, h		PT	5	5	5		81
16	Map scale, in/mi		MS	2.64				82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h			0				
	OUTPUT DATA							
19	Rate of spread, ch/h	[A]	ROS	.2	.4	.35		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	167	227			90
21	Fireline intensity, Btu/ft/s	[B]	INT	1	2			53
22	Flame length, ft	[R/S]	FL	.3	1			54
23	Spread distance, ch	[C]	SD	.9	1.9	1.8		42
24	Map distance, in	[R/S]	MD			.1		43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

* Shade 3 and wind zero because of inversion and smoke.
Temp. est. 60° and RH 50% average for the projection period.

FIRE BEHAVIOR WORKSHEET

Sheet 2 of 3

NAME OF FIRE Blackfoot

FIRE BEHAVIOR OFFICER Ron Prichard

DATE 8/5/79

TIME 2000

PROJ. PERIOD DATE 8/6/79

PROJ. TIME FROM 1100 to 1400

INPUT DATA

Two-fuel-model- concept

								TI-59 Reg. No.
1	Projection point			2	2			
2	Fuel model proportion, %			25	75			
3	Fuel model			8	5	8&5		
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)		SHADE	2	0			60
5	Dry bulb temperature, °F		DB	90				61
6	Relative humidity, %		RH	12				62
7	1 H TL FM, %	Used	1H	2.6	2.0			28
8	10 H TL FM, %	TI-59	10H	3.2	2.5			63
9	100 H TL FM, %		100H	5	-			30
10	Live fuel moisture, %		LIVE	-	100			33
11	20-foot windspeed, mi/h			(15)	(15)	( )	( )	
12	Wind adjustment factor			(.2)	(.25)	( )	( )	
13	Midflame windspeed, mi/h		M WS	3	3.8			79
14	Maximum slope, %		PCT S	0	0			80
15	Projection time, h		PT	3	3	3		81
16	Map scale, in/mi		MS	2.64	2.64			82
17	Map conversion factor, in/ch							
18	Effective windspeed, mi/h							

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	2	21	16		88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	232	775			90
21	Fireline intensity, Btu/ft/s	[B]	INT	6	294			53
22	Flame length, ft	[R/S]	FL	1	6			54
23	Spread distance, ch	[C]	SD			49		42
24	Map distance, in	[R/S]	MD			1.6		43
25	Perimeter, ch	[D]	PER					40
26	Area, acres	[R/S]	AREA					89
27	Ignition component, %	[E]	IC					44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR					52

FIRE BEHAVIOR WORKSHEET

Sheet 3 of 3

NAME OF FIRE Blackfoot

FIRE BEHAVIOR OFFICER Ron Prichard

DATE 8/5/79

TIME 2000

PROJ. PERIOD DATE 8/6/79

PROJ. TIME FROM 1400 to 1800

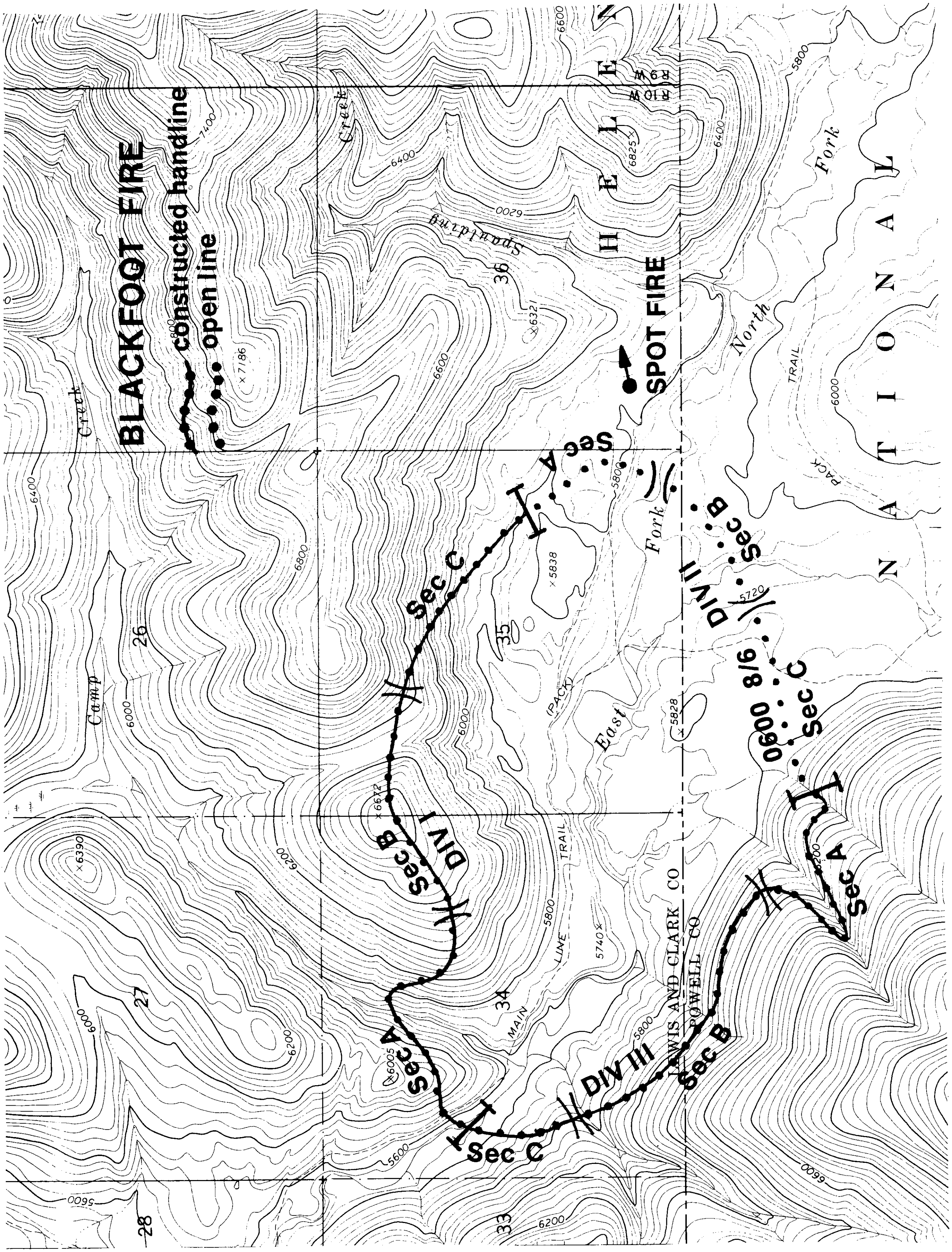
Fire is expected to enter fuel model 10 at 1400.

INPUT DATA

							TI-59 Reg. No.
1	Projection point		3				
2	Fuel model proportion, %		100				
3	Fuel model		10				
4	Shade value (0-10%=0; 10-50%=1 50-90%=2; 90-100%=3)	SHADE	3				60
5	Dry bulb temperature, °F	DB	90				61
6	Relative humidity, %	RH	12				62
7	1 H TL FM, %	1H	2.8				28
8	10 H TL FM, %	10H	3.5				63
9	100 H TL FM, %	100H	5				30
10	Live fuel moisture, %	LIVE	100				33
11	20-foot windspeed, mi/h		(15)	( )	( )	( )	
12	Wind adjustment factor		(.2)	( )	( )	( )	
13	Midflame windspeed, mi/h	M WS	3				79
14	Maximum slope, %	PCT S	0				80
15	Projection time, h	PT	4				81
16	Map scale, in/mi	MS	2.64				82
17	Map conversion factor, in/ch		–				
18	Effective windspeed, mi/h		–				

OUTPUT DATA

19	Rate of spread, ch/h	[A]	ROS	5				88
20	Heat per unit area, Btu/ft^2	[R/S]	H/A	1474				90
21	Fireline intensity, Btu/ft/s	[B]	INT	146				53
22	Flame length, ft	[R/S]	FL	4				54
23	Spread distance, ch	[C]	SD	21.6				42
24	Map distance, in	[R/S]	MD	0.7				43
25	Perimeter, ch	[D]	PER	–				40
26	Area, acres	[R/S]	AREA	–				89
27	Ignition component, %	[E]	IC	42				44
28	Reaction intensity, Btu/ft^2/min	[R/S]	IR	–				52


BLACKFOOT FIRE
constructed handline
open line
SPOT FIRE
DIV I
DIV II
DIV III
Sec A
Sec B
Sec C
Sec A
Sec B
Sec C
Sec A
Sec B
Sec C
Sec A
Sec B
Sec C
0600 8/6
LEWIS AND CLARK CO
POWELL CO
H E L E N
N A T I O N A L
North
Fork
East
Fork
Spaulding
Creek
Camp
Creek
Creek
MAIN
LINE
TRAIL
PACK
TRAIL
(PACK)
TRAIL
R10W
R9W
26
27
28
33
34
35
36
6390
6672
6005
5740
5828
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6321
7186
6825
6000
6200
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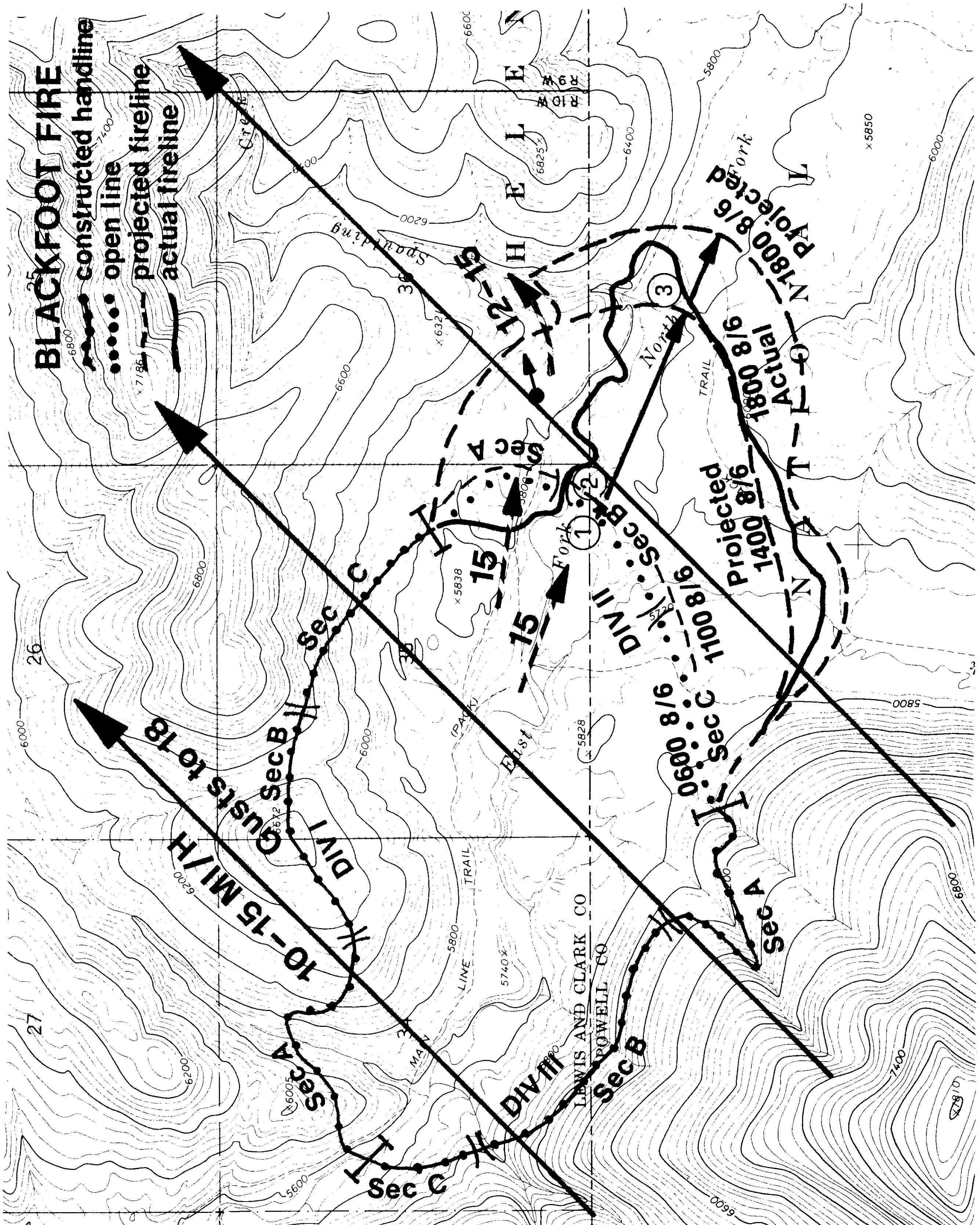
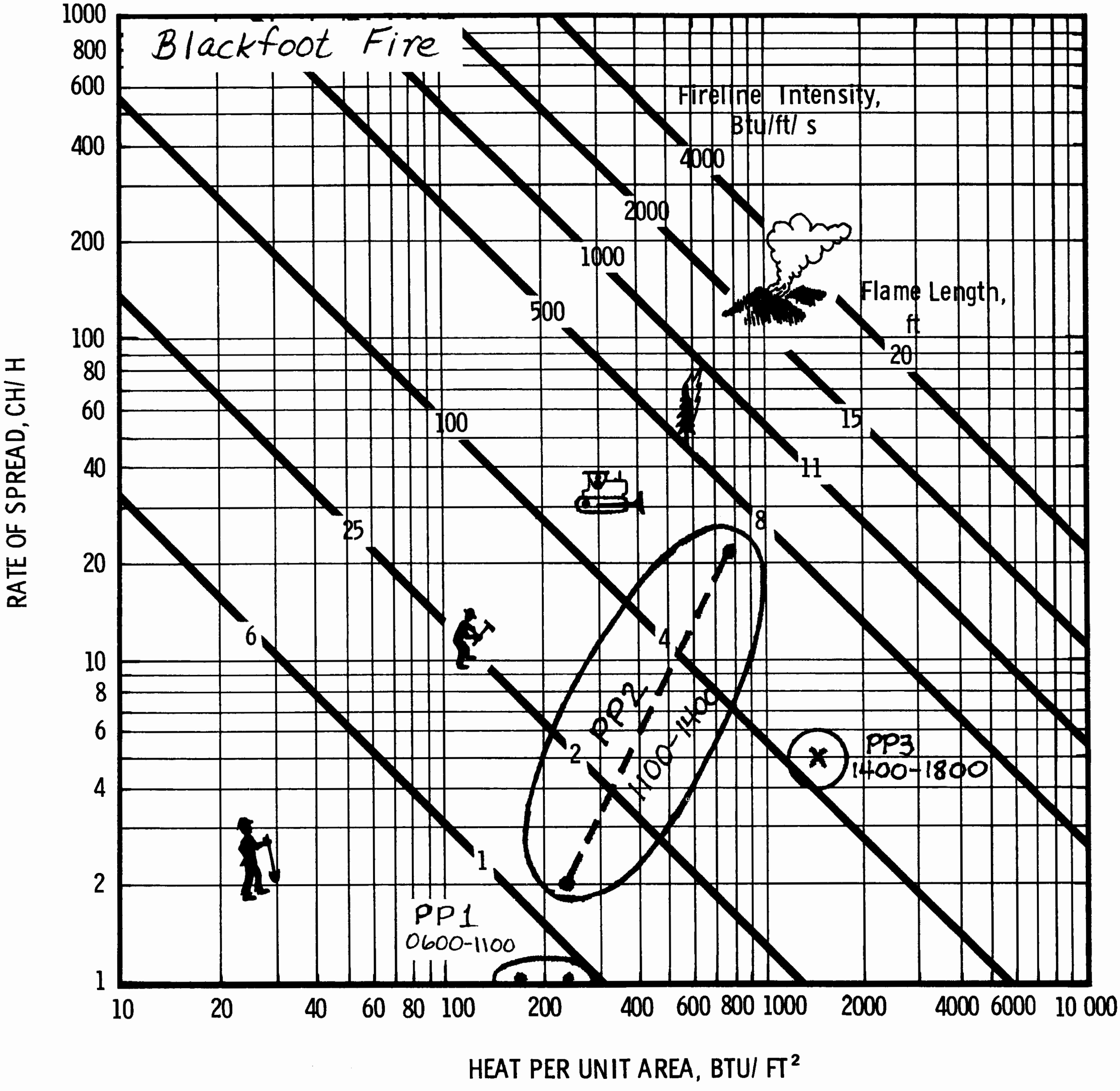
6600


BLACKFOOT FIRE
constructed handline
open line
projected fireline
actual fireline
10-15 MI/H Gusts to 18
DIV I
DIV II
DIV III
Sec A
Sec B
Sec C
0600 8/6
1100 8/6
Projected 1400 8/6
1800 8/6 Actual
1800 8/6 Projected
12-15
15
15
1
2
3
Spaulding Creek
North Fork
East Fork
TRAIL
MAIN LINE TRAIL (PACK)
LEWIS AND CLARK CO
POWELL CO
R10W R9W
25
26
27
28
33
36

FIRE BEHAVIOR

Fire Characteristics Chart
(Logarithmic Scale)



FIRE BEHAVIOR FORECAST NO. 2

Solution Example

NAME OF FIRE: Blackfoot
FOREST: Lolo
TIME AND DATE
FORECAST ISSUED: 2100 hours 8/5/79

PREDICTION FOR: Day SHIFT
SHIFT DATE: August 6, 1979

SIGNED: ______________________
FIRE BEHAVIOR OFFICER

WEATHER SUMMARY: See attached weather report.

Be alert for cumulus buildup in the vicinity of the fire after 1400 hours that may cause strong, gusty, erratic winds. (Morrell Lookout alerted to warn of cumulus buildup.)

FIRE BEHAVIOR:

General: Severe burning conditions continue to exist in the old burn on east side of fire. Very dry fuels will keep fire active in all unlined sectors. High temperatures and low relative humidity increase occurrence of spotting potential to one-fourth mile. Whirls likely to form on lee side of ridges and in blackened area during late afternoon-early evening. Fuels inside line will continue to make uphill runs in draws and on steep slopes. Flame lengths of 6 ft will be common in brush fuels along east flank until old burn is completely consumed by approximately 1400 hours. Potential for reburn is moderate to high in areas where crowns are scorched by ground fire. ROS up to 21 chains/hour in brush fuels.

Specific:

Division I.—Be alert for spots across line. Favorable burnout conditions above inversion (approx. 6,000 ft) until 1100 hours when developing upslope winds will call for extreme caution if burnout is to proceed. Below 6,000 ft in sector C high humidity will hamper burnout until inversion breaks about 1000 hours, then increasing up-canyon winds will make burnout risky. Be alert for wind shift.

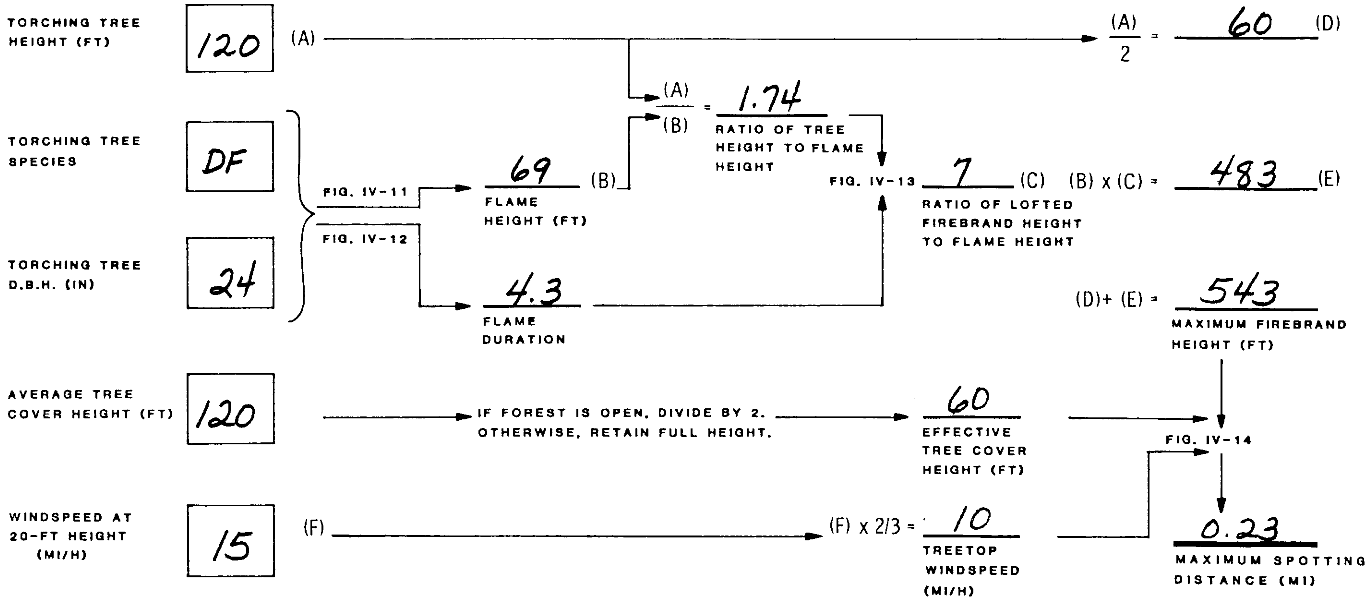
Division II.—Ladder fuels will cause torching, with spotting to one-fourth mile. Fire will be intense in brush fuels, with flame lengths of 6 ft; too hot for crews to work near fire. ROS up to 21 chains/hour will occur. Position lookouts to alert crews if safety is threatened. Unfavorable conditions in all sectors for entire shift due to high RH until inversion is lifted by up-canyon winds which will then push fire against control lines. Where burnout must proceed, use extreme caution to avoid creating large amounts of heat near the line.

Division III.—Favorable burnout conditions above 6,000 ft until 1100 hours. Portions of sectors B and C where burnout remains to be done below 6,000 ft will have favorable conditions after inversion is broken about 1000–1100 hours when winds will begin to blow into fire or parallel to control line. Burnout should be complete by 1300 hours to avoid strong afternoon upslope winds. Avoid generating large amounts of heat in draws in sector A. Watch for spots above these draws.

AIR OPERATIONS: Temperature inversions will hold smoke in valleys below 6,000 ft until 1000 hours stopping low level operations and helicopter access to base camp. Ridgetop winds of 15 to 20 mi/h will cause low level turbulence at ridgetop helispots.

SAFETY: Potential for extreme fire behavior throughout day. Be sure of escape routes and post lookouts. Watch for rolling debris and falling snags.

SINGLE TORCHING TREE, FLAT TERRAIN, UNIFORM FOREST COVER



TORCHING TREE HEIGHT (FT) 120 (A)

$\frac{(A)}{2}$ = 60 (D)

$\frac{(A)}{(B)}$ = 1.74 RATIO OF TREE HEIGHT TO FLAME HEIGHT

TORCHING TREE SPECIES DF

TORCHING TREE D.B.H. (IN) 24

FIG. IV-11 → 69 (B) FLAME HEIGHT (FT)

FIG. IV-12 → 4.3 FLAME DURATION

FIG. IV-13 7 (C) RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT

(B) x (C) = 483 (E)

(D)+ (E) = 543 MAXIMUM FIREBRAND HEIGHT (FT)

AVERAGE TREE COVER HEIGHT (FT) 120 → IF FOREST IS OPEN, DIVIDE BY 2. OTHERWISE, RETAIN FULL HEIGHT. → 60 EFFECTIVE TREE COVER HEIGHT (FT)

FIG. IV-14

WINDSPEED AT 20-FT HEIGHT (MI/H) 15 (F) → (F) x 2/3 = 10 TREETOP WINDSPEED (MI/H)

0.23 MAXIMUM SPOTTING DISTANCE (MI)

CONDITIONS IN FIREBRAND LANDING AREA:

FINE FUEL MOISTURE (%)________ AIR TEMPERATURE (°F)________ SHADING (%)________ TABLE IV-4________ ________ PROBABILITY OF IGNITION (%)

Shift Briefing for Line Overhead Example

Day shift, August 6, 1979

I. What has fire done since you left line?
Fire has been relatively quiet during the night with no major runs or unexpected behavior due to cold temperatures, humidities up to 70 percent, and favorable night winds blowing into the fire on the open east flank.

II. Reasons for previous behavior.
After initial run of fire, which was pushed by 40 mi/h winds, the rates of spread have decreased due to return of more normal wind velocities of 10 to 15 mi/h during the day. High temperatures and low humidities, resulting in very low fuel moistures, have made conditions favorable for continued spread. The fire has been most active along the east flank where it is burning in flashy brush fuels, with ladder fuels causing some spotting ahead of the fire. This area of the fire is also affected by strong up-canyon winds during the heat of the day.

III. Weather
Continuation of hot, dry weather. Below normal precipitation for the past 6 weeks, with no moisture in sight. (Read today's weather prediction.)

IV. Fuels
Division II is presently burning in an old burn with 75 percent brush and 25 percent short needle conifer saplings and poles up to 25 ft in height. The unburned remnants of this old burn will be consumed by 1400 hours today when the fire will enter a mature stand of Douglas-fir, larch, and lodgepole. The fire will be much easier to contain in the mature timber stands because intensities and spread rate will be reduced to levels that will permit direct attack this afternoon. Fuel moisture from the NFDRS D9b form for the AFFIRMS station at Lincoln, Mont. (18 miles south) are:

Saturday, August 4, 1979:
1 hr TL = 6%
10 hr TL = 10% = 12% at fire
1,000 hr TL = 14% = 16% at fire

V. Topography
Most active area of the fire is presently confined to flat valley bottom, but steeper side slopes up to 60 percent surround the fire. The narrow steep-sided canyon of Spaulding Creek is in the path of the fire about one-half mile ahead.

VI. What is fire forecasted to do and when?
(Refer to today's fire behavior broadcast.)

VII. Safety

A. Extreme fire behavior potential

1. Signals to watch for:
   - A shift of wind direction
   - An increase in windspeed
   - Downhill line construction
   - Working near heads of draws or brushy ravines
   - Spots across the line
   - Reburn of scorched fuels within the fireline
   - Whirlwinds on lee side of ridges or in the blackened area

B. Expectations of line overhead (what help do I need?)
- Contact FBO to report unusual or severe behavior, wind shifts, cumulus buildup, etc. Intelligence officer and line scouts will be asked to take weather observations on the fire line and radio them to the FBO or Plans.
- Need feedback from line people on accuracy of weather and fire behavior predictions.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983—676-032/1004 REGION No. 8

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

This manual documents procedures for estimating the rate of forward spread, intensity, flame length, and size of fires burning in forests and rangelands. Contains instructions for obtaining fuel and weather data, calculating fire behavior, and interpreting the results for application to actual fire problems.

KEYWORDS: fire behavior prediction, fire spread, fire intensity, fire growth

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with the University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)