FIRE BEHAVIOR

In Northern Rocky Mountain Forests

by

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- Northern -
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PREFACE

Although forestry dates back hundreds of years, organized forest fire research has been underway less than 30 years. During much of this time the major efforts have been devoted to studies of fire behavior or closely allied fields. As a result, much has been learned about how fires act, in spite of the relatively short period of organized effort. Knowledge stemming from many research projects, plus the experience gained from the control of thousands of fires, provides a good foundation for a general understanding of the complex subject.

The main purpose of this publication is to summarize the most important aspects of fire behavior as we now know them. The author recognizes that there are still many unknowns in the behavior of forest and range fires. These unknowns will be the targets of future research. In the meantime it is important that the best available information on fire behavior be placed in the hands of the men who must carry on the vital task of fire control.

In many respects this is a progress report on fire behavior research. A large part of the publication interprets the significance of past research results to an understanding of how fires start and spread under various forest conditions. Other parts of the publication reflect the results of recent research. Some of the information on fuel classification, burning index variations, topographic influences, and rate-of-spread estimates is reported for the first time.

Four major phases of fire research at the Northern Rocky Mountain Forest and Range Experiment Station provided basic knowledge which makes this publication possible. The development of methods for measuring fire weather and rating forest inflammability with a burning index meter fostered systematic evaluation of weather influence on fire behavior. The fuel classification system provided an important basis for analyzing the rate of spread of fires. Studies of fire weather at various positions and aspects at the Priest River Experimental Forest contributed essential information on topographic influences. Detailed analysis of thousands of reports of actual fires uncovered many key facts and provided a means of testing several basic hypotheses on fire behavior.

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Figure 1. Every forest fire in the beginning is small like this one. Whether it will remain small or "blow up" to burn a large area depends upon the weather, topography, fuel at the site, and effectiveness of action taken to control it.

CHAPTER I. INTRODUCTION

Knowledge of fire behavior is an essential requirement for firefighters. Successful fire control operations depend, first of all, upon the ability of the protection forces to judge where and when fires will start and how they will behave once ignition takes place. Every member of the fire-fighting team from ranger to smokechaser must be able to make reliable estimates of the behavior of fires burning under a wide variety of conditions. These estimates must be good enough to provide the basis for decisions which will lead to fast, efficient, and safe firefighting.

FIRE BEHAVIOR AND SUPPRESSION METHODS

The character and difficulty of the suppression job on every fire depends largely upon the behavior of the fire. The speed, strength, and type of attack are governed by the location of the fire and its reaction to the surrounding environment. Each change in environment may change fire behavior and in turn call for some adjustment in firefighting strategy and techniques. The ability of the men handling the suppression job to evaluate the behavior pattern largely determines the efficiency and economy of the entire firefighting operation.

A primary purpose of evaluating the behavior of every fire is to reduce or prevent unexpected "blowups and runs." A careful check on everything that will affect the behavior of a fire reduces the chances for the "unexpected." When a skilled size-up has been made in advance, the unexpected may become expected and a potential blowup or run may often be anticipated soon enough to be prevented. Effective fire control requires that suppression plans and action be carried out in accordance with continuing estimates and forecasts of what the fire is going to do. Analysis of fire behavior is a basic requirement in firefighting applicable equally to the one-man smokechaser fire or the big fire where hundreds of men are in action.

FIRE BEHAVIOR AND SAFETY

An important reason for understanding fire behavior is to provide safety for the firefighters. Every fire behavior situation calls for specific safety measures. Experience gained from fighting thousands of fires has shown that the suppression job may be accomplished with a reasonable degree of safety. To achieve safety it is highly important that all firefighters have a general knowledge and the leaders of the firefighting forces have a high degree of knowledge of fire behavior.

The most dangerous individual in a suppression organization is usually the man who is afraid of fire. Fear is largely a result of ignorance. Many risks can be eliminated from firefighting if each man knows what to expect the fire to do. The average firefighter need not be an expert on all phases of fire behavior, but he should have a working knowledge of ignition, combustion, and rate of spread of fires burning in forest fuels. Equipped with such basic fire behavior "know-how" the individual firefighter can approach his job without fear and with confidence that he can perform required duties in a safe and efficient manner.

FIRE BEHAVIOR AND THE FOREST MANAGER

In the northern Rocky Mountains fires influence many phases of the forest management job. The behavior of fires is an important factor in the growth, harvesting, and regeneration of forest crops. How often fires occur and how hot they burn affect both the quality and quantity of products harvested from the forest. The forest manager may influence fire behavior by the nature of his operations, especially in timber cutting. When a forest is opened up by thinning or harvesting operations, lower humidities, higher temperatures, and higher wind velocities are created within the stands. Fire behavior is thereby affected. Sometimes the debris remaining after logging constitutes a fuel condition which greatly increases the chance for fires to ignite and burn intensely. For these reasons it is important for forest managers to know fire behavior and to be able to evaluate the influence of forest management operations on it.

JUDGING FIRE BEHAVIOR

Many complex factors influence the ignition, rate of spread, and general behavior of fires. Some of these factors can be measured more or less precisely with instruments. Others do not lend themselves to exact measurements and therefore must be evaluated in general terms. The combined effects of all factors, whether measured precisely or not, determine the behavior of a fire. No single factor, such as wind, steepness of slope, or kind of fuel, will provide the answer to questions of when and where fires will start and how fast they will spread. Likewise, no single instrument or meter will answer these fundamental questions. Therefore it is necessary for the fire control man to develop a system aided by instruments and other guides where available, which will help him evaluate the combined effects of all significant factors influencing fire behavior.

Keen observation is a fundamental requirement in judging fire behavior. Many visible signs are present in the forest to assist the fire control man in arriving at reliable decisions. These include such things as the color of the grass and other annual vegetation, the position of a fire on a slope, the time of day, and the ammount of sunshine filtering through the forest canopy. One of the purposes of this handbook is to analyze the importance and the meaning of the most significant of the many factors that may be observed and to present a method of evaluating their combined effects.

The process of judging fire behavior, as illustrated in figure 2, may be subdivided into five steps:

1. Basic knowledge. The foundation for judging fire behavior must rest on basic knowledge of the principles of combustion: What is necessary for combustion to occur? What causes the rate of combustion to be increased or decreased? How may combustion be reduced or stopped?

2. Forest knowledge. Three basic factors in a forest area -- weather, topography, and fuels -- are important indicators of fire behavior.

3. Aids and guides. Several aids and guides are available to assist in evaluating weather, topography, and fuels.

4. Estimate of situation. The probabilities for various patterns of fire behavior are systematically explored by an estimate of the situation based upon the combined effects of weather, fuels, and topography.

5. Decision. The end product of the fire behavior analysis is a decision outlining when, where, and how to control the fire and spelling out any special safety measures required.

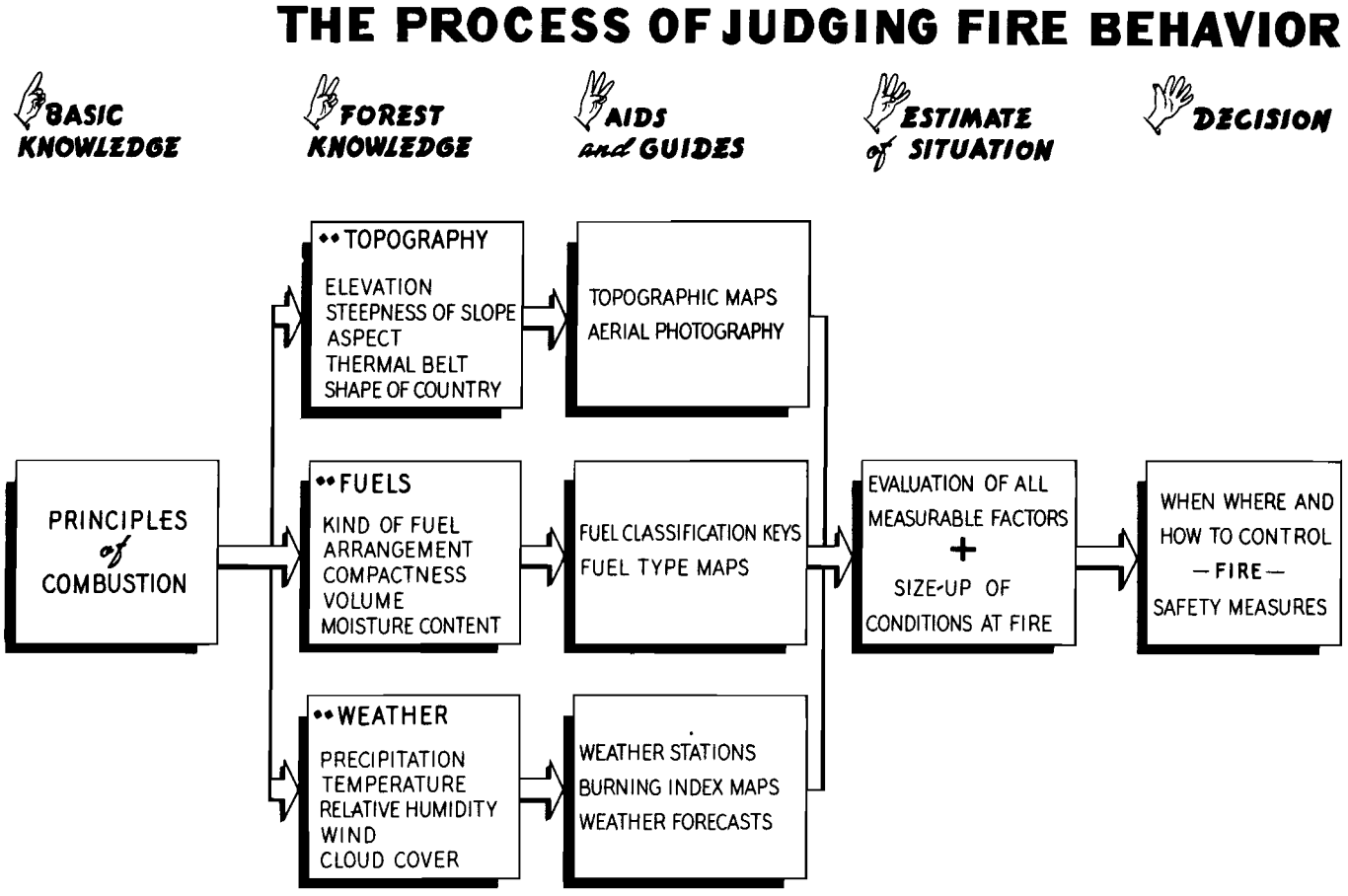

Figure 2. Judging fire behavior requires systematic analysis of many factors.

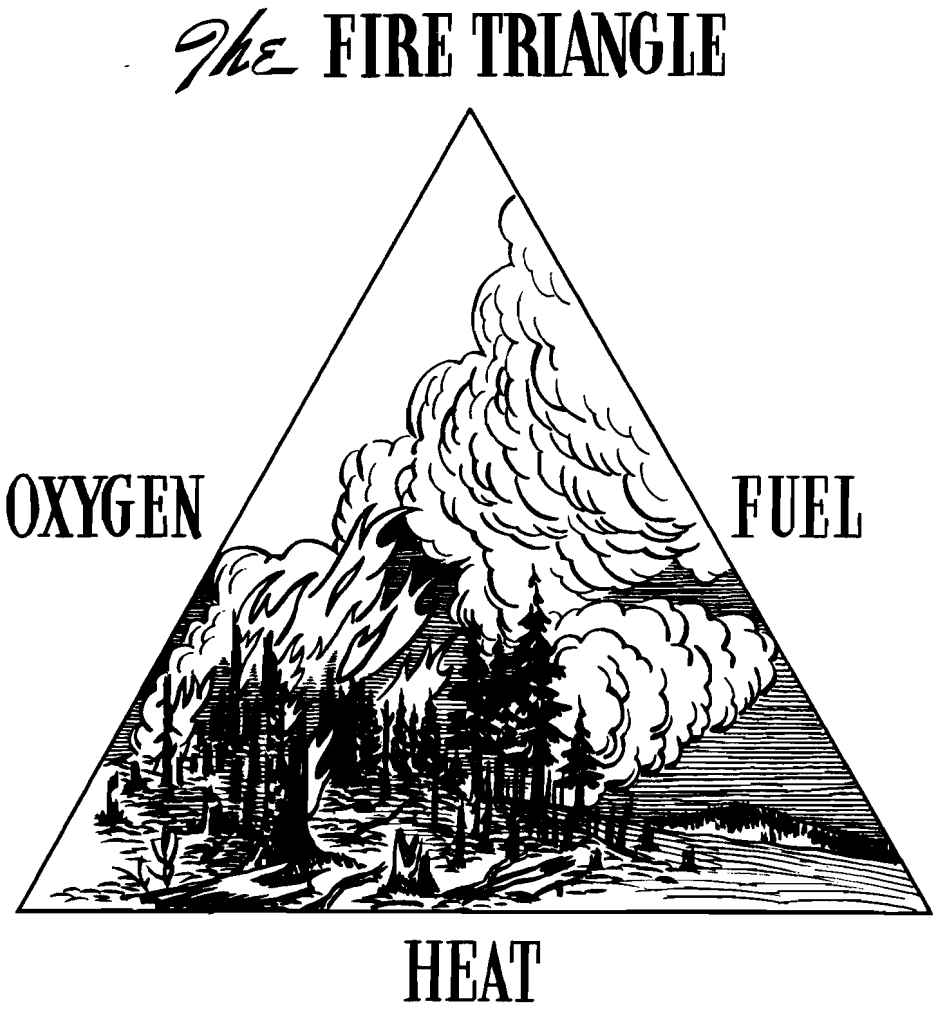

Figure 3. Combustion is a process involving the combination of three things -- heat, oxygen, and fuel. An understanding of the variation of these three factors is fundamental to an understanding of forest fire behavior.

CHAPTER II. PRINCIPLES OF COMBUSTION

Fire is a chemical reaction in which energy is produced. When forest material burns there is a chemical combination of the oxygen in the air with wood, pitch, and other burnable elements in the fuel. In the forest we normally encounter several stages in the fire process -- first the igniting spark, then a period of smoldering, and finally the more rapid combustion of fuels. We know that the phenomenon of fire sometimes involves violent action -- leaping flames, dense smoke, intense heat, loud noises, and occasional explosions. The action of a fire throughout its life is governed by certain natural laws or principles of combustion, as they are termed here. An understanding of these principles is a basic step in judging the effect of various environmental factors on fire behavior.

THE FIRE TRIANGLE

Three things -- heat, oxygen, and fuel -- are required in proper combination before ignition and combustion will occur. If any one of the three is absent, ignition or combustion will not occur. Likewise, if the three elements are not in proper balance, there will be no fire. Variations in balance among heat, oxygen, and fuel govern the violence of the fire, and careful observation of these three essentials indicates to the firefighter whether the fire will only smolder and spread slowly or will flame brightly and travel rapidly.

Everyone has observed some of the fundamental actions of fire. A lighted match is held under a sheet of newspaper and the paper quickly breaks into flame. The fire triangle has been joined. The match provides sufficient heat, a newspaper is a combustible fuel, and the oxygen in the atmosphere is sufficient to support combustion. A glass jar is placed over the burning paper and the flames gradually subside as the oxygen in the confined space is consumed. The fire triangle has been broken by shutting off the oxygen supply.

There are various ways in which the fire triangle may be broken or altered either to slow down or to speed up the combustion process. An attempt is made to ignite a water-soaked sheet of newspaper with a match. In this case the match doesn't provide sufficient heat to cause flame. The balance in the fire triangle has been broken. To regain the balance in the triangle a blowtorch is substituted for the match. The torch dries out the paper and combustion occurs in the part of the paper exposed to the intense heat. The experiment is repeated, this time with a tightly rolled piece of dry newspaper. Again it is difficult for the match to ignite the paper. The fire triangle has been altered because the paper is so tightly rolled that oxygen is not readily available to the combustible material.

The task of the firefighter is to visualize the fire triangle as applied to forest conditions. The same basic principles apply. The ease of ignition and rate of combustion are determined by the amount of heat, the availability of oxygen, and the type of fuel.

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Heat

How much heat is required to ignite forest fuels? It is difficult to answer this question specifically because of the variations in the nature of forest fuels. Nearly all substance on earth may be consumed or changed radically in form by fire if enough heat is applied. Steel may be melted and water boiled away. Most of the easily ignitible and combustible materials are largely composed of carbon. Vegetative material, such as forest fuels, is high in carbon content and ignites at relatively low temperatures provided the moisture content is low and the substance is freely exposed to the air. During the forest fire season a large part of the vegetative matter in a forest -- duff, dead limb wood, pine needles, tree branches, rotted logs, etc. -- becomes dry enough to be ignited easily. Actual heat requirements for ignition of forest fuels varies from approximately 500° to 750°F. Many common ignition sources provide the required heat, including a burning match, a glowing cigarette, and a lightning bolt.

Ignition often depends upon the length of time that the fuel is exposed to heat. Dry pine needles may be ignited in a few seconds by the heat from a flaming match. Moist pine needles also may be ignited by a match if subjected to the heat for several minutes. When wood fuels are exposed to heat for a long period of time, the normal ignition temperature may be lowered. David J. Price of the Bureau of Agricultural Engineering and Chemistry has shown that wood exposed to a temperature of 400°F. for approximately half an hour will ignite (7).1/

The ease of ignition of forest fuels when exposed to heat for a considerable time has an important influence on fire behavior. In a coniferous forest a hot fire burning in a tangle of down logs and dry limb wood may generate enough heat to transform the green tree crowns above the fire into an easily ignitible condition. All that is needed to cause the tree crowns to break into flame is a flying ember and a gust of wind. Similarly, a fire smoldering in a pile of leaves may generate enough heat to lower the normal ignition temperature. When the leaves are stirred up, the whole pile breaks into flame. The stirring of the pile lets in enough oxygen for the preheated leaves to be easily ignited.

Oxygen

Normally the atmosphere at elevations where forest fires occur contains about 21 percent oxygen. When the oxygen content of the air is reduced to less than 15 percent, most materials will not burn. Within the forest there is sufficient oxygen to permit ignition and combustion. However, some of the forest fuels may be arranged so that air, and consequently oxygen, is not available in sufficient amount to support a fire. In deep, tightly compacted duff only the top particles can get enough air to permit a fire to burn. In this situation a fire will burn from the top down with combustion taking place in each layer as it is exposed to the air. On the

1/ Numbers in parentheses refer to Literature Cited listed at the end of this report.

other hand, in a very loose layer of pine needles the entire mass is fairly well exposed to air and consequently combustion will take place rapidly (figure 4).

FUEL ARRANGEMENT INFLUENCES IGNITION

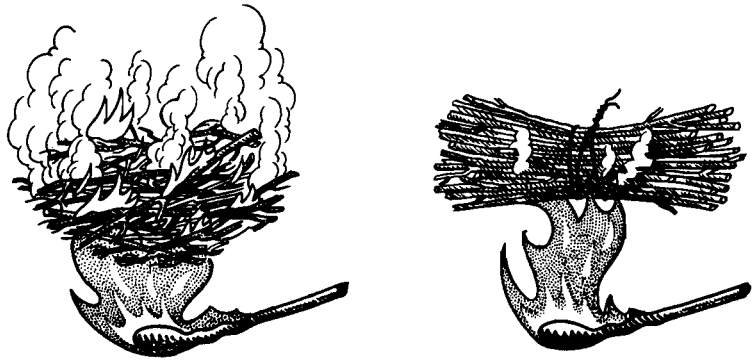

Figure 4. A loose pile of sticks ignites more easily than a tightly packed bundle because more surface area of the fuel is exposed to air.

When wind blows on a fire, a forced draft of oxygen is present to speed up the combustion process. In addition, as will be shown later, the wind has a physical reaction on the flames, often bending them into positions that create more favorable situations for the spread of the fire. Wind forces oxygen around fuel particles where the flow of air may be normally restricted.

Fuel

Under forest conditions fuel is a major variable in the fire triangle. Fuel constitutes the leg of the triangle that is often most difficult to evaluate properly. The firefighter must become acquainted with the general nature of forest fuels if he is to attain a thorough understanding of the principles of combustion.

Ease of ignition and combustion of forest fuels (figure 5) depends mainly upon the kind of fuel (is it logging slash or dense duff in a green forest?), fuel continuity (is the fuel distributed more or less evenly over the area or only present in patches?), moisture content (does it feel damp when touched or does it crackle and appear very brittle?), and fuel temperature (is the fuel exposed to the heat of the sun or does it lie in cool shade?).

SHAGGY BARKED SNAGS IGNITE EASIER THAN SMOOTH SNAGS

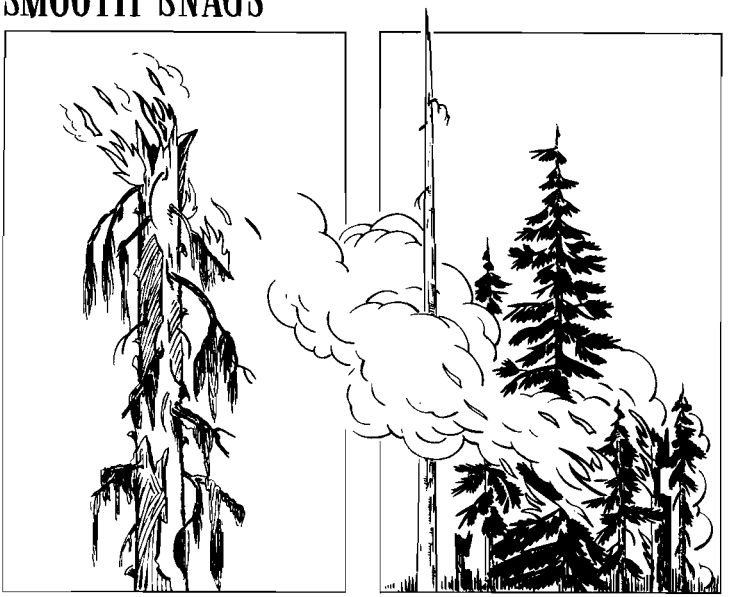

Figure 5. A shaggy-barked snag ignites easily because the finely divided stringers of bark provide dry kindling material fully exposed to air.

COMBUSTION

When fuels are heated to a given temperature, gases are produced which will ignite if combined with oxygen. When one observes a log fire, he will note that the flames may appear to be coming directly from the fuel. Actually the flames come from the ignited gases emerging from the heated log. This phenomenon may be illustrated by heating dry pine needles in a covered coffee can with a nail-sized hold in the lid to permit liberation of gases. These gases may be ignited with a match (figure 6). Flames will not occur within the coffee can, but if heat is applied to the can long enough, the pine needles will be consumed and only ashes will remain.

The process of combustion is actually oxidation in which the combustible substance ignites with oxygen. There may be several stages to the oxidation process. Under certain conditions oxidation may be so slow that it is not accompanied by the heat and light normally associated with combustion. In this so-called "slow combustion" stage heat is dissipated very rapidly, in fact nearly as fast as it is liberated; and as a result no appreciable rise in temperature occurs. "Slow combustion" is not common in forest fuels.

GASES FROM HEATED FUEL WILL IGNITE

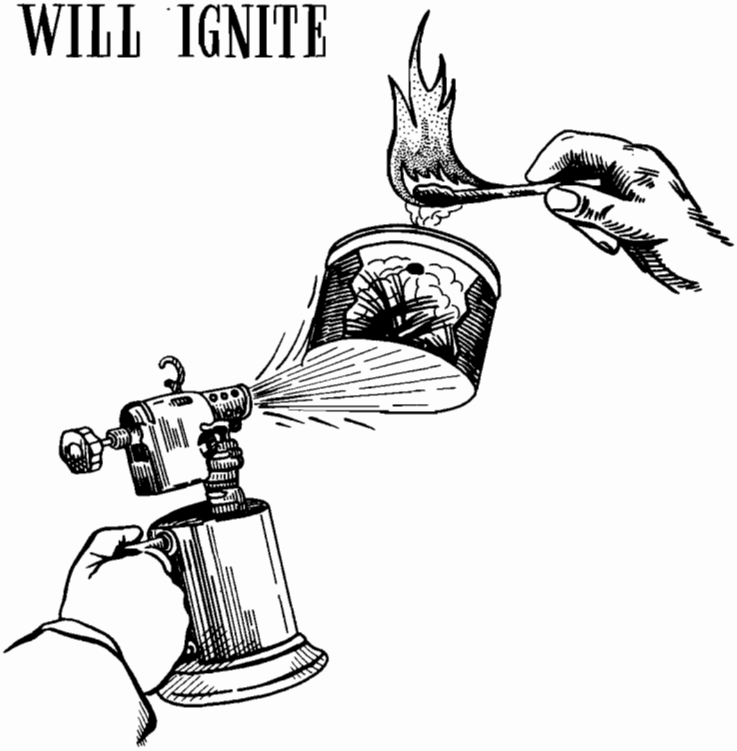

Figure 6. Heat applied to a coffee can full of pine needles will generate ignitible gases. In the combustion process the visible flames are actually burning gases liberated by heated fuel.

In forest fires two common stages of combustion are smoldering and flaming. In the smoldering stage heat is liberated and a rise in fuel temperature occurs. However, flame is absent or present only intermittently. Normally the absence of flame is caused by insufficient oxygen or by moisture in the fuels. Lack of oxygen or moisture in the fuels will slow up the oxidation process. When a fire is in the smoldering stage, all the elements of the fire triangle are present but not in a combination to permit rapid combustion.

When a fire is in the flaming stage, all the elements of the fire triangle -- heat, oxygen, and fuel -- are in proper combination for rapid oxidation to occur. Thus flame in itself provides a guide to an understanding of fire behavior.

The flames of very hot fires may be observed intermittently in the smoke at a considerable distance above the fire. In some cases oxygen is consumed so rapidly near the base of the fire that combustion of the gases is incomplete. As these superheated gases rise, they reach a fresh oxygen supply and break into flame. For this reason it may appear that the smoke of some fires is itself flaming.

Re-ignition of apparently dead fires is an important factor to be observed in the combustion process. The important element in re-ignition is heat. Although neither flames nor smoke may be observed, a fire can break out again if sufficient heat remains. Re-ignition occurs easily where fuels have been subjected to heat for a considerable length of time. To prevent re-ignition the good firefighter feels out fuels with his hands before leaving the area. If heat is still present, he knows that the control job is incomplete.

BREAKING THE FIRE TRIANGLE

In fire control operations the objective is to prevent combustion by breaking the fire triangle. The fire triangle is broken when any one of the heat, oxygen, and fuel legs is removed or altered to such an extent that combustion can no longer occur. Many methods may be employed in this process (figure 7). Use of water reduces heat: if a sufficient volume of water is applied, the fuel temperature can be lowered below the ignition point. Smothering with dirt reduces oxygen: if the air supply can be shut off until all fuels are thoroughly cooled, further combustion can be prevented. Building a line in which all inflammable material is removed from the path of the fire prevents further spread by robbing the fire of fuel.

Usually in forest firefighting combustion is reduced or stopped by attacking more than one of the three legs of the fire triangle. The actual method of suppression is often dictated by the available equipment and manpower. However, the most effective methods for each part of the fire and for each stage of the suppression operation can be determined by keen observation of the combustion process.

Reducing Heat

The principles of combustion indicate the best method of applying water to reduce heat. Since the objective is to reduce fuel temperature, water should be applied directly on the fuels being consumed. A common mistake is to apply water on the flames rather than the fuels. As explained previously, the flames are actually burning gases liberated by the heated fuels. If the liberation of these gases is to be stopped, the fuels themselves must be cooled by the water. Some of the water played on the flames may reach the fuels, but a large part of it will either miss its mark or be lost through vaporization. If water is being used for cooling purposes, the ultimate target is always the fuel.

Occasionally water may be used for other purposes than direct cooling of fuels. In a very hot fire accompanied by leaping flames the nozzle-man may not be able to get close enough to the fuels to apply water directly on the trouble spot. In such cases a fog nozzle should be used to knock

Figure 7. In forest fire control the objective is to stop combustion by removing or altering one or more legs of the fire triangle.

down the flames. Fog performs a smothering function on the flaming gases by occupying air space with millions of finely divided particles of water. These water particles also assist in cooling the heated gases being liberated by the fuels. Once the flames have been knocked down the nozzleman immediately returns to his primary job of thoroughly cooling the heated fuels that are generating inflammable gases.

The type of fuel largely influences the nature and rate of combustion, and in turn each fuel calls for special techniques in the use of water to reduce heat. For example, in oil tank fires it is sheer folly to direct a high-pressure straight stream of water onto the surface of the oil. Such a penetrating force of water will only punch a hole in the oil surface, stir up the fuel, and expose more area to be burned. In oil fires a fog should be applied to perform the dual function of smothering and cooling. Various forest fuels likewise call for specific techniques when an attack is made on the heat leg of the fire triangle. These techniques will be discussed later in the chapter on fuels.

Reducing Oxygen

Fires burning in forest fuels are difficult to smother completely. Soil thrown on burning forest material may retard combustion by shielding portions of the fuel surface from the air. Because of the porous nature of most soils, it is difficult to shut off completely the supply of oxygen in this manner. Throwing dirt on fires is nevertheless an important means of reducing the rate of combustion after which the control operation may be continued by attacking one of the other legs of the fire triangle.

In very fine fuels, such as dry grass, the oxygen supply may be reduced easily. Fuels of this nature do not retain heat for long periods, and therefore combustion may normally be checked by temporarily shielding the fuel surface from the air. For this reason gunnysacks, fire swatters, and shovelfuls of earth correctly applied are effective implements in smothering grass fires. Wherever larger accumulations of inflammable material, such as dead stems and leaves, lie beneath the stand of grass, there is danger of re-ignition. The understory material may hold enough heat to cause the fire to break out again as soon as an adequate supply of oxygen becomes available. This danger can be determined by careful observation of the fuel.

Removing Fuel

In forest fire control work the removal of fuel is the most common method of attacking the fire triangle. Actually this method does not prevent combustion in the area on fire. The fire continues to burn until the fuel is consumed or the combustion process is broken by some other means. However, removal of the fuel in the path of the fire does prevent the fire from spreading any further. Thus the fire triangle is broken indirectly.

The nature of the fuel removal operation is dictated by the influence of fuels on behavior of the fire. A slowly advancing fire burning in sparse ground fuels may be checked simply by constructing a fire line down to mineral soil. However, a hot or a fast-running fire may require several other fuel removal operations. Snags which may cause spot fires may have to be felled. Thickets of reproduction or dry brush may have to be weeded out. Low-hanging limbs which may permit the build-up of a crown fire may have to be removed. Concentration of limbs and logs may have to be broken up. The objective throughout all these operations is to remove or to reduce the inflammable substance which may either allow the fire to build up in intensity or to continue to spread.

HEAT TRANSFER

The rate and amount of heat transferred influences the rate of spread and the intensity of a fire. Combustion cannot be sustained unless heat continues to be transferred. Heat transfer occurs by three means -- radiation, convection, and conduction.

Radiation

Radiation is a process by which heat energy is transmitted from its source to an object. Radiant heat is commonly known as an important means of warming the interiors of buildings. Heated pipes laid in the floor of a room release heat energy which is transmitted to objects and individuals. In forest fires radiation is an important means of transferring heat from a burning fuel to another fuel nearby.

Radiant heat transfer decreases inversely with the square of the distance from the fire (figure 8). If an object located 1 foot from the fire receives 100 heat units, then an object 2 feet from the fire will receive only 25 heat units, and an object 10 feet away only 1 unit. The actual number of heat units will vary according to the intensity of the fire, but the decrease of radiant heat according to distance from the source always will remain in the same ratio.

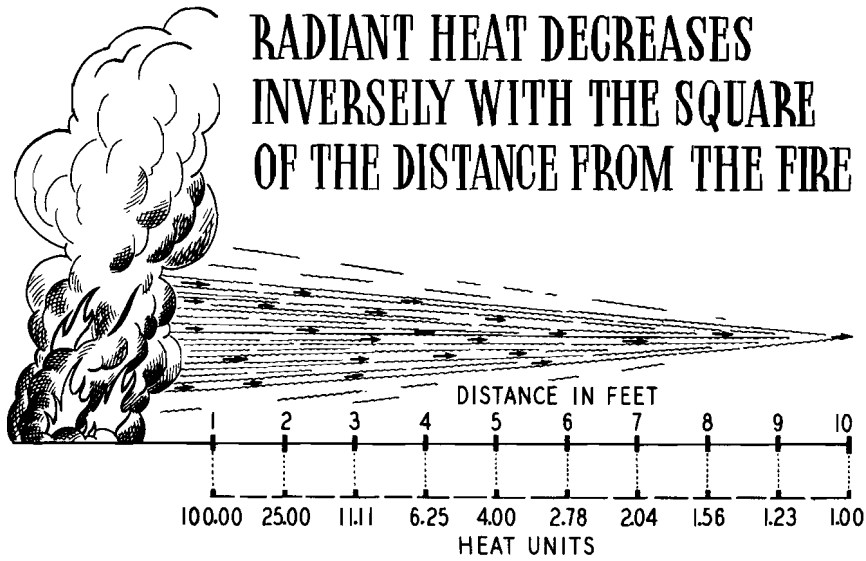

Figure 8. Radiant heat transfer decreases inversely with the square of the distance from the fire.

Radiant heat transfer plays an important part in fire behavior. A pile of logs may create a hot fire because the burning logs radiate heat to each other (figure 9). However, if these logs are separated and laid out a foot or two from each other, the fire will quickly die down. Separating the logs effectively reduces radiant heat transferred from one fuel unit to another. In firefighting, the laws governing radiant heat transfer can be used as a guide for suppression techniques. The location and width of fire lines must be governed in part by the rate of radiant heat transfer. Potentially hot fires and spots where dangerous flareups might occur can often be prevented by breaking up the fuels or, in other words, by reducing the radiant heat transfer between fuels.

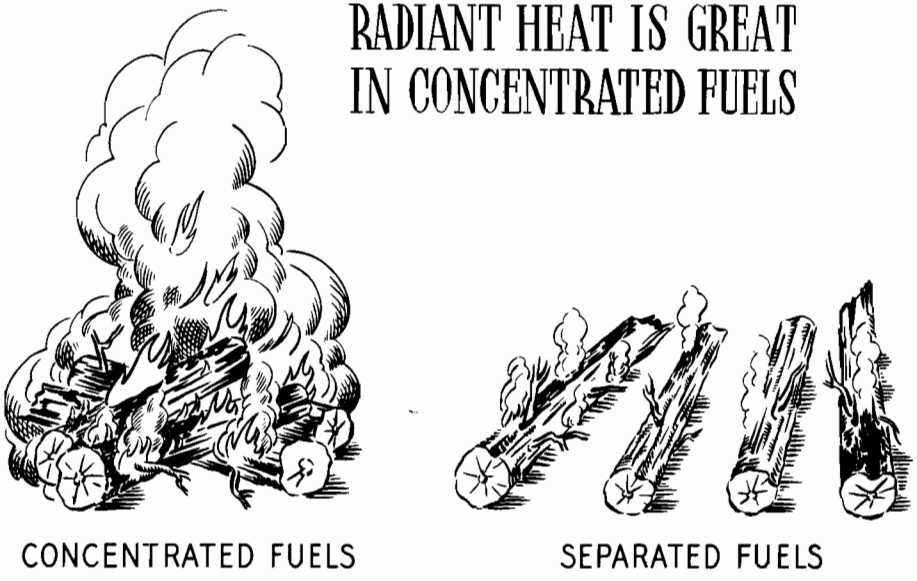

Figure 9. A pile of logs creates a hot fire because the burning logs radiate heat to each other. When the pile is broken up, radiant heat transfer is greatly reduced.

Figure 10. Fuels upslope from a fire receive more heat than fuels on the downslope side.

Steepness of slope influences the amount of radiant heat transmitted to fuels upslope and downslope from the fire (figure 10). On the upslope side of a fire the fuels receive more heat because they are closer to the source of that heat. This is one reason why fires often spread more rapidly on steep slopes than on level ground.

Wind influences radiant heat transfer in two ways. First, wind increases the rate of combustion, thus creating a hotter fire; and second, wind bends the flames, thus decreasing the distance between the heat source and fuels lying in the path of the fire (figure 11). The dual effect of the hotter fire and the bent-over flames dries and heats the fuels lying ahead to such an extent that rate of spread may be greatly accelerated. Often a fire will burn into the wind. This action occurs because the wind increases combustion to such a degree that a large amount of radiant heat may be transmitted even to the fuels lying on the upwind side.

WIND INCREASES RADIANT HEAT TRANSFER

Figure 11. Wind bends over flames and thus provides more radiant heat to fuels immediately downwind from the fire.

Convection

Heat is also transferred through the movement of hot masses of air -- a process called convection. The common hot-air furnace used in homes takes advantage of the principle of heat transfer by convection. Air is easily heated and is capable of holding and transmitting heat. When forest fuels become heated by hot air masses moving from an adjacent fire, more favorable conditions are created for those fuels to be ignited and to burn.

Hot air masses have a tendency to rise because of their light weight in relation to cooler air masses. The air near the ceiling of a heated room is warmer than that near the floor. Kindling is placed at the bottom

when you light a wood fire so that the fuels above may receive heat through convection. In a forest fire the fuels lying in the path of convection currents are heated and thus transformed into a more inflammable condition. The hot air mass rising from a surface fire transfers a large amount of heat to the tree crowns and brings them nearer to the ignition temperature (figure 12).

Figure 12. Tree crowns receive heat through convection currents rising from ground fires.

When fires break out in tree crowns and other aerial fuels, heat transfer by convection is often increased. Sparks and burning embers from the burning tree crowns and snags will drop to start new fires in fuels on the ground. As these ground fires gain in intensity, more hot air masses rise through the aerial fuels and a type of chain reaction is created. For this reason firefighters are always alert to the danger of hot surface fires burning underneath a forest canopy. These surface fires must be cooled promptly, and bad fuel masses which are apt to create hot fires should be broken up.

Heat transfer through convection is increased by wind which moves hot masses of air ahead of the fire. Wind again performs a dual function by increasing the rate of combustion, thus creating more heat, and by accelerating the transport of hot air masses. When driven by wind, the hot convection currents may move closer to the ground fuels and create more inflammable conditions in the understory vegetation of the forest.

Fuels located above a fire on steep slopes also receive heat by the movement of convection currents up the slope. This is one more reason why fires often burn very rapidly up the sides of steep mountains. The fuels upslope are subjected to an accelerated rate of heating and drying.

Conduction

Wood is a poor conductor of heat. This is well illustrated by the fact that a wooden handle on a hot frying pan remains cool enough to be grasped by a bare hand. Because wood is such a poor conductor of heat, this method of heat transfer is relatively unimportant in evaluating forest fire behavior.

Figure 13. Fire danger stations provide essential weather information needed in evaluating fire behavior.

CHAPTER III. WEATHER

Weather is the most important variable to be considered in evaluating fire behavior. Hourly, daily, weekly, monthly, and yearly variations in weather conditions all exert some influence on how, when, and where fires will start; how they will behave once ignited; and how difficult they will be to control. Weather is of special importance because it may change quickly and because the changes may result in rapid and very significant differences in fire behavior.

REGIONAL WEATHER CONDITIONS

In the northern Rocky Mountain region weather conditions are significantly different in three broad zones.

The Western Zone

The western zone includes all of northern Idaho, northeastern Washington, and a small area in northwestern Montana. The zone is characterized by wet, moderately cold winters and hot, dry summers. Annual precipitation in forest areas varies from 20 to 60 inches and occurs mainly in the form of snow except during the spring and fall rainy seasons. Monthly precipitation in both July and August normally averages less than 1 inch. Thunderstorms, accompanied by little or no rain, are frequent and intense during the summer months. Hot, dry winds, usually of moderate velocity, blow into the zone during the summer from the semi-arid plateaus of Idaho and Washington. The western zone receives enough winter precipitation to foster dense forest growth and thus has abundant fuels. In the dry summers the heavy fuels often become highly inflammable and contribute to one of the most severe fire problems in the United States.

The Central Zone

The central zone covers nearly all of Montana west of the Continental Divide. This zone has the same general fire weather characteristics as the western zone except that it receives considerably less winter and spring precipitation. In the forest areas annual precipitation varies from 12 to 50 inches. Fuels range from light and flashy types in the grass and open timber lands to heavy types in the densely forested areas.

The Eastern Zone

The eastern zone includes all of Montana east of the Continental Divide, northwestern Wyoming, and the forested areas of northwestern South Dakota. Annual precipitation in forest areas varies from 8 to 25 inches. One of the basic differences between the eastern and the central or western zones is the character of summer thunderstorms. In the eastern zone the thunderstorms are frequently accompanied by moderate amounts of rain which prevent excessive drying of fuels. However, only a slight decrease in summer precipitation is required to bring about dangerous burning conditions. Because of the low annual precipitation in much of the eastern zone, fuels are sparse and generally flashy in character.

USE OF WEATHER INFORMATION

Weather is both the friend and the foe of the firefighter. During very hot, dry, or windy weather fires burn rapidly and are difficult to control. On the other hand, cool, damp weather may create conditions where fires hardly burn at all and are easily controlled. Between these two extremes are many variations influencing combustion. One of the big jobs of the firefighter is to interpret these conditions to show probable rate of spread and general behavior of fires and difficulty of control.

Full use and interpretation of weather information requires:

1. Daily measurement of key variables. Fire weather stations are located at key points in forest areas to measure basic weather factors such as temperature, precipitation, relative humidity, fuel moisture, and wind velocity and direction.

2. Plotting and analysis of seasonal trends. The cumulative effects of long periods of hot, dry weather or cool, damp weather can be visualized best if the daily measurements of key factors are plotted on charts or graphs. Periodic analysis of these charts provides a valuable means of interpreting seasonal trends.

3. Integration of key factors into a single index. Use of the burning index meter provides a means of interpreting the combined effects of basic weather factors.

4. Observation and analysis of weather forecasts. When evaluating probable fire behavior it is necessary to look ahead. Today's weather and burning conditions must be compared with those which will probably occur tomorrow. Throughout the fire season daily fire weather forecasts are available for this purpose.

5. Interpretation of weather conditions in various fuels and topography. Weather conditions have different effects on fire behavior in various fuels and topography. Fuel rate-of-spread tables and burning index conversion tables (contained in the appendix) are available to assist in the interpretation of these factors.

6. Keen observation of weather at the site of a fire. Fully localized weather measurements may not be available on each fire. However, keen observation of certain weather indicators, such as character of the vegetation and dampness of the ground, may assist in estimating fire behavior.

MEASURED FIRE WEATHER FACTORS

Certain weather conditions may be measured more or less precisely. In forest fire control work these measurements are taken daily at fire weather stations located at key points in each forest area. The principal weather factors measured and the instruments used to measure them are:

Weather Factor	Instruments
Precipitation	Rain guage
Temperature	Thermometer 2/
Relative humidity	Fan or sling psychrometer 2/
Wind velocity	Anemometer
Fuel moisture	Fuel moisture indicator sticks and scales

Precipitation

Precipitation varies widely in rough, mountainous country. Normally, precipitation is greater at higher than at lower elevations. Air is pushed upward as it flows across high mountains, resulting in cooling and condensation. Because of the increased condensation, precipitation may occur over mountains for a longer period than over lower country. For this reason winter snowfall is greater in the high mountain areas. Evaporation loss accounts for part of the reduced precipitation at lower elevations. This loss is especially noticeable during summer thundershowers.

In the northern Rocky Mountains precipitation generally decreases from west to east. The western zone of the region is often under the influence of moist maritime air coming in from the Pacific. Successive mountain ranges prevent much of this air from reaching the eastern zone. As a result the annual average precipitation in the eastern zone is about half that of the western zone. Annual precipitation in the central zone falls about midway between these two extremes.

The precipitation year, for fire control purposes, is measured from October 1 through September 30 rather than on a calendar year basis. This is done to show the effect of autumn and early winter precipitation on fuels which may be subjected to fire during the following summer. Great variations in rainfall occur during the precipitation year in the various zones of the region. As shown in figure 14, the wettest year at the Priest River Experimental Forest in the western zone had nearly 24 more inches of rainfall than the driest year. At Missoula, Montana, in the central zone the variation between wettest and driest years is nearly 13 inches; and at Helena, Montana, in the eastern zone the same variation is over 18 inches (figure 15).

Rainfall in July and August is of great interest to firefighters. Even when a dry winter or spring has occurred, it is still necessary to have a dry summer to bring about a critical fire season. As shown in figure 16, great variations in summer rainfall have been observed at representative weather stations in the western, central, and eastern zones of the region. At Missoula in the summer of 1889 no measurable precipitation occurred during July and August. Stations in both the eastern and western zones of the region have recorded much less than $\frac{1}{2}$ inch of rain for these two months.

2/ At some stations temperature and relative humidity are continuously recorded on a hygrothermograph.

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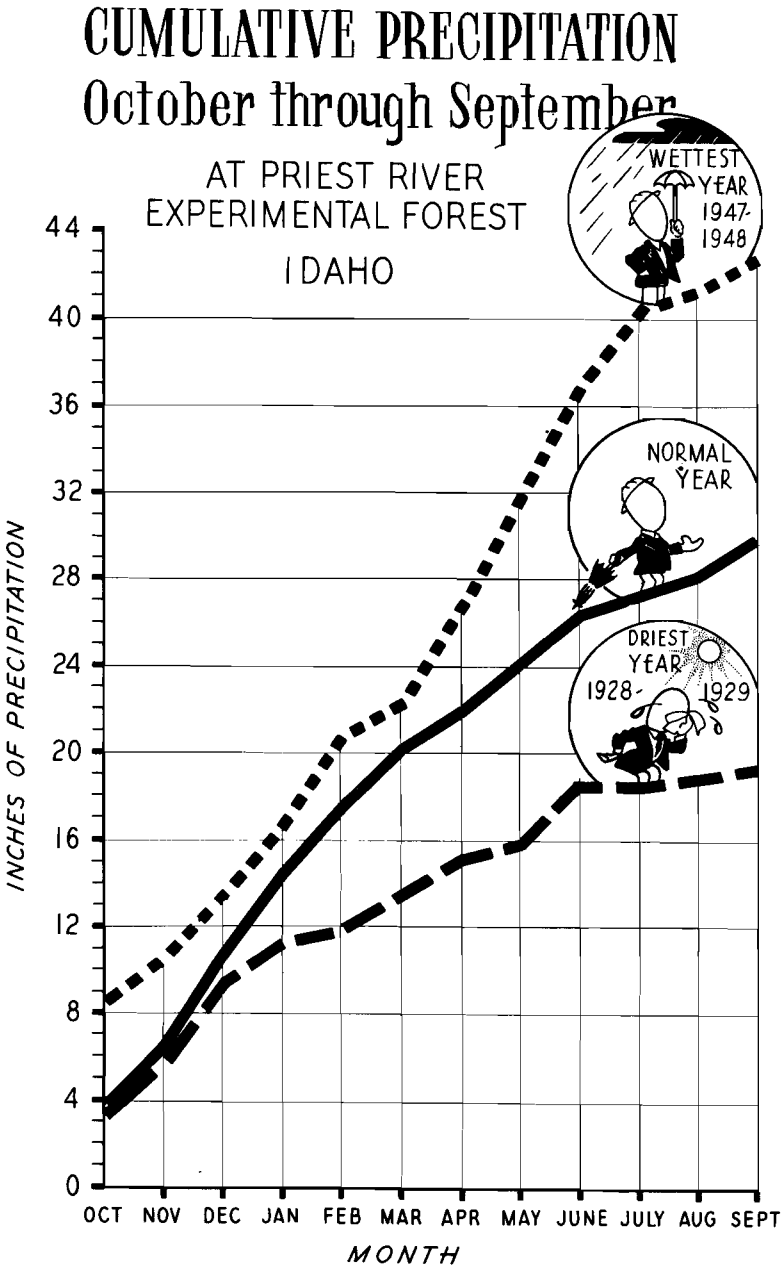

Figure 14. Cumulative precipitation, October through September, at Priest River Experimental Forest in wettest, normal, and driest years.

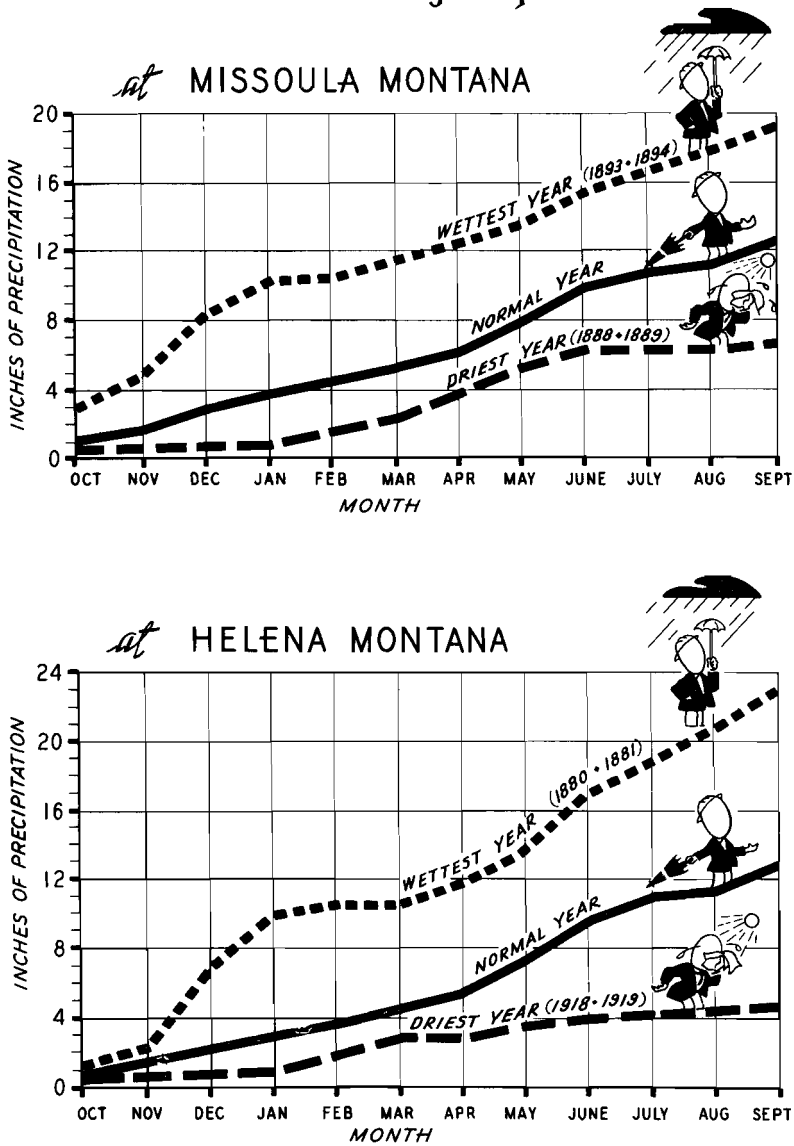

Figure 15. Cumulative precipitation, October through September, at Missoula, Montana, and Helena, Montana, in wettest, normal, and driest years.

TOTAL JULY and AUGUST PRECIPITATION
IN NORMAL, WETTEST and DRIEST YEARS

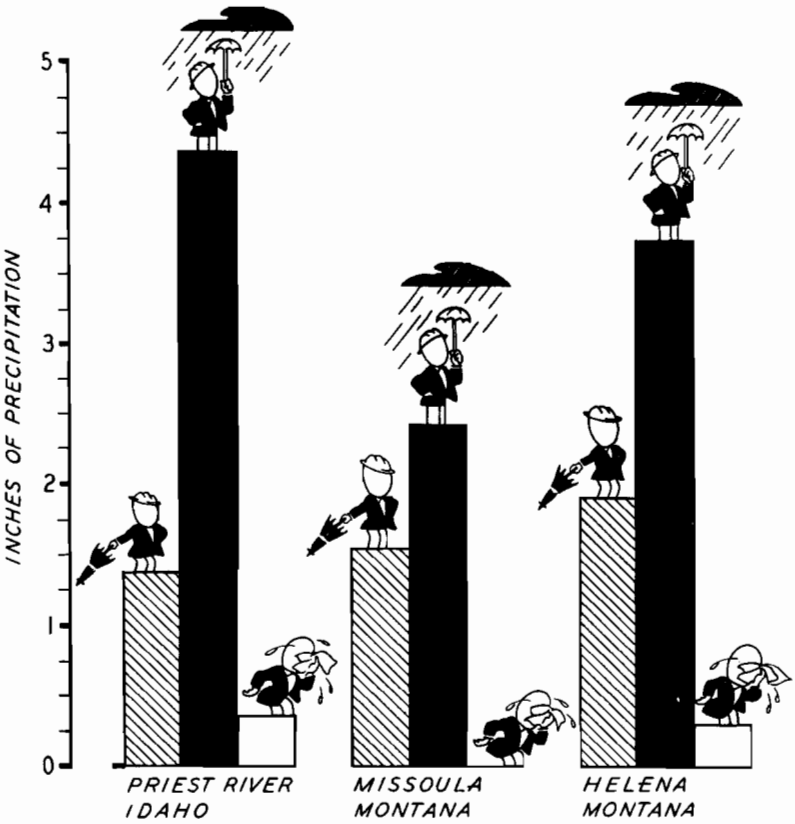

Figure 16. July and August precipitation at Priest River Experimental Forest, Idaho; Missoula, Montana; and Helena, Montana, during normal, wettest, and driest years.

The time of year when precipitation occurs is an important factor influencing fire behavior. Heavy winter precipitation does not mean that the following fire season will be an easy one. The effect of winter precipitation may be broken by a long, dry spring and summer. Likewise, the effect of light winter precipitation may be nullified by a wet spring or summer. However, precipitation is a valuable indicator of trends, and

when cumulative rainfall is recorded and plotted the firefighter obtains a good idea of whether the fire season may be characterized as being wet, normal, or dry.

The principal effect of rainfall is to dampen fuels. For this reason, and as explained later, it is necessary to measure fuel moisture specifically as an important element in fire danger rating. Rainfall has different effects in different fuels. These effects may be summarized as follows:

Light flashy fuels (such as grass or lightly compacted pine needles). A small amount of rain quickly slows up combustion but the effect will be short-lived. Two or three hours of sunshine nullifies the effects of a light rain.

Medium fuels (such as dead limbwood and twigs). More rain is required to prevent or slow down combustion in medium fuels than in light fuels. However, once medium fuels of this nature are dampened, the effect will last longer than in light flashy fuels.

Heavy fuels (such as large limbs and down logs). Long periods of dry weather are necessary to transform heavy fuels into a dangerously inflammable condition. Once dried out these fuels are affected only slightly by light rains. Soaking rains of more than one-quarter inch are required to reduce inflammability materially.

The length of time between summer rains has an important bearing on the curing of grass and other annual vegetation. Even when total July-August precipitation is relatively low, the occurrence of frequent very light rains will retard the rate of curing of herbaceous vegetation and thus shorten the period of high inflammability. Long dry spells in late June and early July have the effect of moving up the date of curing of annual vegetation and thus creating a longer period of high inflammability.

Temperature

Air temperature has a direct influence on fire behavior because of heat requirements for ignition and combustion. Fuels receive heat by radiation from the sun and by convection from the surrounding mass of air. If air temperature is high, fuel temperature will be affected. As a result there will be a decrease in the amount of additional heat required for ignition. For example, if a fuel ignites at 500 degrees and the fuel has a temperature of 150 degrees, then only an additional 350 degrees are required to start combustion.

Fuel temperature influences the rate of spread of a fire. Warm fuels burn faster than cold fuels because less heat energy is required for ignition. Fuel temperature will vary according to site conditions. In open areas fuels exposed to direct sunshine will be warmer than those in the shade. In some areas heat reflected from limestone cliffs or light-colored ground also may increase fuel temperature.

Relative Humidity

Relative humidity is the term used in fire control to express the dryness of the air. Relative humidity may be defined as the ratio of actual mass of water vapor per unit of space or volume to the mass of water vapor that would saturate that volume at the same temperature and pressure. Thus when relative humidity is expressed as 30 percent, it means that space contains 30 percent of the moisture that it could hold at that temperature and pressure.

Relative humidity is a very important indicator of fire behavior. In the earlier years of organized fire control relative humidity was about the only daily weather variable used in evaluating burning conditions. In some states logging operations are shut down when relative humidity falls to a given level. Research has shown the need to evaluate other weather factors in rating burning conditions, but nevertheless relative humidity in itself is a useful indicator.

As with precipitation, the effect of relative humidity varies according to fuel condition. Light flashy fuels are sensitive to changes in relative humidity. In a grass fire changes in relative humidity are quickly reflected in the rate of combustion. In a fire in heavy fuels these changes occur more slowly because of the increased time required for the heavier material to gain or lose moisture.

In the northern Rocky Mountain region four general humidity classes may be used to describe differences in burning conditions:

Burning Conditions	Relative Humidity
Easy	Above 40 percent
Moderate	26 to 40 percent
Dangerous	15 to 25 percent
Critical	Below 15 percent

Research at the Priest River Experimental Forest has shown the frequency of days in each relative humidity class during the heart of the fire season. As illustrated in figure 17, an average of 46 percent of the days during July and August have a minimum relative humidity in the moderate class, while 39 percent are classified as dangerous, 13 percent easy, and 2 percent critical.

Relative humidity fluctuates widely during each 24-hour period. Relative humidity is higher in the early morning hours because the temperature is lower. Relative humidity is partly a function of temperature. Consequently, since cool air cannot hold as much moisture as warm air, the relative humidity must rise whenever temperature falls, if there has been no change in moisture content. For the same reason the humidity is almost always higher over high country than over low country on hot afternoons. As will be shown later, relative humidity also fluctuates according to aspect.

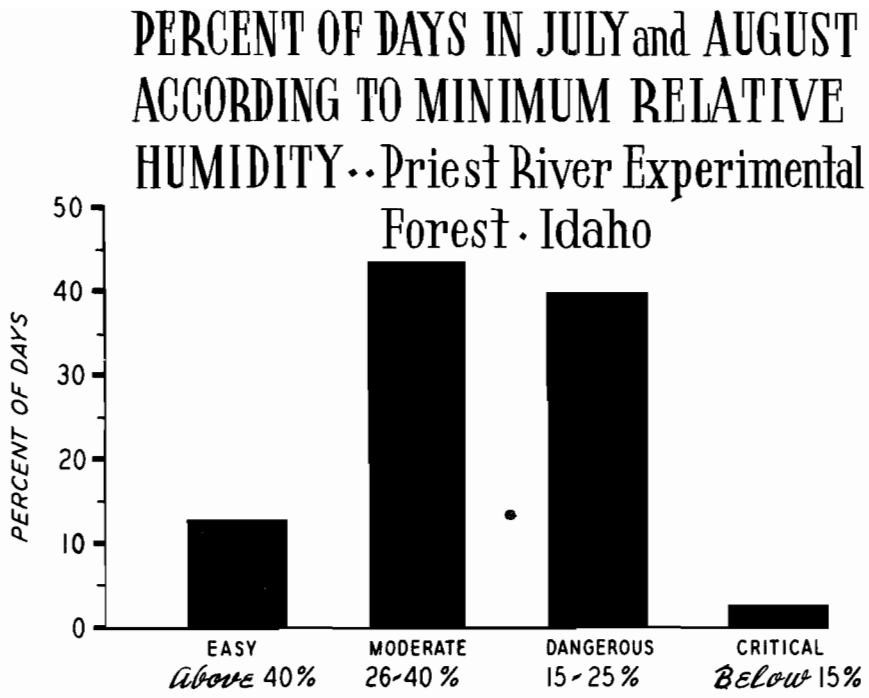

Figure 17. Frequency of occurrence of each relative humidity class during July and August at the Priest River Experimental Forest, Idaho.

Wind Velocity and Direction

Wind influences the rate of spread and general behavior of a fire. High winds cause the flame front of a fire to move ahead rapidly. In addition they may cause the fire to run in the crowns of trees, to jump barriers that would normally stop a fire, and to spot ahead of the main fire front.

Studies of area burned have shown that wind velocity is a key factor influencing the size of a fire (1). As illustrated in figure 18, the average size per fire increases greatly as wind velocity increases. Where wind velocity at time of initial attack was of gale force, fires averaged 3500 acres in size as compared to only 8 acres when light wind velocity occurred.

Fortunately, high winds are not common during the fire season in the northern Rocky Mountains. Studies of over 1200 fires have shown that light wind velocities occur on 56 percent of the fires. Winds are generally stronger in areas east of the Continental Divide. Over 20 percent of the fires east of the Continental Divide had wind velocities greater than 18 miles per hour as compared to only 7 percent in areas west of the divide.

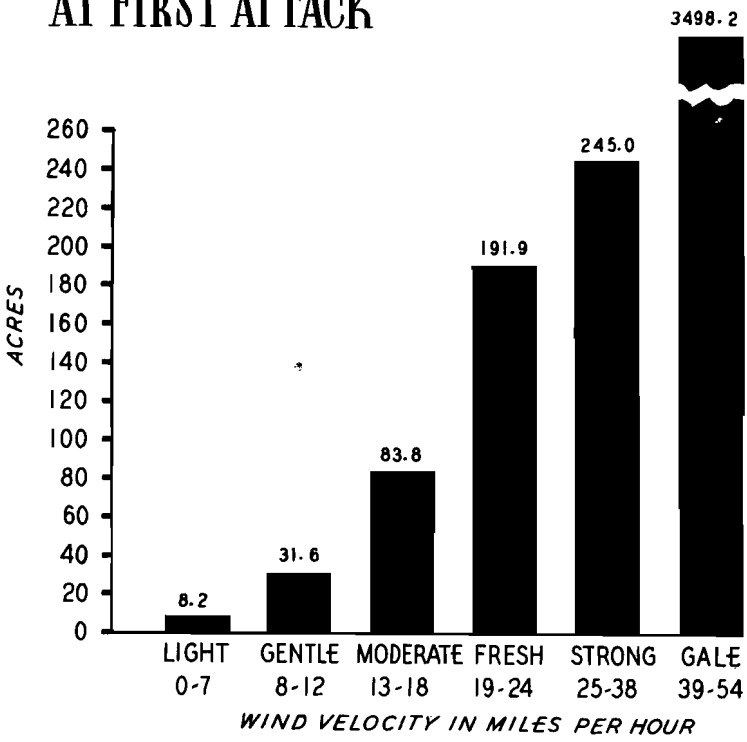

Figure 18. Average final size per fire in the national forests of Region 1 according to wind velocity at time of first attack. (Basis 12,790 fires, 1936-1944)

Under forest conditions wind velocities vary greatly between ground and tree top level. Studies in a dense stand of timber at the Priest River Experimental Forest have shown that average wind velocities are about 7 times greater at a height of 150 feet above the ground than they are 2 feet above the ground (2). This fact emphasizes the importance of preventing fires from climbing into tree crowns. The firefighter has a much greater chance of effecting control if he can fight the fire while it remains in ground fuels.

Average wind velocities also vary according to the type of forest cover. In open stands of timber or brush and grass air movement is much less restricted than in dense forests. In areas where trees are closely spaced or where underbrush is thick, air movement is obviously restricted. Elevation also is an important factor influencing wind velocities. Winds are normally much greater in high mountain areas.

When high winds occur, fires have a pronounced wedge shape. The point of the wedge is pushed forward by the wind. Wind may cause several long fingers to protrude ahead of the main front of large fires. Flames on the edges of a wind-blown fire will be drawn toward the center by the updraft caused by intense heat. For this reason it is often possible to make a flanking attack on the edges of a wedge-shaped fire, whereas great difficulty and often great danger will be experienced in attempting to work on the narrow, fast-moving flame front at the head of the fire.

Wind velocities are measured by anemometers at all fire weather stations. These observations should be carefully watched by fire men to gain a full appreciation of daily variations. In addition it is often necessary to estimate wind velocities in the field where precise measurements are not available. Wind velocities may be estimated by keen observation of moving grass, waving tree tops, or smoke drift. The Northern Rocky Mountain Scale of Wind Velocity, shown in figure 19, may be used as a guide for classifying wind velocities into broad ranges.

Wind direction varies widely in rough, mountainous country. High ridges and mountains may form partial barriers to prevailing winds. Narrow canyons often form troughs channeling wind according to the direction of the canyon. Local observation of prevailing wind directions under various topographic conditions should be made in all areas as a part of the fire preparedness program.

Gusty winds and frequent abrupt changes in wind direction are danger signals which usually indicate the presence of unstable air. These conditions should serve as a warning signal that a fire may change rapidly in intensity or direction of travel. Gusts of high velocity frequently cause fires to spot ahead. The sudden occurrence of gusty winds may be the first indication that a general increase in wind velocity is to occur.

Forecasts of changes in wind direction or velocity are highly important. Because up-to-date Weather Bureau forecasts cannot be provided for the local conditions encountered on every fire, it is usually necessary for the firefighter to make his own estimates. The following are some general guidelines which may assist him in making such estimates:

Morning winds. Shortly after sunrise winds from the east may be expected because heated air warmed by the sun which is already shining in more eastward areas will move toward the west as progressive heating occurs. This effect is most noticeable along ridges and at higher elevations.

Aspect and wind velocity. During a daily period wind velocities usually increase first on east-facing slopes and next on south-facing slopes. This order of increase in velocity occurs because east slopes are the first aspect heated by the sun in the morning. This progressive increase in wind velocity will continue to occur as the sun moves around the compass from east to west.

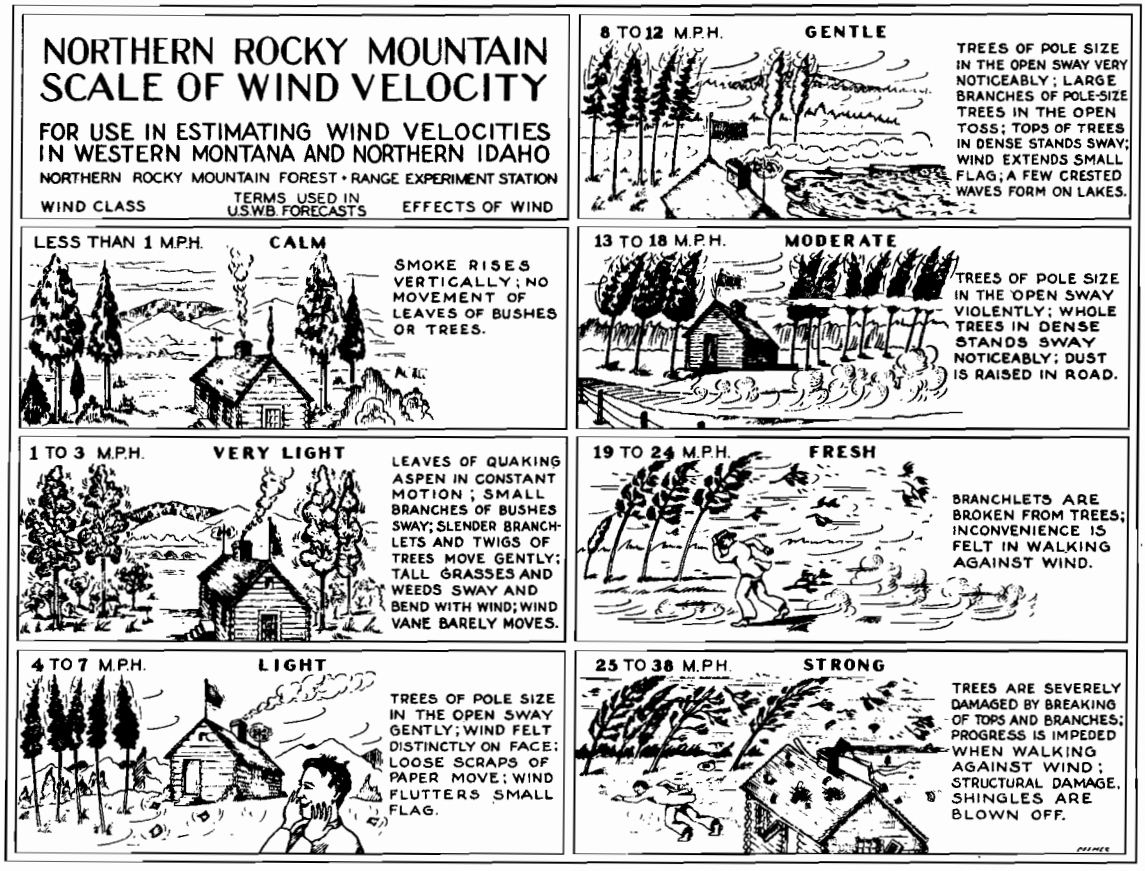

Figure 19. Use of the NRM scale of wind velocity enables estimates to be made of wind conditions when actual measurements are not available.

Upslope winds. In the morning at about 9 o'clock upslope winds will generally commence and will continue throughout most of the day. At 9 a.m. the night inversion which has resulted from radiational cooling and drainage of cold air into the valleys has been broken by the heating of air at lower elevations. This heated air is relatively light in weight and has a natural tendency to rise.

Downslope winds. In the late afternoon, shortly after shadows fall in an area, the upslope winds will stop. After a short transition period downslope winds will commence as heavy cold air drains into the valleys.

Peak wind velocities. Under normal atmospheric conditions mid-summer wind velocities normally reach their peak during the mid-afternoon hours. On the upper slopes of the mountains the peak velocities may be reached much later in the day, and frequently at night.

Fuel Moisture

The moisture content of forest fuels has an important influence on fire behavior. When fuels are moist, combustion is slow because part of the required heat is wasted in converting moisture to steam. As fuels become drier, the rate of combustion is increased because less heat is required to drive off moisture.

Fuel moisture is a factor which reflects the influence of other weather factors. Forest fuels pick up and give off moisture according to temperature, precipitation, dryness of the air, and wind. Fine fuels, such as grass, have the greatest day-to-day variation because more of the fuel surface is exposed to the air. Heavy fuels, such as large logs, fluctuate rather slowly in moisture content. Only the surface of a large log is exposed to air, and therefore drying or wetting must take place progressively from the outer layer inward. For this reason heavy fuels do not become very dry until long periods of dry weather have occurred. For the same reason light rains affect only the outer layer of a dry log, and the log will return to a dry condition again after the surface is exposed to dry air.

In fire control work throughout the West fuel moisture content is measured by specially prepared fuel moisture sticks $\frac{1}{2}$ inch in diameter which have an oven-dry weight of 100 grams. These sticks are exposed to the air at fire weather stations and are weighed daily to determine fuel moisture content in percent. Thus, a stick weighing 106 grams has a moisture content of 6 percent. The readings represent the moisture content of dead branchwood and other fuels of this character.

Research at the Priest River Experimental Forest has shown the average fluctuations of fuel moisture sticks. During July and August 69 percent of the days will have a late afternoon fuel moisture reading of 6 to 10 percent. On 19 percent of the days the moisture content will be over 10 percent, and on 12 percent of the days stick moisture falls below 6 percent. Readings of less than 6 percent indicate that small to medium-sized fuel particles are highly inflammable. Continued readings showing low moisture content in $\frac{1}{2}$-inch sticks indicate that heavier fuels are becoming very dry.

OBSERVED FIRE WEATHER FACTORS

In addition to factors which are measured at fire weather stations, several other aspects of weather may provide important information on the ignition and general behavior of fires. These observed factors include lightning, cloud cover, and certain weather indicators such as the occurrence of dust devils.

Lightning

In the northern Rocky Mountains lightning causes 75 percent of the fires. Lightning fires occur in every month from April through October, with July and August being the peak occurrence periods. Generally, the number of lightning fires builds up during the season in three stages, with occurrence rising steadily through the last of May, then falling off slightly before again building up to the seasonal peak reached in the last 10-day period of July. After the July peak a remarkable mid-season slump in lightning fires normally occurs in early August and then is followed by a third build-up lasting through the month and occasionally into September.

The region averages nearly 1600 lightning fires annually. The worst occurrence zones are in western Montana and northern Idaho forests. Nearly six times as many lightning fires occur in forests west of the Continental Divide as in the eastern slope forests. Lightning fires often occur in bunches. During the 15-year period 1931 through 1945 individual national forests had daily loads of 10 or more lightning fires on 354 occasions. During the same period daily regional loads of 50 or more fires occurred 76 times. In July 1940 nearly 1500 lightning fires occurred on the national forests during the middle 10-day period of July.

Lightning fires have several peculiar fire behavior characteristics. Ignition often takes place in aerial fuels such as tree tops or snags. Studies of approximately 12,000 fires have shown that nearly 50 percent of the lightning fires start in a dead snag, green tree top, or in tree moss (1). Burning material from these aerial fuels will drop to the ground and start fires there. If light to moderate amounts of rain occur with the lightning, these fires may smolder and remain undetected for a considerable length of time. Turbulent winds often accompany thunderstorms and may fan lightning fires in their incipient stages.

Cloud Cover

The type of clouds that pass over a fire may give indication of probable fire behavior. The average firefighter cannot be expected to be expert enough in meteorology to identify quickly and accurately all types of clouds. However, he should be alert to some basic and readily recognizable features of clouds which will provide valuable information on the probable behavior of a fire.

Cumulus type clouds are frequently troublemakers in that the air ahead of them and surrounding them is of a very turbulent nature. One of the most common cumulus type clouds is the cumulonimbus cloud normally associated with thunderstorms. As illustrated in figure 20, this cloud with its towering, turbulent-appearing head may be easily recognized. Whenever a

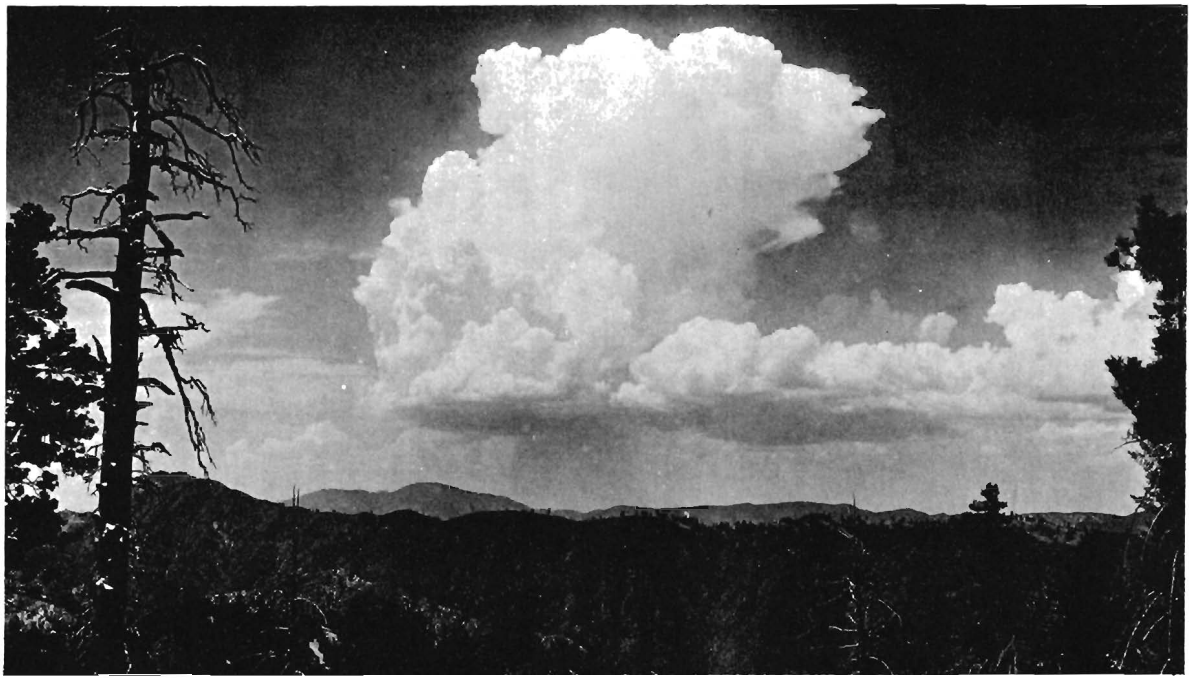

Figure 20. Cumulonimbus cloud. Turbulent air usually occurs in the vicinity of cumulonimbus clouds. (Photo by F. Ellerman, U. S. Weather Bureau)

sizable cumuliform cloud passes near a fire, stronger, gusty surface winds should be expected. The strongest winds will occur in front of the cloud blowing away from the cloud center, but some increased wind also should be expected on both leading sides of the formation, blowing away from the cloud. On a large fire cumulonimbus clouds may develop overhead because of the convective rise of great masses of heated air. In such cases the turbulent air resulting from the formation of the cloud usually will not materially affect the fire itself because that air will be moving ahead of the cloud.

Lenticular clouds, or windblown clouds as they are sometimes called, may often provide advance warning of an increase in wind velocity. As illustrated in figure 21, these clouds may be recognized by their tops which have a definite streamered or windblown appearance. When lenticular clouds appear in a fire area, the occurrence of high wind velocity in the upper atmosphere is indicated. This is often followed by increased wind velocities at ground level. Surface wind direction will be oriented in direction of obvious stream effect of lenticular clouds.

Stratified clouds virtually always indicate conditions favorable to the firefighter. When stratified clouds, such as the stratocumulus or altostratus shown in figure 22, are present, it is usually an indication of stable conditions in the atmosphere. Under stratified clouds vertical convection will be low and air movement will be limited. For these reasons fires may be expected to remain quiet when a more or less uniform covering of stratified clouds is present. This will be particularly true if stratified clouds are low.

Dust Devils

Dust devils are miniature whirlwinds in which turbulent air picks up loose soil and other fine material on the surface of the ground and lifts it into the air with a spiraling motion. Dust devils indicate the presence of very unstable air and are usually associated with high temperature conditions. They are especially noticeable in open, flat areas or areas which contain sparse vegetation. On a fire they may be sometimes observed inside the burn picking up ashes.

Dust devils may be the warning signal that a whirling action will occur on the fire. So-called blowups may be preceded by the appearance of dust devils. In all cases they should be regarded by the firefighter as a definite signal that gusty winds, changing wind directions, and general turbulent conditions are occurring or are about to occur, and that as a result the fire may be expected to pick up in intensity or possibly change the direction of its run. Although winds under these conditions will be gusty and locally changeable, the general movement usually will be south or southwest to north or northeast, and this direction will be shown by movement of the dust devils.

Figure 21. Lenticular clouds (altocumulus lenticularis) indicate high wind velocities at upper elevations and may be the warning signal that winds will increase at the site of a fire. (Photo by Maxwell Parshall, U. S. Weather Bureau)

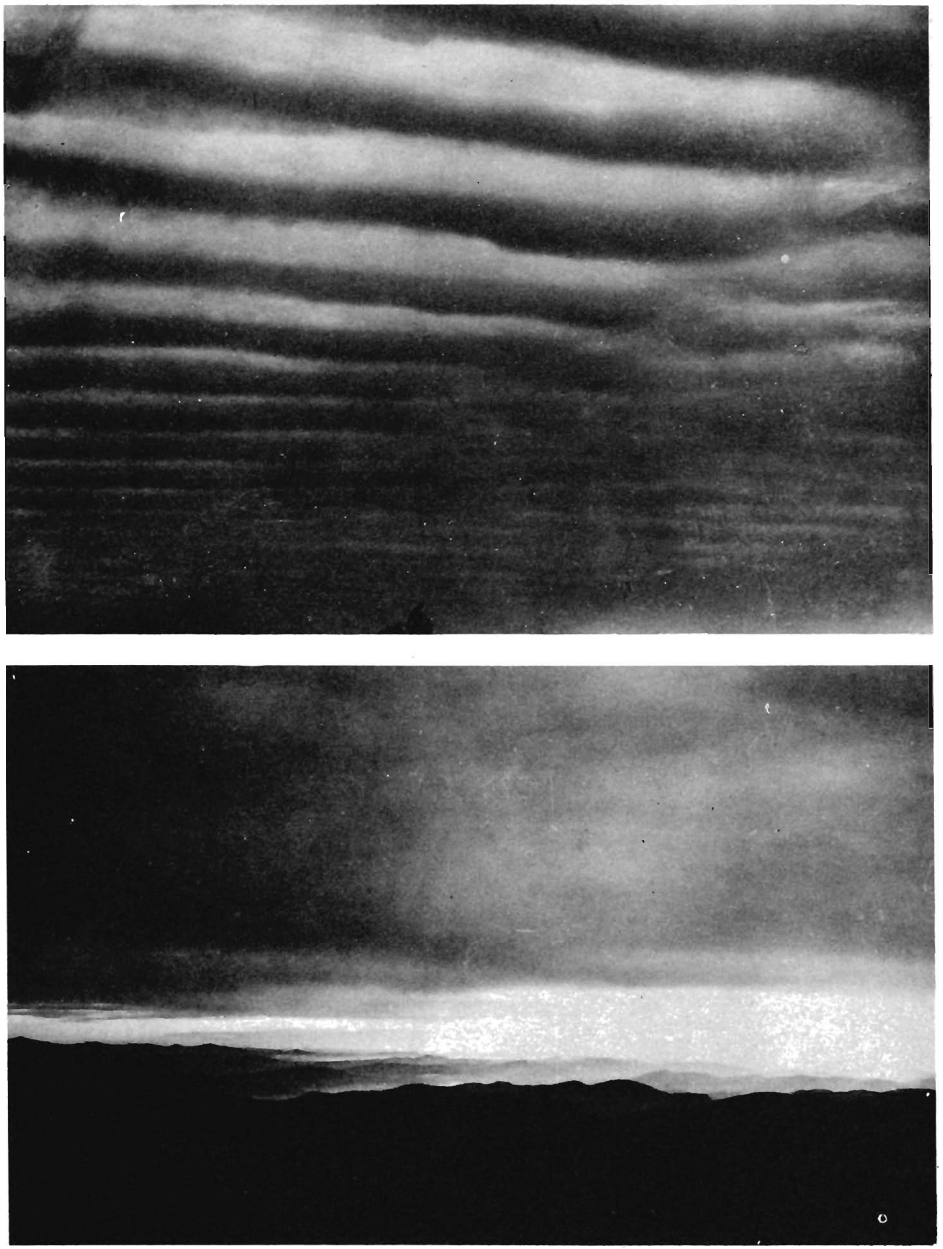

Figure 22. Stratified clouds, such as the stratocumulus in the upper photo and altostratus in the lower photo, indicate stable conditions in the atmosphere. Under such conditions fires will receive very little wind. (Photos by W. S. Davis and C. F. Brooks, U. S. Weather Bureau)

FIRE DANGER RATING

From the beginning of organized protection fire control men have recognized the need for a rating system which would integrate the effect of key weather factors on fire behavior. At the Northern Rocky Mountain Forest and Range Experiment Station fire research technicians have spent many years studying this problem and performing necessary field experiments (3). As a result fire control men now have an extremely valuable method of making systematic evaluations of burning conditions.

Burning Index

Burning index expresses the relative severity of burning conditions as influenced by key weather factors. The purpose of burning index is to provide a uniform system for evaluating and expressing burning conditions.

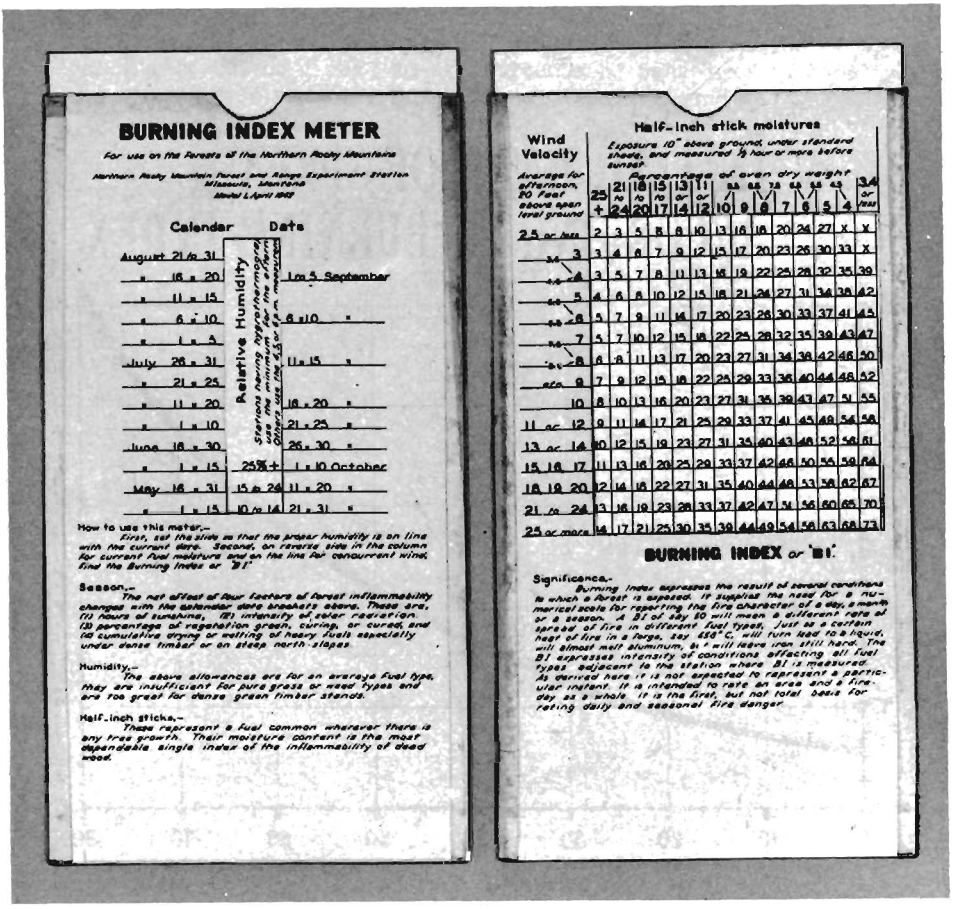

Figure 23. The Northern Rocky Mountain burning index meter.

In the old days one ranger might describe the burning conditions on his district as being "pretty tough." Another might say "dry as a bone." Still another might say "moderate, or not bad." These descriptions were not uniform in character nor could they be properly analyzed. Today the picture has changed. Fire control men now have a sound and uniform method of measuring, evaluating, and describing burning conditions. In describing the day-to-day situation all fire control men now talk the same language. They say burning index is 55 or 70 or whatever the situation may be as measured by instruments at fire weather stations and evaluated by the burning index meter.

In the northern Rocky Mountains four key factors are used in determining burning index. These factors in effect express the combined influence of many other weather factors. Calendar date is used to express the cumulative effect of drying of fuels as the fire season progresses. Relative humidity is used to evaluate the dryness of the air, and fuel moisture to evaluate the dryness of fuels. Wind velocity expresses the important factor of air movement. The combined effects of these four factors are rated by the Northern Rocky Mountain burning index meter (figure 23). Burning index is expressed in numerical terms from 1 to 100 with 1 indicating the easiest burning conditions and 100 the most severe.

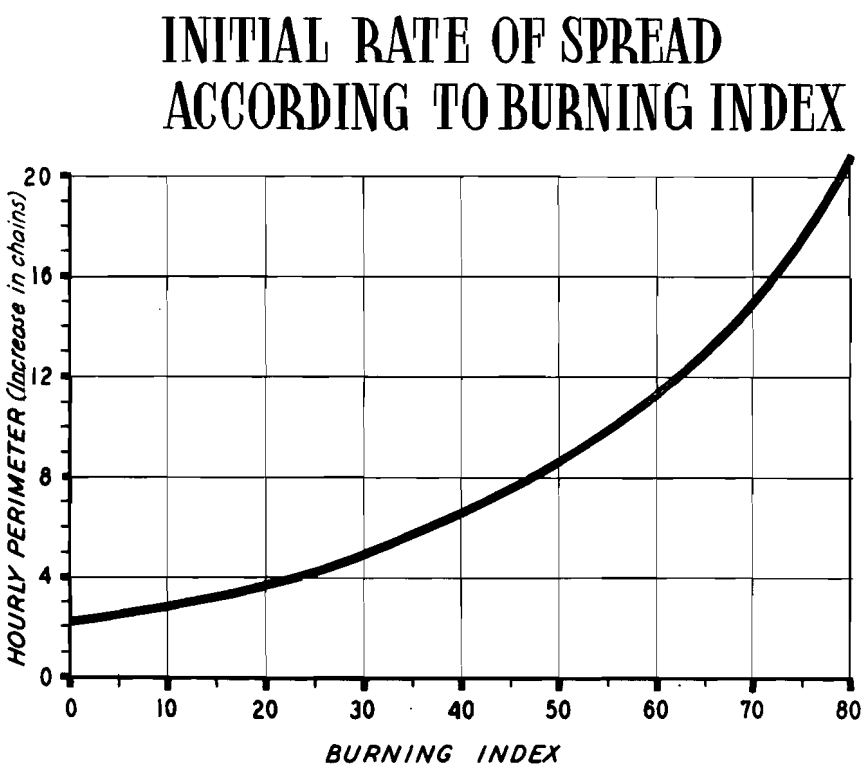

Figure 24. Average rate of spread from discovery to first attack according to burning index. (Basis 2953 fires, national forests, R-1, 1936-1948)

Studies of thousands of fires have shown the meaning of burning index. As burning index increases, the rate of spread of fires increases. Likewise, as burning index increases, the average final size per fire increases. As illustrated in figure 24, at a burning index of 20 the average initial rate of spread of fires from discovery to attack is less than 4 chains per hour perimeter increase. At a burning index of 80 average rate of spread increases to over 20 chains per hour. Studies of more than 10,000 fires have shown that final perimeters average nearly six times greater at a burning index of 80 than at a burning index of 20 (figure 25).

Burning index varies throughout each 24-hour period. Normally, the peak burning index is reached in the late afternoon hours and the lowest burning index in the early morning hours (figure 26). Hourly variations in burning index differ according to aspect and elevation. These differences are discussed in detail in the chapter on topography.

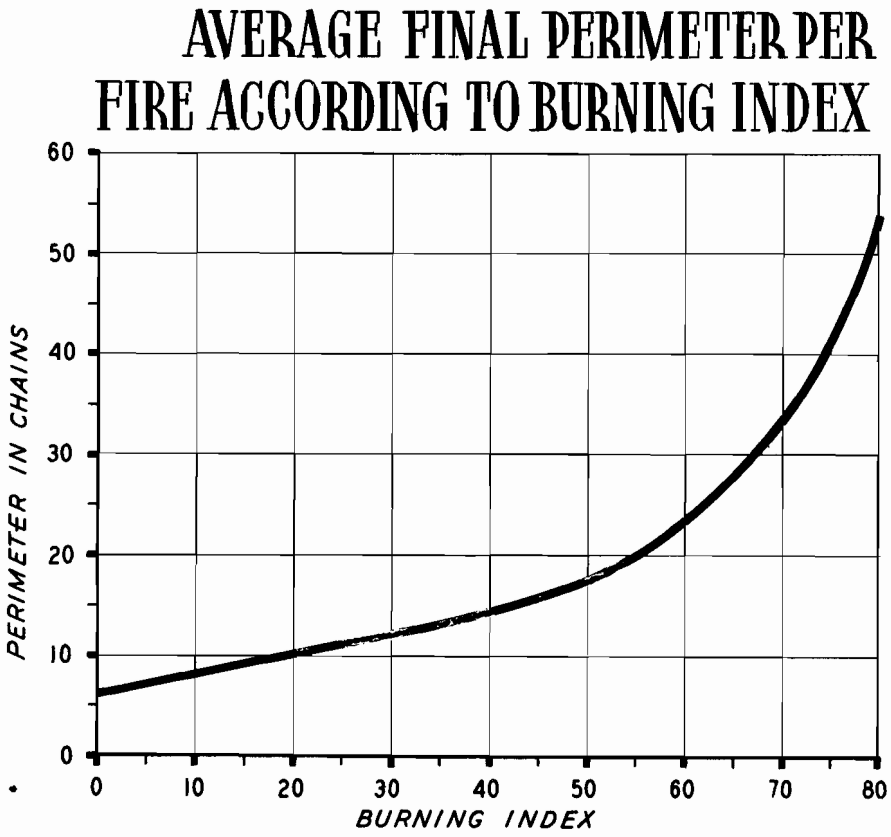

Figure 25. Average final perimeter per fire according to burning index on day of attack. (Basis 10,724 fires, national forests, R-1, 1936-1944)

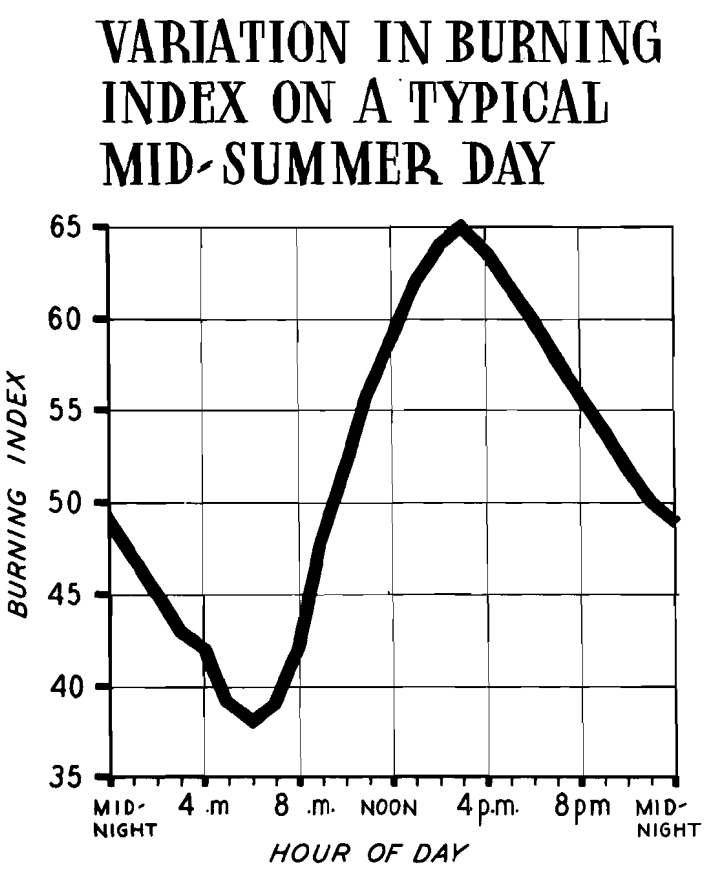

Figure 26. Average daily variation in burning index on a typical mid-summer day at the Priest River Experimental Forest. (Basis July-August observations, 1936-1939)

Use of burning index in evaluating fire behavior requires careful observation of daily ratings throughout the fire season. Daily ratings should be plotted on a chart so that seasonal trends can be visualized by the firefighter. When he estimates behavior of a specific fire, he should convert burning index as measured at fire weather stations to the probable index at the site of the fire. This can be done with conversion tables (contained in the appendix) which allow for variations caused by aspect and elevation at various periods of the day.

Under critical fire weather conditions it is often advisable to measure burning index at more than one time during the day. Normally, the instruments at fire weather stations are read and burning index computed just prior to 5 p.m. However, when action is being taken on fires at other

hours of the day, it is often necessary to obtain current information on burning index so that proper fire behavior estimates may be made. When weather conditions are stable, it is possible to anticipate changes in burning index for a few hours ahead. Tables for this purpose are contained in the appendix.

Burning index must be interpreted separately in each major fuel type. Fires in flashy fuels, such as dry grass, will begin to spread rapidly at a much lower burning index than in heavy fuels. Detailed studies of hundreds of fires have shown that the average rate of spread in dry grass is over 20 chains per hour at a burning index of 50. On the other hand, medium fuels, such as may be found in many coniferous forests, will have an average rate of spread of only 4 chains per hour at a burning index of 50. A series of tables contained in the appendix is available for making estimates of rate of spread in all major fuel types according to variations in burning index.

Fire Danger Classes

In evaluating fire danger two factors that have no influence on fire behavior -- lightning occurrence and visibility -- are added to burning index to obtain a fire danger rating. In the northern Rocky Mountains a fire danger meter is used for this purpose. The meter, as shown in figure 27, uses the burning index rating, visibility measured at lookout stations, and lightning occurrence during the last 24, 48, or 72 hours to obtain a numerical fire danger rating on a scale of 1 to 100. When visibility is restricted by haze or smoke, added danger is created because lookouts and others may not be able to detect fires, and therefore the danger class rating is raised by the meter. Likewise, when lightning has occurred, there is a stronger likelihood of an increased fire load. If visibility is unrestricted or lightning has not occurred, the burning index and fire danger ratings are the same. In estimating fire behavior the burning index meter should be used in all cases. The fire danger meter provides additional information needed in manning various positions and stations and in general fire preparedness planning.

An analysis of over 7000 daily observations obtained during a 12-year period has shown the frequency of occurrence of various classes of fire danger. In the northern Rocky Mountain region the danger class on over 42 percent of the days in July and August runs from 45 to 62. As illustrated in figure 28, very few days of especially low fire danger occur. Only 6 percent of the days in July and August have a danger rating of less than 28. However, 24 percent of the days in July and August have a fire danger rating of 63 to 78, and 4 percent have ratings of 79 to 95. Thus, during about 30 percent of the summer an especially high degree of fire preparedness is required.

WEATHER FORECASTS

Personnel throughout the fire control organization must be alert to changes in the weather. Good fire control men develop an attitude of constantly looking forward, of anticipating what the consequences will be of either improved or more critical weather in the hours and days ahead. In studying

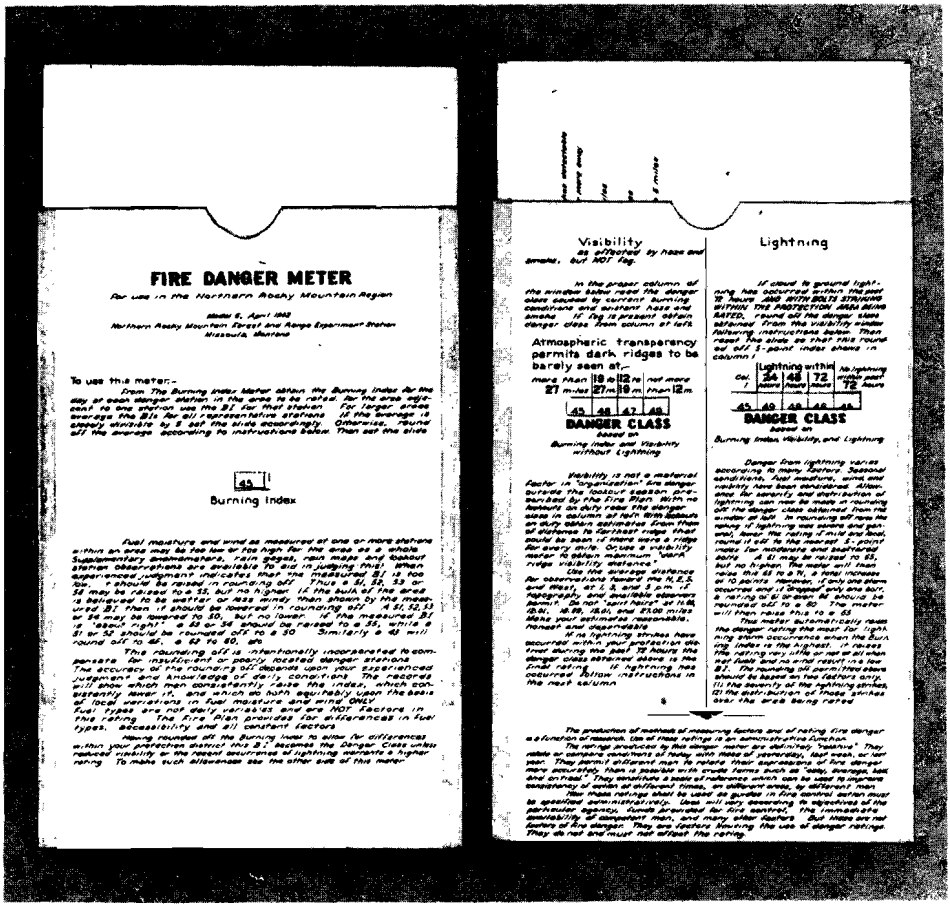

Figure 27. The Northern Rocky Mountain fire danger meter.

probable fire behavior, the firefighter must compare today's weather with that which will probably occur tomorrow. On a going fire the fire behavior conditions brought about by current weather must be compared with those which may be anticipated in the immediate future.

During the fire season daily fire weather forecasts are issued to all fire control organizations. While these forecasts are localized by the Weather Bureau as far as possible, they are necessarily somewhat broad in character. To make these forecasts fully useful, fire control men on each protection unit should analyze their significance in accordance with local knowledge of the country and of the generally prevailing weather.

Wherever possible the weather forecast should be interpreted in terms of burning index. For example, assume that the burning index at 5 p.m. today is 65. For tomorrow the weather forecast predicts lower humidity

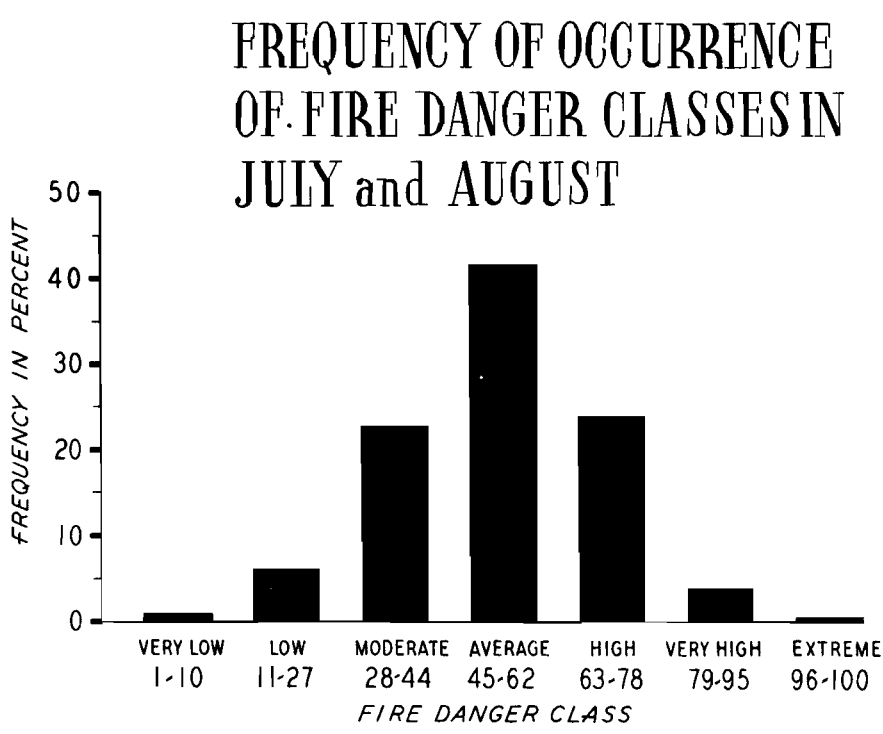

Figure 28. Frequency of occurrence of various classes of fire danger during July and August. (Basis 7440 daily observations on the 11 western national forests, R-1, 1936-1945)

and stronger winds. With such a forecast a much higher burning index would be expected. Calculations of this nature should be made every day. Daily practice in this procedure assists greatly in the development of ability to interpret weather forecasts and, as a result, to become more skilled in estimating fire behavior.

Figure 29. Topography is an important factor in fire behavior in rough, mountainous country.

CHAPTER IV. TOPOGRAPHY

In rough country such as the northern Rocky Mountains topography has a great influence on fire behavior. Land masses influence the general climate of an area, but in addition differences in topography cause local variations in climate and day-to-day weather conditions. These variations in turn influence the character of forest growth and the inflammability of fuels.

Topography provides a useful and easily recognized indicator of fire behavior. Fires often have distinctive behavior characteristics according to aspect, elevation, position on slope, steepness of slope, and shape of the surrounding country. These topographic features are usually easy to identify in the field and thus are important factors in the evaluation of fire behavior.

ASPECT

Aspect, sometimes referred to as exposure, describes the direction in which a slope faces. Fire conditions vary greatly according to aspect. These variations occur primarily because different aspects receive different amounts of sunshine and wind.

In general, south and southwest slopes provide favorable conditions for the ignition and spread of fires. These slopes receive more direct sunshine, and therefore air and fuel temperatures are somewhat higher. Over much of the northern Rocky Mountain region summer winds from the southwest are hot and dry. Snow melts at an earlier date on south slopes. For these reasons the vegetation on south-facing slopes is not only sparser but is also drier and more inflammable than vegetation on north-facing slopes.

Research at the Priest River Experimental Forest has shown north and south slope variations in temperature and relative humidity (4). On south slopes average July-August temperature in higher and relative humidity is lower. However, as discussed later in this chapter, elevation also plays an important part in these variations. When the combined effects of aspect and elevation are considered, some striking indicators of fire behavior become evident.

Detailed studies of over 21,000 fires on the national forests have shown how fire occurrence and rate of spread vary by aspect (1). More fires occur on south and southwest slopes than on any other aspect. As shown in figure 30, about 31 percent of all fires occur on these two aspects. Similarly, more fires become large in size on these aspects. About 7 percent of the fires originating on south or southwest slopes reach sizes of 10 acres or more (figure 31). On north slopes less than 3 percent of the fires reach these sizes. The large-fire potential is nearly $2\frac{1}{2}$ times greater on south or southwest slopes than on north slopes.

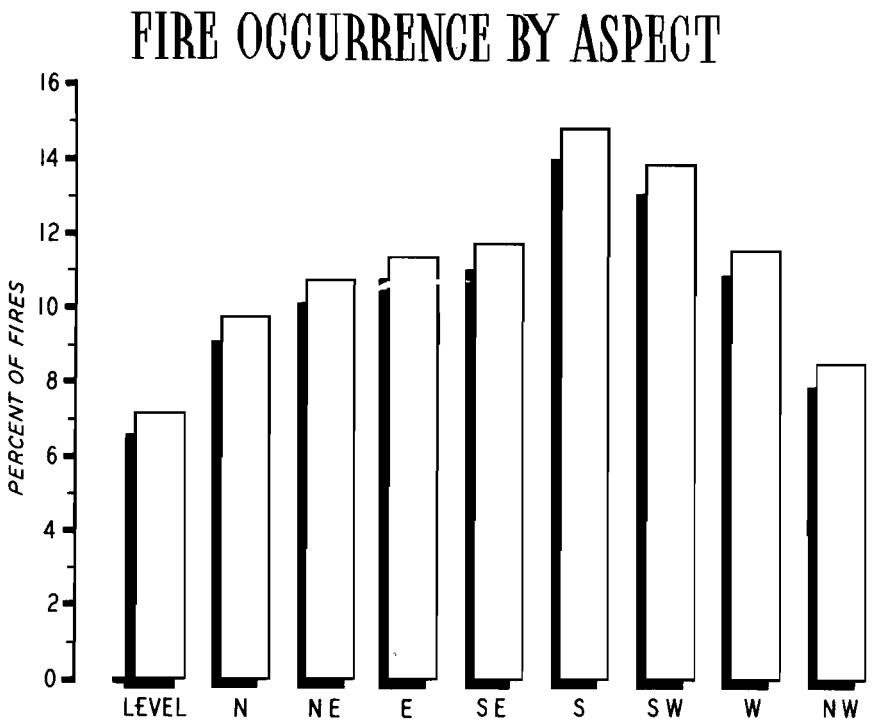

Figure 30. Percent of fires according to aspect at point of origin. (Basis 21,048 fires, national forests, R-1, 1931-1944)

ELEVATION

In the northern Rocky Mountains there is a vertical difference of more than 10,000 feet between the lowest valleys and the highest mountains. At Lewiston, Idaho, the elevation is only 757 feet above sea level. Along the Continental Divide there are many peaks over 10,000 feet, and in northwestern Wyoming some peaks are over 13,000 feet above sea level. Between these extremes of elevation are a variety of weather and fuel conditions which create distinctive fire control problems.

Fire behavior evaluations call for the interpretation of two broad elevation factors -- elevation above sea level and elevation in relation to surrounding country.

Elevation Above Sea Level

Climatic differences in the northern Rocky Mountains may be readily observed. On a hot July day a man in shirt sleeves standing in a valley bottom may look up at eternal snow on mountain peaks. This man is in a

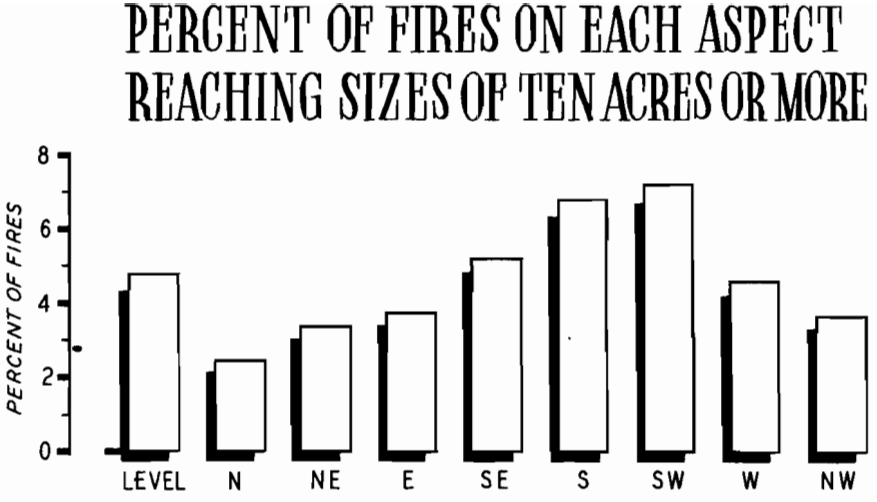

Figure 31. The percent of fires reaching large size increases steadily around the compass from north to south. (Basis 21,048 fires, national forests, R-1, 1931-1944)

temperate climatic zone, but the mountain peaks above him are in a subartic zone. Between these two extremes are a wide range of climatic conditions in which forest fire behavior problems are vastly different.

For fire control purposes northern Rocky Mountain topography may be classified into four broad elevation zones -- lowland, mountain, subalpine, and alpine. Elevation ranges within these zones will vary somewhat according to latitude and position east or west of the Continental Divide. A summary of the important factors within these zones is shown in table 1.

The lowland zone is generally the most arid part of the northern Rocky Mountain region. With the exception of some areas in northern Idaho and northeastern Washington, tree growth is limited in this zone. Outside the agricultural areas, grass, brush, and scattered stands of ponderosa pine characterize the vegetation. The fire season is longer in this zone than in any part of the region. Snow has usually melted in this zone by the end of March. Generally, the fire season begins in May and continues through most of October. Except in very wet seasons, grass and other herbaceous vegetation begin to cure early in July and by the middle of the month are in a highly inflammable condition.

The mountain zone contains the great bulk of the forest growth. Fire conditions within this zone vary widely according to local climatic factors. Snow begins to melt in April, and a large part of the zone contains bare ground by the end of May. The fire season is shorter than in the lowland zone and generally begins about the middle of June, reaches a peak during the last 2 weeks of August, and extends through most of September. Herbaceous vegetation normally begins to cure late in July and is highly inflammable by the middle of August.

Table 1. Fire conditions in various elevation zones in the northern Rocky Mountains

Elevation Zone	Position Relative to Continental Divide	Elevation Range 1/	Average Date Snow Melts 2/	Average Date Grass Cures 3/	Average Length of Fire Season 4/
Lowland	East	3000-5000 feet	March 20-April 10	July 15-30	May 15-Oct 15
	West	1000-3000 feet	March 15-30	July 5-20	May 1-Oct 20
Mountain	East	5000-8000 feet	April 10-June 15	July 25-Aug 15	June 15-Sept 20
	West	3000-6000 feet	April 1-June 15	July 20-Aug 10	June 20-Sept 20
Subalpine	East	8000-10,000 feet	June 15-July 25	Aug 15-Sept 1	July 20-Sept 15
	West	6000-9000 feet	June 15-Aug 1	Aug 10-Sept 1	July 25-Sept 15
Alpine	East	Above 10,000 feet	July 15-Aug 25 5/		
	West	Above 9000 feet	Aug 1-Sept 1 5/		

1/ Elevation above sea level.
2/ Average date when about 90 percent of ground is exposed.
3/ Average date when more than 50 percent of herbaceous vegetation will ignite and carry fire.
4/ These dates indicate periods when about 90 percent of fires will occur. A few fires may occur before and after these dates. Peak of fire season when maximum preparedness is needed is a much shorter period.
5/ Many snow fields never melt.

The subalpine zone is an area of great contrasts. During much of the year this zone is covered with snow, but during a short part of the summer very high fire danger may prevail. Forest growth is characterized by mixed stands of Engelmann spruce, alpine fir, and limber and white-barked pine. The fire season is short, usually extending only from late July into the first week or two of September. Most of the snow does not melt until July, and scattered snow banks may remain through August. In a normal season very little of the grass cures. Under severe conditions scattered stands of cured and highly inflammable grass will be found in late August. High winds are common in this zone.

The alpine zone generally presents no fire problem in this region. This zone occurs only in the highest mountain areas and is almost entirely devoid of tree growth. Tundra, alpine flowers, and grasses characterize the vegetation. Only in the most critically dry seasons will any of this vegetation carry fire.

Elevation in Relation to Surrounding Country

Mountain tops and valley bottoms have different burning conditions at various times during a 24-hour period. Under settled, mid-summer atmospheric conditions a daily interchange of air occurs between the valley bottoms and the mountain tops. During the day the air in the valley bottoms is much warmer than that near the mountain tops. Because of its light weight this heated air has a tendency to rise. At night when the heating by the sun discontinues, heavier cold air masses drain into the valley bottoms. As a result of this interchange, summer nighttime temperatures are usually lower in the valley bottoms than at the mountain tops.

Research at the Priest River Experimental Forest has shown the differences in both temperature and relative humidity between valley-bottom and mountain-top stations (4). As illustrated in figure 32, July-August temperatures have been found to be higher on the mountain tops from 10 p.m. through 6 a.m. The mountain-top air is also drier at night. At Priest River relative humidity was found to be lower on the mountain tops from 8 p.m. through 8 a.m. Tests elsewhere in the region have shown that these same conditions generally prevail.

The differences between valley bottoms and mountain tops are very important in evaluating fire behavior. For about a 12-hour period from 8 a.m. to 8 p.m. valley bottoms have the most dangerous fire conditions. As night approaches the trend is reversed. Cool, moist air pours into the valley bottoms and the fire danger diminishes. However, on the upper slopes fire danger is higher, and for this reason many fires may not quiet down materially during the nighttime hours.

The Thermal Belt

As pointed out above, fire conditions are different at various times of day on the mountain tops and in valley bottoms. Between these two extremes is a mid-slope area called the thermal belt where summer fire conditions are usually more severe than in any other topographic subdivision.

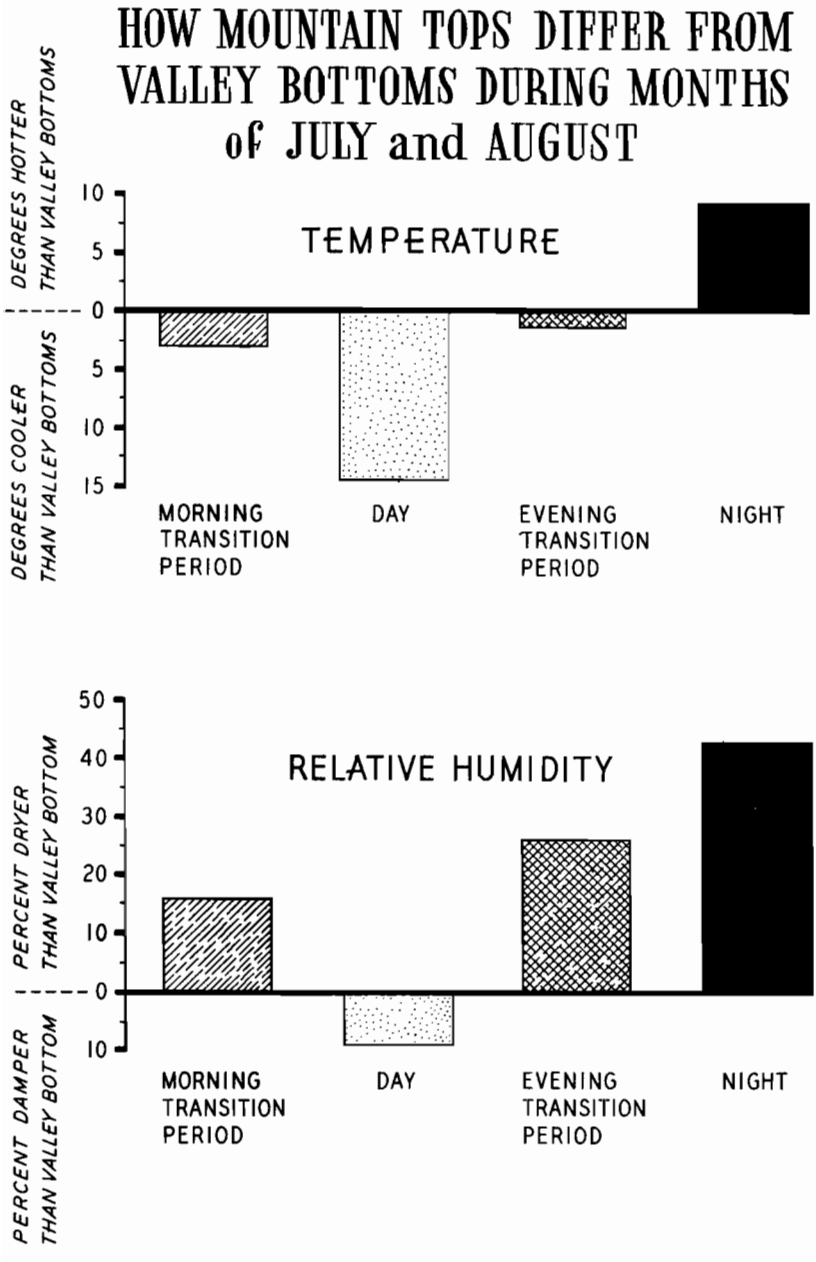

Figure 32. Variations in temperature and relative humidity during July and August between mountain tops and valley bottoms at Priest River Experimental Forest, Idaho. (Basis 1936-1939 measurements at weather stations located at 2300 feet and 5600 feet above sea level)

The thermal belt normally occupies the middle one-third of mountain slopes, and its elevation range in the northern Rocky Mountains may vary from 3000 to 8000 feet. During settled July-August weather conditions the thermal belt has neither the very high temperatures of valley bottoms nor the relatively low temperatures of the mountain tops. Research at the Priest River Experimental Forest has shown that during a 24-hour period the thermal belt has higher average temperatures and lower relative humidity than occurs in any other zone (4).

Elevation and Fire Occurrence

In the northern Rocky Mountains elevation is an important indicator of fire occurrence. More fires start on or near the mountain tops than in any other position. As shown in figure 33, 35 percent of all fires on the national forests start near the top of a slope. Mid-slope areas have the second greatest number of fires, base of the slope third, and level areas have the fewest fires.

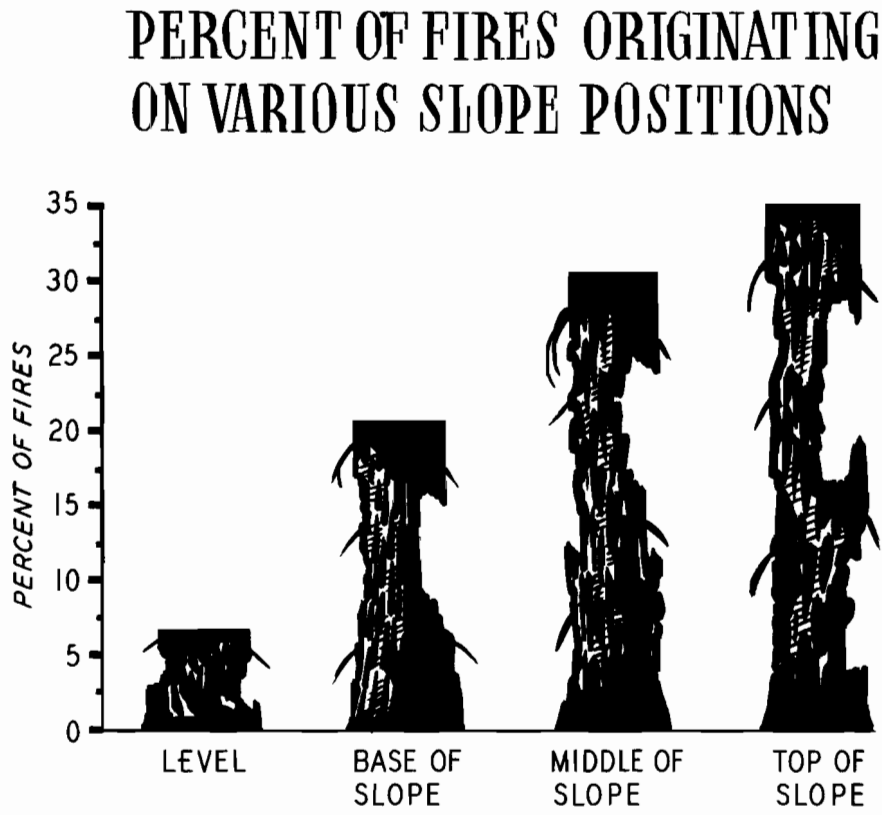

Figure 33. Percent of fires according to slope position at point of origin. (Basis 12,796 fires, national forests, R-1, 1931-1939)

Lightning accounts for the high fire occurrence near the mountain tops. This is especially true in areas where the elevation range and other factors are of a nature which permits tree growth to the tops of the mountains. As shown in figure 34, 74 lightning fires per million acres occur between 5000 and 6000 feet in the national forests lying west of the Continental Divide. In the national forests east of the Continental Divide the greatest number of lightning fires occur at the lowest elevations. The reason for this unusual situation is probably that many of the high mountain areas on the eastern national forests contain very sparse fuels. On the other hand, the area lying between 3000 and 4000 feet is characterized by scattered stands of ponderosa pine and grass. Such fuels become very dry during the fire season and are easily ignited.

Man-caused fires occur in greatest numbers in the elevation zones where Man's activities are the greatest. In the forests lying west of the Continental Divide the greatest number of man-caused fires occur between 2000 and 3000 feet. In the national forests lying east of the Continental Divide peak man-caused fire occurrence is in the 5000- to 6000-foot zone.

COMBINED EFFECTS OF PERIOD OF DAY, ASPECT, AND ELEVATION

The foregoing paragraphs have emphasized basic influences of aspect and elevation on fire ignition and behavior. When a firefighter sizes up burning conditions, he must consider the combined effects of these factors. In addition he must recognize that the combined effects of aspect and elevation will be different during various periods of the day.

The combined effects on fire behavior of period of day, aspect, and elevation may be illustrated by observing how burning index fluctuates under the influence of these factors. Table 2 illustrates these fluctuations on a typical mid-summer day. Assume that at 8 a.m. during the morning transition period burning index, as measured at a valley-bottom fire danger station, is 40. On the same day at 2 p.m. the burning index has increased to 61. At 8 p.m. during the evening transition period burning index has dropped to 53, and by 2 a.m. it is down to 43. These are typical variations in burning index during settled mid-summer weather. The lowest burning index is recorded during the morning transition period and the highest during the day, usually in the late afternoon.

The problem of the firefighter is to convert the valley-bottom burning index to that which will probably occur at some place on a mountain slope. Table 2 shows the general relationships of burning index on various aspects and elevations to that occurring in the valley bottom. These relationships may be summarized as follows:

Lower elevations. On the north slopes burning index is lower during all periods of the day and night than at valley-bottom stations. On south slopes burning index is slightly higher during all periods except the evening transition period when it is about the same as the valley bottom.

Thermal belt. On north slopes burning index is about the same as the valley bottom during the morning transition period, is lower during the day and evening transition period, and is higher at night. On south slopes burning index is higher at all times than in the valley bottom or at any other elevation.

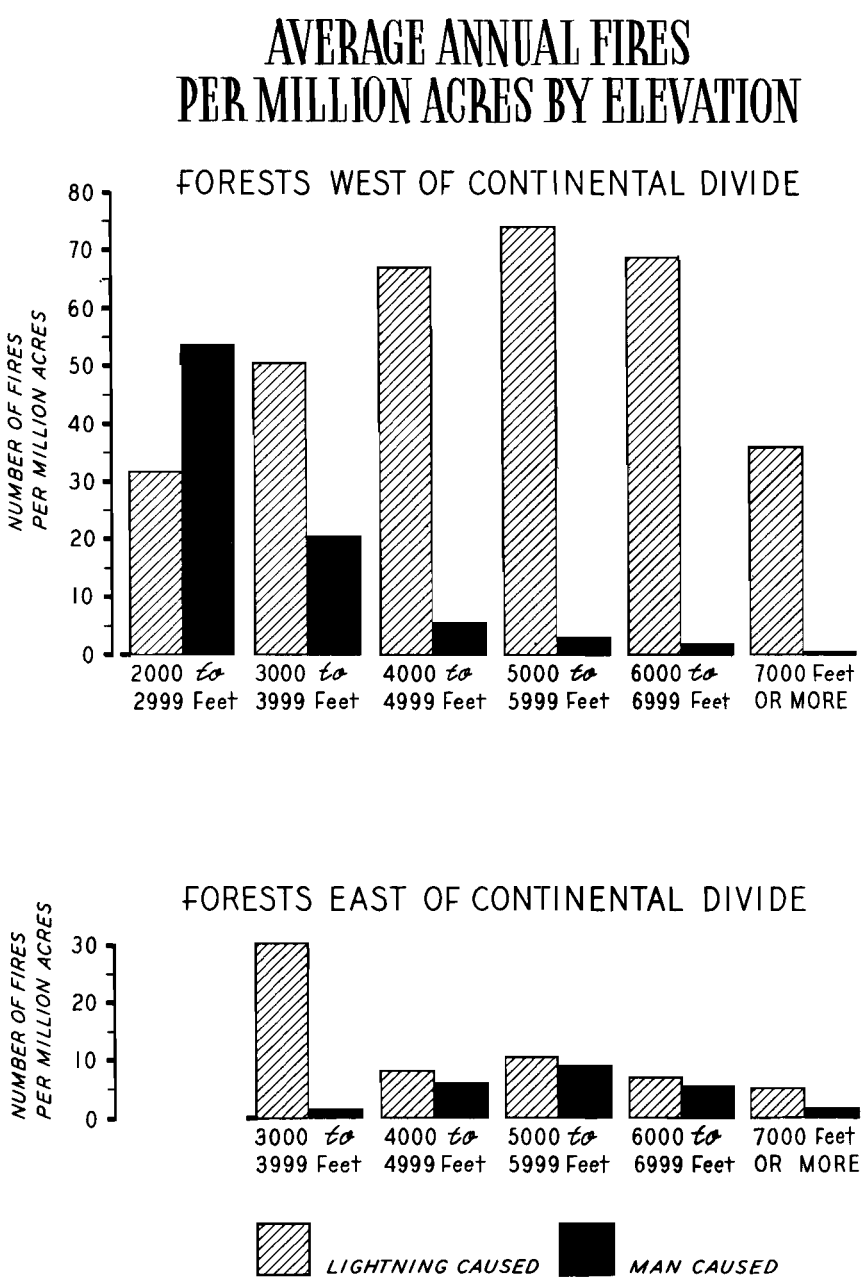

Figure 34. Average annual number of fires per million acres in each 1000-foot elevation zone in forests east and west of the Continental Divide. (Basis 16,793 fires, national forests, R-1, 1936-1944)

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Table 2. How burning index varies by period of day, aspect, and elevation 1/

Period of Day	Burning Index at Valley Bottom Station	Burning Index on Mountain Slopes			
		Aspect	Lower Elevations	Thermal Belt	Higher Elevations
Morning Transition Period 6 a.m. - 10 a.m.	40	North	30	40	40
		South	43	54	47
Day Period 10 a.m. - 6 p.m.	61	North	44	50	52
		South	64	66	58
Evening Transition Period 6 p.m. - 10 p.m.	53	North	38	49	47
		South	54	57	51
Night Period 10 p.m. - 6 a.m.	43	North	37	45	45
		South	45	51	48

1/ Based upon July-August measurements at Priest River Experimental Forest, 1936-1939.

Upper elevations. On north slopes burning index is about the same during the morning transition period as at the valley bottom, is lower during the day and evening transition period, and is higher at night. On south slopes burning index is higher than the valley bottom at night and during the morning transition period, and is lower during the day and evening transition period. In general, there is less difference between north and south slopes at upper elevations than in the thermal belt or at lower elevations.

Analysis of many thousands of fires in several years of fire weather measurements has provided data for tables showing burning index conversion factors for all hours of the day at various aspects and elevations. These tables, contained in the appendix, are intended for use as general guides in evaluating fire behavior. However, they must be interpreted as showing trends and are not intended to show exact burning index ratings.

POSITION OF FIRE ON SLOPE

Fire behavior at various positions on a slope may be influenced not only by aspect and elevation but also by the magnitude of the fuel body and topographic barriers. When a fire starts at the bottom of a slope, an entire mountainside of fuels may lie in its path. Once a fire starting at the base of a slope gains headway, the availability of a continuous fuel body makes a large burn possible. As shown in figure 35, a high percentage of fires starting at the base of a slope reach sizes of 10 acres or more. The fact that these fires are large in size probably means that they travel into the thermal belt, and in many cases into the upper slopes. The dangerous burning conditions in the thermal belt and at some periods of the day in the upper slopes may contribute to the large size of such fires.

STEEPNESS OF SLOPE

Other conditions being equal, fires burn more rapidly on steep slopes. In general, as steepness of slope increases, rate of spread increases. As explained previously, combustion is accelerated on steep slopes primarily because of increased heat transfer through radiation and convection.

Because of the rugged character of the country in the northern Rocky Mountains the majority of the fires will occur on moderate to steep slopes. Studies of over 21,000 fires on the national forests have shown that 62 percent of the fires occur on slopes that are steeper than 20 percent. Only 16 percent of the fires occur on slopes of 5 percent or less. These studies have shown also that more fires spread to large size on the steeper slopes. As illustrated in figure 36, over 7 percent of the fires on very steep slopes reach sizes of 10 acres or more as compared to less than 4 percent on gentle slopes.

Fires running up a slope generally have a wedge shape similar to the shape of fires driven by strong winds (figure 37). Flames on the flanks of the fire will be pulled inward by the intense heat. When fires reach

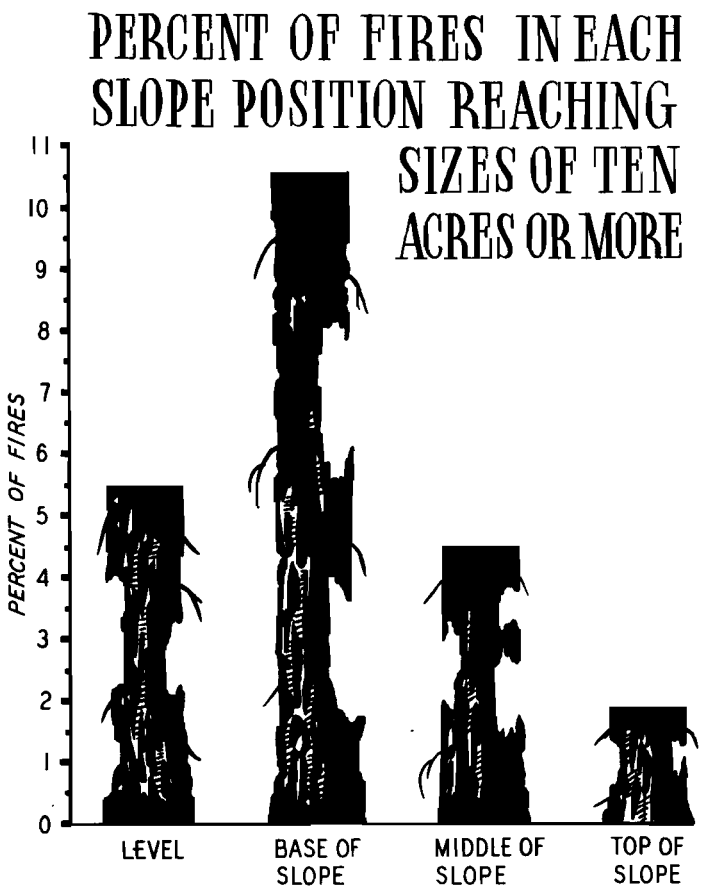

Figure 35. More fires starting at the base of the slope reach large size because a greater fuel area is available for spread of the fire. (Basis 12,796 fires, national forests, R-1, 1931-1939)

the top of a slope, the flames usually will be bent back toward the rear of the fire (figure 38). This typical curling back of flames at the slope summit is caused by the natural rise of warm air on the opposite slope as well as the tendency of this air to be drawn toward the fire.

Fires may travel rapidly downhill, especially at night when air masses are moving downslope. Fires may be expected to travel downhill whenever a temperature inversion is causing heavier air to flow into valley bottoms. Normally, this downslope spread of fires will be slower than the upslope spread except where strong winds accompany the inversion.

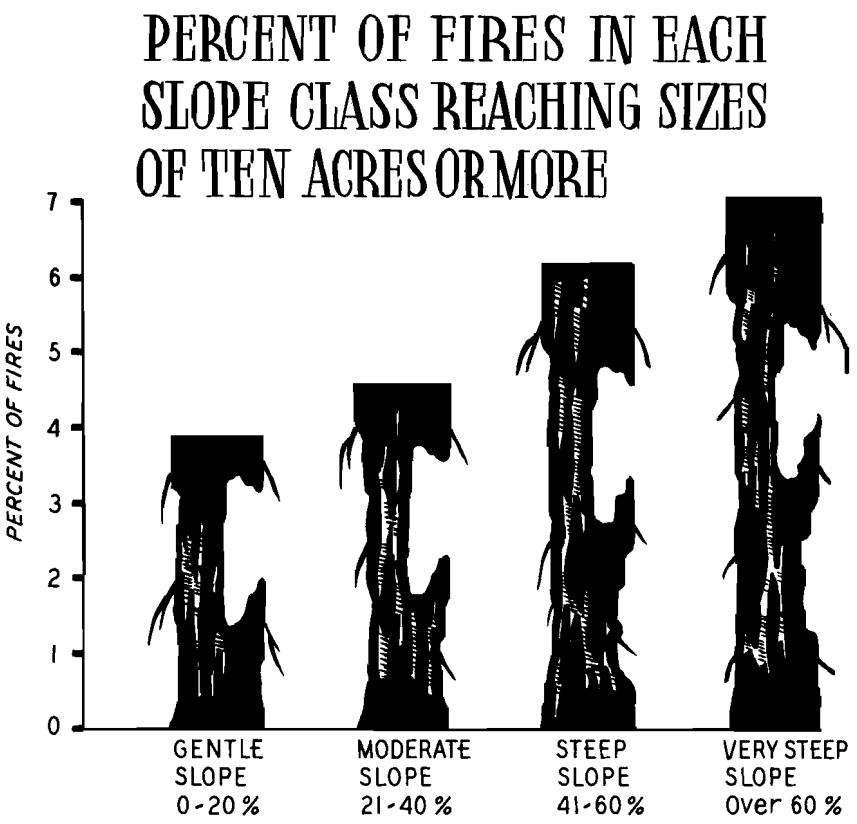

Figure 36. As slope steepness increases, a higher percentage of fires reach large size. (Basis 21,158 fires, national forests, R-1, 1931-1944)

In forest areas a ground fire creeping downslope may create a dangerous situation for a reburn in the tree crowns. Heat from the ground fire dries out the tree crowns as it moves downslope; and whenever conditions are favorable for an upslope movement of air, a crown fire is likely. This condition is most likely to occur on the day after a night movement of a fire downslope.

Steep slopes exert several physical effects on a fire. Burning material may roll downhill and start spot fires below the main fire. On steep slopes a vertical fire line running up and down the slope on the sides of a fire may be outflanked by a spot fire starting on the bottom of the slope (figure 39). Because of this possibility the flanks of fires on steep slopes cannot be considered safe until the lower slope portions have been thoroughly mopped up.

FIRES ON STEEP SLOPES HAVE A WEDGE SHAPE

Figure 37. Fires on steep slopes usually are characterized by a definite head, wedge shape, and flames on the flanks drawn inward.

FLAMES BEND BACK INTO THE FIRE AT THE TOP OF A SLOPE

Figure 38. As a fire reaches a slope summit, the updraft from the opposite side of the mountain will bend flames into the burn.

SPOT FIRES ON STEEP SLOPES MAY OUTFLANK MAIN FIRE

Figure 39. The spot fire on the left of the fire line may burn rapidly upslope and outflank the main fire.

SHAPE OF COUNTRY

In rugged mountainous areas the shape of the country is of great importance to the firefighter who must evaluate fire behavior. Narrow canyons, side drainages, sharp ridges, and massive irregular slopes all have a bearing on the direction of travel, rate of spread, and general behavior of fires. Experience in this region has shown the following topographic features to be of special importance:

Narrow canyons. Wind direction will normally follow the direction of the canyon. Wind eddies and strong upslope air movement may be expected at sharp bends in a canyon. Radiant heat transfer from one slope to another is great, and as a result fires may easily spot across the canyon (figure 40). Near the bottom of the canyon there is little difference between conditions on various aspects.

Wide canyons. Prevailing wind direction will not be altered to any great extent by the direction of the canyon. Cross-canyon spotting of fires is not common except in high winds. Strong differences will occur between general fire conditions on north and south aspects.

Box canyons. Fires starting near the base of box canyons will react similar to a fire in a stove (figure 41). Air will be drawn in from the canyon bottom creating very strong upslope drafts. These same conditions may occur at the head of narrow canyons and at the head of high mountain valleys.

FIRES EASILY CROSS NARROW CANYONS

Figure 40. Fuels on the opposite slope from a fire in a narrow canyon are subjected to intense heat and flying embers.

FIRES IN A BOX CANYON HAVE AN UPWARD DRAFT LIKE A FIRE IN A STOVE

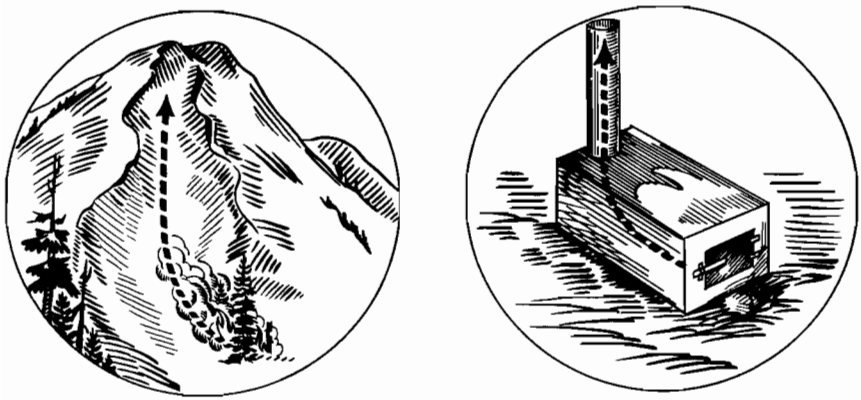

Figure 41. Box canyons and chimneys created by sharp ridges provide avenues for intense updrafts.

Ridges. Fires burning along lateral ridges may change direction when they reach a point where the ridge drops off into a canyon (figure 42). This change of direction is caused by the flow of air in the canyon. In some cases a whirling motion by the fire may result from a strong flow of air around the point of a ridge.

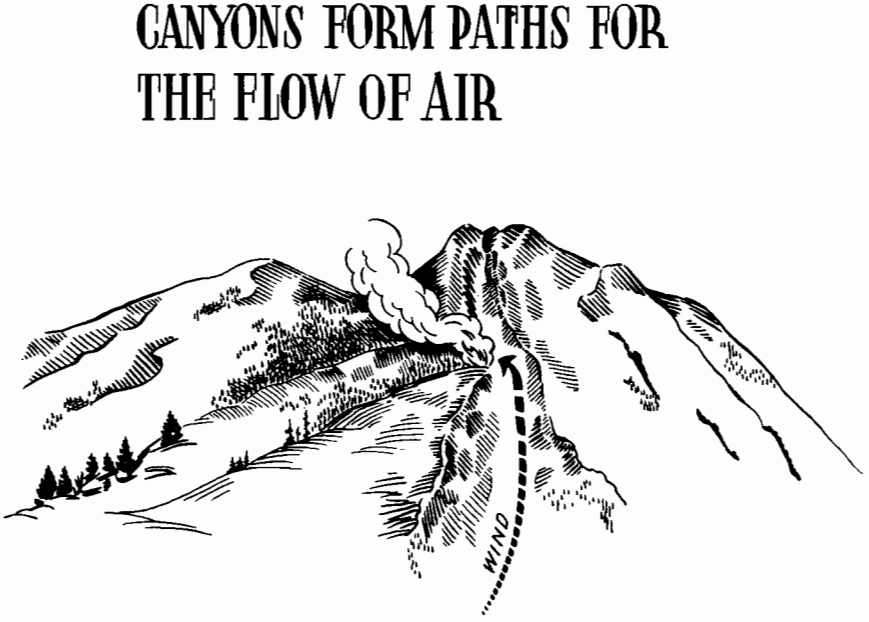

Figure 42. In narrow canyons wind may follow the direction of the canyon. Fires approaching a canyon on a lateral ridge may change direction when they reach the zone influenced by the canyon air movement.

Figure 43. A forest contains a wide variety of fuel lying on the ground and suspended in the air. Recognition of the inflammability of various fuel combinations is an essential part of fire behavior analysis.

CHAPTER V. FUELS

Keen observation of variations in forest fuels is essential in making reliable estimates of fire behavior. Fuel is the material of primary concern to fire control men. The good firefighter must be able to evaluate both inflammability and difficulty of control in the various fuel situations encountered in a forest area.

INFLAMMABILITY ANALYSIS

In a forest great differences exist in the character of the inflammable material. Deep duff, newly fallen dead leaves, clumps of grass, litters of dry twigs and branches, down logs, low shrubs, green tree branches, hanging moss, snags, and many other types of material are present. Each of these materials has distinctive burning characteristics. The inflammability of a particular fuel body is governed by the burning characteristics of individual materials and the combined effects of the various types of materials present.

Before fuel inflammability can be analyzed, the physical characteristics of combustible forest materials must be classified. Such a classification permits the identification of the fuel factors which influence inflammability. After the fuel has been properly classified, topographic and weather factors must be considered before rate of spread and general behavior of fires in that fuel can be determined.

Because forest fuels are so varied and complex, it is necessary to develop a systematic approach to inflammability analysis. First, the fuel body is subdivided into two broad classes -- ground fuels and aerial fuels (figure 44). Then each of these classes is evaluated according to the arrangement, compactness, continuity, volume, and moisture content of the principal materials involved. To the beginner in fuel classification the inflammability analysis procedure may seem somewhat complex and time-consuming. However, after practice the procedure becomes more or less automatic and is performed quickly and easily. The thoroughly trained and experienced fire man constantly, although subconsciously, makes an inflammability analysis of the various fuels encountered on a fire.

GROUND FUELS

Ground fuels include all inflammable material lying on or immediately above the ground or in the ground. The principal materials are duff, tree roots, dead leaves, grass, fine dead wood, down logs, stumps and large limbs, and low brush and reproduction.

Duff

Duff is partially decayed vegetative matter on the forest floor. Duff seldom has a major influence on the rate of spread of a fire because normally it is moist and rather tightly compressed so that little of the surface is freely exposed to air. However, duff is inflammable even though the rate of combustion is slow. In forest fires most of the duff

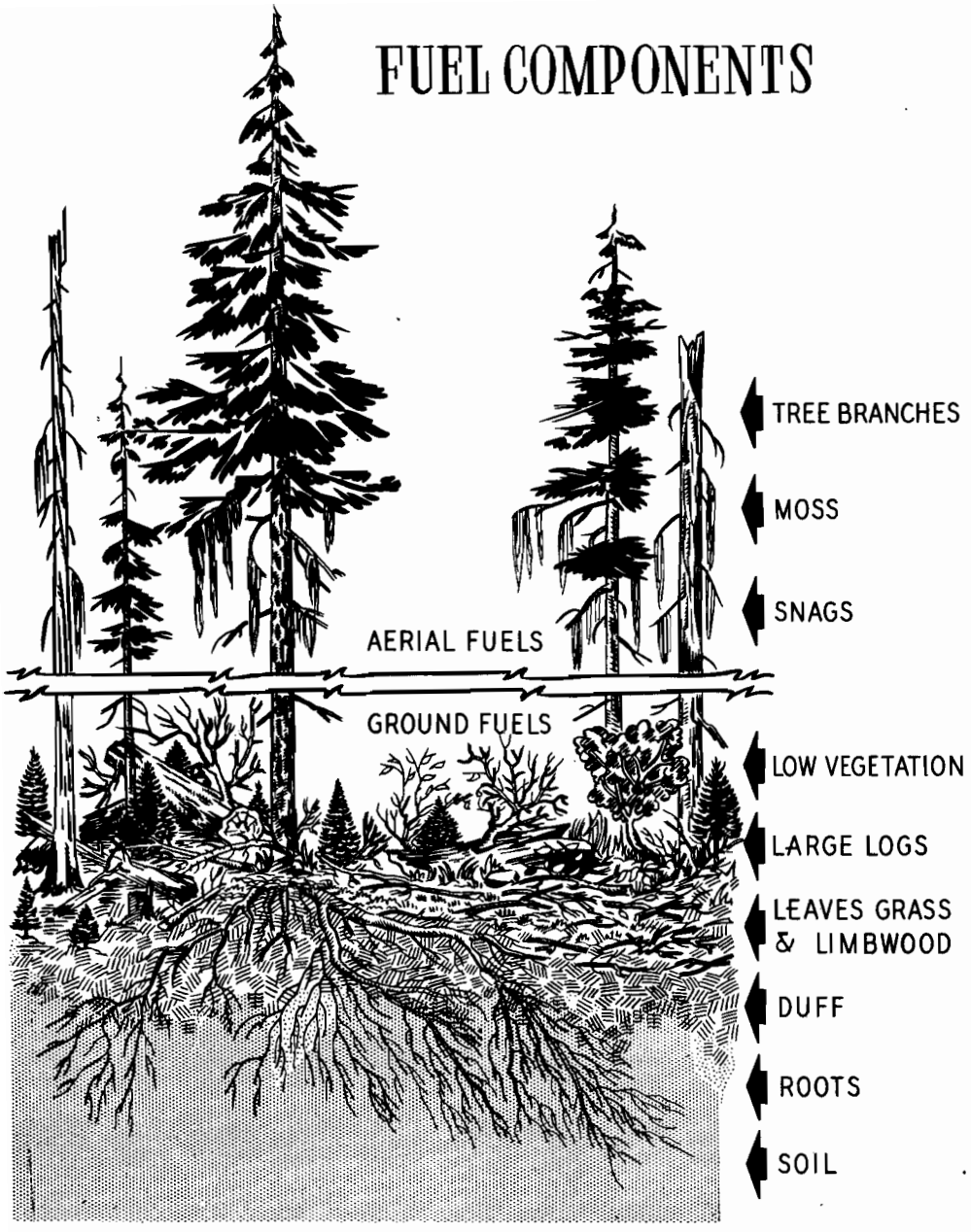

Figure 44. Principal components of ground fuels and aerial fuels.

is consumed down to mineral soil. Sometimes duff contributes to the rate of spread by furnishing a path for the fire to creep between patches of more inflammable material.

The smoldering characteristics of duff fires make them somewhat difficult to control. Fire lines dug down to mineral soil are required in duff areas. The only exception to this general rule can be made when examination by an expert fire technician shows that the lower layers of duff are too wet or too tightly compressed to burn. Frequently duff fires inside a fire line are best mopped up by turning over the duff with a shovel, loosening the material for better exposure to air and allowing it to burn out. Water may be used effectively, but great care must be taken to stir the fuel to make certain that all particles are thoroughly soaked. Extinguishing duff fires by smothering with dirt is very difficult to accomplish.

Roots

Roots are not an important factor in rate of spread because greatly restricted air supply prevents rapid combustion. However, fires can creep slowly in roots -- in fact some fires have escaped control because a root provided an avenue for the fire to cross the control line. The most inflammable roots are the large laterals stemming out from dead snags. Control of root fires is accomplished simply by cutting the root where it crosses the fire line. Mop-up of persistent fires may require complete excavation of roots.

Dead Leaves

As leaves on the ground decay, they gradually become part of the duff layer. However, before this decay takes place, leaves are a highly inflammable material and should be considered separately in evaluating ground fuels. In northern Rocky Mountain forests the cover of dead leaves on the ground is composed primarily of needles which have dropped from coniferous trees. Ponderosa pine needles are the most inflammable. Their large size and shape lead to a loose arrangement allowing free circulation of air. Smaller needles, such as those from Douglas-fir, generally are less inflammable because they are more tightly compacted on the ground.

Needles which are still attached to dead branches are especially inflammable because they are freely exposed to air and normally are not in direct contact with more moist material on the ground. Needles remaining on fallen limbs form a highly combustible kindling for larger material. For this reason logging slash containing dry needles is a very dangerous fuel.

Many techniques are necessary in controlling fires where leaves or needles are the primary fuel. The advance of a fast-running fire may be checked temporarily by smothering with dirt or cooling with water. Only a light cover of dirt thrown with a sweeping motion of a shovel is necessary to slow down a needle fire. When water is used in checking the advance, a spray or fog-type stream is most effective, with the water being aimed at

the base and directly in front of the flames. A penetrating straight stream of water is most effective for mopping up a needle fire. Careful stirring of all inflammable material is necessary. A fire line is essential around all fires burning in a continuous cover of needles.

Grass

Grass, weeds, and other small plants are important ground fuels influencing rate of spread. The key factor in these fuels is the degree of curing. Succulent green grass acts as a fire barrier. During the course of a normal fire season grass goes through a curing process and gradually becomes drier and more inflammable. Finally the stems and leaves of the grass die due to lack of moisture and the major part of the cover becomes highly inflammable. Cured grass, if present in large and uniform volume, provides the most inflammable ground fuel found in the region.

Grass and other small plants occur on the floor of almost all forests. Firefighters need to observe the volume and continuity of the grass cover. In dense forests where little sunlight reaches the ground, there is very little grass. In more open forests, such as mature stands of ponderosa pine, there may be a large amount. If a more or less continuous cover of dry grass occurs on the forest floor, the rate of spread of a fire will be governed largely by that cover rather than by the heavier fuels normally associated with a forest.

The ease of control of fires in dry grass depends mainly on the volume of grass. If the volume is low, the fire is often cool enough to permit work near the edge of the flame front. If the volume of grass is great, the resulting hot fire handicaps work close to the fire front. In grass fires smothering with dirt or swatters and cooling with a spray or fog stream of water are effective control methods. Both methods require follow-up to insure that no hangover fires remain. Wherever forest material, such as a mat of dead pine needles, twigs, or small limbs, is intermixed with the stand of grass, a fire line dug down to mineral soil usually is required.

Fires in dry grass often have very high rates of spread. For this reason special safety measures must be observed. A discussion of the required safety measures is contained in Chapter VI.

Fine Dead Wood

Fine dead wood consists of twigs, small limbs, bark, and rotting material. Normally the fine dead wood classification is confined to material with a diameter of less than 2 inches. These fine dead ground fuels are among the most important of all materials influencing rate of spread and general fire behavior in forest areas. Fine dead wood is ignited easily and often provides the main avenue for carrying fire from one area to another. It is the kindling material for larger heavier fuels.

In areas where there is a great volume of fine dead wood, a fire rapidly develops tremendous heat. The effect would be much the same if a fireplace or stove were loaded with nothing except kindling. Timber stands

that are decadent, fire-killed, bug-killed, or diseased, or that are heavily wind-thrown, usually have large amounts of fine dead wood on the ground. The greatest volume of fine dead wood usually is found in areas containing logging slash. Under dry conditions fires in such areas will burn violently, and the strong convection currents created by the intense heat will pick up burning embers and throw them out ahead, thus causing spot fires beyond the main fire front.

In some areas the occurrence of fine dead wood may be spotty. Accumulations of this material may be found bunched up under an occasional tree or snag. In such cases the firefighter must be alert to the fact that a very hot fire may develop in these accumulations. Sometimes a crown fire may break out above a jungle of fine dead limb wood or a blaze may creep up a snag. These troublesome situations may be avoided by breaking up the worst bunches of fine dead wood before the fire reaches them.

Granulated dry rotten wood, while not an especially important factor in rate of spread, is a highly ignitible fuel. Flying embers from the main fire often cause spot fires in rotten wood lying on the ground or in hollow places on old logs or stumps. Firefighters searching for spot fires should seek out and carefully check these areas. Granulated rotten wood consists of millions of finely divided particles which are partially exposed to air. Accumulations of rotten wood burn in a manner similar to a sawdust pile. When such material is on fire, a control line dug down to mineral soil is essential because complete smothering with dirt or cooling with water is very difficult to accomplish.

In most forest fires the control job must be aimed largely at checking the spread of fires in fine dead wood together with the associated material (mainly duff and leaves) lying underneath. Unless a large volume of dry grass is present, the fine dead wood is the most important fuel and should receive the first and most concentrated attention. If the fire is very hot, the first action may require smothering with dirt or cooling with water. The smothering and cooling stage should be regarded as a temporary step to check the spread of the fire. Final control requires a fire line dug down to mineral soil in nearly all cases.

Down Logs, Stumps, and Large Limbs

Heavy fuels, such as down logs, stumps, and large limbs, require long periods of hot dry weather before they become highly inflammable. However, when such material reaches a dry state, very hot fires may develop. The most dangerous heavy fuels are those containing stringers of dry wood, shaggy bark, or many large checks and cracks. Smooth-surfaced material is less inflammable because it dries out more slowly, has little surface exposed to air, and contains less attached kindling fuel. Extremely hot fires may develop in piles of down logs and large limbs or in crisscrossed windfall because the various fuel components will radiate heat to each other. However, individual limbs and logs will not burn hotly unless the fire is supported by large accumulations of fine dead wood.

The control of an advancing fire seldom rests on ability to suppress the fire in heavy fuels. In almost all areas containing large logs and limbs there will also be an accumulation of fine dead wood which is a much more important factor influencing rate of spread. Usually fires will not advance from log to log unless finer fuels are present or the area is literally covered with logs which radiate heat to each other.

Once a fire becomes well established in heavy fuels, complete suppression is difficult. A control line around the area is essential. Smothering with dirt or cooling with water is effective but requires very large volumes of both agents. In some cases it is necessary to allow the fire to burn out until the heat has subsided sufficiently to permit final mop-up operations to take place. When a fire is allowed to burn out in logs containing stringers of bark, a careful lookout must be kept for spot fires caused by embers carried in the strong convection currents. If at all possible, hot fires in such areas should be promptly cooled by any available means.

Low Brush and Reproduction

Low brush, tree seedlings, and small saplings are classified as ground fuels because they are so closely intermixed with the inflammable material on the forest floor. This understory vegetation may either accelerate or slow up the rate of spread of a fire. Normally, during the early part of a fire season the shading from understory vegetation prevents rapid drying of other ground fuels. However, as the season progresses continued high air temperature and low relative humidity will dry out both the fuel lying on the ground and the understory vegetation. When this stage is reached, much of the low vegetation, and especially small coniferous trees, become fire carriers.

The understory vegetation in a forest often provides a link between ground fuels and aerial fuels. The crowns of small trees may catch on fire and in turn spread the fire to aerial fuels in the forest canopy. Thickets of reproduction or dead brush may provide the first means for a surface fire to flare up and spread into the crowns of the overstory trees. In anticipation of this possibility alert firefighters will break up reproduction thickets along the fire line, or wherever possible will locate control lines to prevent the fire from spreading into these danger areas.

It is not uncommon for a fire to creep through ground fuels under low brush or reproduction during periods of low burning index, such as during the night. The heat from the creeping fire dries out the leaves and stems of the low brush and reproduction. Then on the following day as the burning index increases, a reburn occurs. Often on the reburn the dried low vegetation burns hotly and carries the fire to the aerial fuels causing a crown fire.

AERIAL FUELS

Aerial fuels include all green and dead material located in the upper forest canopy. The main aerial fuel components are tree branches and crowns, snags, moss, and high brush.

Tree Branches and Crowns

The live needles of coniferous trees are a highly inflammable fuel. Their arrangement on tree branches allows free circulation of air. In addition the upper branches of trees are more freely exposed to wind and sun than most ground fuels. These factors, plus the volatile oils and resins contained in coniferous needles, make tree branches and crowns important components in aerial fuels.

Tree branches and crowns are flashy fuels which react quickly to changes in relative humidity. Crown fires seldom occur when relative humidity is high. However, coniferous needles will dry out quickly when exposed to hot dry air. The dryness of needles is influenced by the transpiration process in a tree. When the ground is moist, trees are pumping a large amount of moisture into the air through the leaves. As the ground becomes drier, the transpiration process slows down and as a result leaves and branches become drier and more inflammable.

Dead branches on trees are an important aerial fuel. Concentrations of dead branches such as found in insect- or disease-killed stands may cause a fire to spread from tree to tree. Likewise, concentrations of dead branches on the lower trunks of trees may provide an avenue for fires to spread from ground fuels into tree crowns. The most inflammable dead branches are those still containing needles.

Fires in the upper crowns of trees are extremely difficult to control. The main control method must be aimed at suppressing the fire in ground fuels and, if possible, in preventing the fire from entering the tree crowns. Removal of limbs on the lower trunks of trees is one method of preventing crown fires. Limbs should be removed wherever a concentration of ground fuels makes a crown fire likely.

Snags

Snags are one of the most important aerial fuels influencing fire behavior. Studies of nearly 12,000 fires in the national forests of Region 1 have shown that over 34 percent of the fires started in snags (1). This high fire occurrence rate indicates the inflammability of snags. Although in most forests green trees greatly outnumber snags, more fires start in the latter because the fuel is drier and is arranged for easier ignition.

Snags vary widely in character and consequently in their effect on fire behavior. Smooth, solid snags containing very little bark and few checks or cracks are not highly inflammable. On the other hand, broken-topped, shaggy-barked, or partially decayed snags are ignited easily and have a major influence on the spread of fires. Burning embers blown from shaggy-barked snags are prolific starters of spot fires. In areas containing very large numbers of snags the fire may spread from one trunk to another because of the intense radiation of heat.

Fires in burning snags must be controlled promptly. Wherever possible the main control effort on the fire must be designed to prevent the blaze from getting into snags. When fires do become established in snags, the

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control method usually requires that the snags be felled. Snag-falling is especially important if shaggy bark is being carried from the burning trunk by wind or strong convection currents.

Tree Moss

Moss hanging on trees is the lightest and flashiest of all aerial fuels. Moss is important principally because it provides a means of spreading fires from ground fuels to other aerial fuels or from one aerial component to another. Like other light flashy fuels moss reacts quickly to changes in relative humidity. During dry weather crown fires may develop easily in heavily moss-covered stands. Control methods of moss fires are aimed primarily at breaking up ground fuels so as to prevent the fire from entering the tree crowns through the hanging moss. In addition, lower limbs containing tree moss should be removed at all danger spots.

High Brush

The crowns of high brush are classified as aerial fuels because they are distinctly separated by distance from ground fuels. In the northern Rocky Mountain region heavy stands of brush may develop in old burns and often form the principal vegetative cover in such areas. Crown fires in brush fuels ordinarily will not occur unless heavy ground fuels are present to develop the required heat. However, in some brush stands a high proportion of dead stems may create a sufficient volume of fine dead aerial fuels to permit very hot and fast-spreading crown fires. Key factors in evaluating the behavior of fires in high brush are therefore the volume, arrangement, and general condition of ground fuels and the presence of fine dead aerial fuels.

FUEL CONTINUITY

Fuel continuity describes the distribution of fuels in a given area. Fuel continuity is an important fire behavior factor because the distribution of fuels influences the potential area where a fire may spread as well as the rate of spread. If a dangerous fuel is uniformly distributed over an entire area, a high potential exists for a complete burn to occur at a rapid and uninterrupted rate of spread. However, if the fuel body is broken up by patches of bare ground or much less inflammable material, both the potential area of the burn and the rate of spread of the fire are affected.

A wide range of fuel continuity conditions will be found in most forest areas. However, for the sake of simplicity in making fire behavior estimates, two broad fuel continuity classes are recognized as follows:

Uniform fuels (figure 45) -- include all fuels distributed continuously over the area being evaluated. Areas containing a network of stringers or blocks which connect with each other to provide a continuous path for the spread of fire are included in this classification.

Patchy fuels (figure 46) -- include all fuels distributed unevenly over the area being evaluated. Definite breaks should be present, such as patches of rocky outcroppings or plots where the dominant vegetation is of much lower inflammability than the main fuel body.

UNIFORM FUELS

Figure 45. Uniform fuels are characterized by a continuous layer of inflammable ground cover.

PATCHY FUELS

Figure 46. Patchy fuels are characterized by definite breaks in the ground cover which will reduce the rate of spread of a fire.

FUEL VOLUME

As the amount of inflammable material in a given area increases, the amount of heat produced by a fire also increases. The hottest fires, as well as those most difficult to control, occur in areas containing the greatest quantity of fuel.

In evaluating fuel volume the quantity of both small- and large-sized fuel components should be observed (figure 47). A great volume of small materials, such as fine dead wood, indicates ample kindling for the ignition of other fuels. A great volume of either small- or large-sized material indicates a high potential for a hot fire. Where fires develop in areas containing a great volume of large-sized material, there will be intense radiation of heat to fuels lying in the path of the fire.

FUEL COMPACTNESS

Fuel compactness -- the number of individual fuel particles per unit of volume -- varies greatly in all kinds of fuel but is significant principally in duff and dead leaves lying on the ground. Fires burn rapidly in loosely compacted fuels because more of the individual fuel particles are freely exposed to air.

Compactness of duff and dead leaves varies according to tree species. In ponderosa pine the needles are loosely compacted because of the shape and size of the needles. For this reason surface fires usually spread more rapidly in a ponderosa pine forest than in other species. An uncompacted arrangement of needles also occurs in western red cedar, but intense shading and higher fuel moisture usually keep rate of spread in ground fuels below that observed in ponderosa pine. In forests composed of most of the other species, the smaller needles become densely compacted on the ground, thus reducing the surface freely exposed to air and reducing the rate of spread of fires.

FUEL MOISTURE

Two conditions of fuel moisture have major influences on the rating of fuel types. One concerns the greenness or curing stage of vegetation. The other relates to the shade and protection furnished by green timber.

In grass fuels moisture content is a critical factor in determining inflammability. Fires either will not spread at all or will spread only at a low rate in grasses which are rank green; but when the same grasses become cured and dry, fires will race through them at an extremely rapid rate. The degree of curing of grass is difficult to evaluate and requires keen observation of the grass stand. For purposes of considering fire behavior, the moisture content of grass can be judged according to the state of curing as follows:

Green -- In the normal June with frequent rains grass is rank green. The condition can be recognized by the green color, and by the cool, moist feel when crushed in the hand.

Figure 47. Typical example of a large volume of both small- and large-sized components in ground fuels.

Curing -- As summer drouth periods occur and hot, dry weather prevails, grasses ordinarily progress through a period of gradual curing. This stage is detected by close observation of the individual grass clumps or stems. For cheatgrass the curing stage is typified by a lavender tinge commonly referred to as the purple stage. For most other grasses the curing stage is less easily detected. At first only the tips of grass blades become tan or brown in color, or individual grass blades take on a cured appearance. In early stages of curing the grass stand may appear to be green, and the curing stage can be recognized only by close inspection of individual grass stems. In the advanced stages of curing the grass stand usually appears tan or brownish, and close inspection is necessary to detect the green condition of leaf bases.

Cured -- In the cured stage grasses are completely dried to a tan or brownish hue, and the stems feel dry or crackly when crushed or rubbed in the hand.

The progress of grass curing varies considerably with species, weather conditions, and soil. Cheatgrass ordinarily cures two to three weeks earlier than other species. In the normal summer cheatgrass is completely cured by mid-July. Weather influences curing depending upon summer rains. During the usual summer when July and August rains are confined to infrequent showers of light or moderate intensity, most grasses commence to cure during early July and gradually progress to the cured stage by late July or early August. In wet years grasses may not cure until late August. Conversely, there are years with spring drouth when grasses cure completely by early July. Soils influence curing primarily because of soil moisture relationships. In the deep, moist soils bordering creeks curing is much slower than in the thin soils on slopes.

Some grasses seldom reach a dangerous cured condition. During most years beargrass, prevalent in the high country, and the sedges found in high mountain meadows do not cure to a dangerous state like common bunch grasses.

The shade and protection afforded by timber stands influence fuel type ratings because of favorable fuel moisture conditions that are created (5). In a dense forest ground fuels are protected from the sun and wind. Temperatures and wind velocities are lower so that moisture does not evaporate as rapidly from the dead fuels on the ground (6). As these favorable influences are constant, the effects can be accounted for when rating fuel types. Lower ratings are assigned to fuels which are situated beneath dense timber canopies.

The moisture content of fuels is influenced also by aspect, but this influence is not constant. Large variations occur with altitude, time of year, time of day, and other factors. Hence, for the purpose of fuel type classification, aspect is disregarded. 3/ Fuel types are classified on the

3/ In the past aspect has been considered in preparing fuel type maps. Recent research has shown that it is more desirable to use aspect only in making actual rate-of-spread estimates according to burning index.

basis of the physical characteristics of the fuels disregarding any differences created by aspect. When rate of spread of a fire is estimated, aspect enters the considerations through its influence on weather factors.

SPECIAL FIRE BEHAVIOR FACTORS IN FUELS

Spot Fires

The development of spot fires depends not only upon the topographic and weather factors but also upon the character of fuels in the main fire and the fuels beyond the main fire. In the main fire rotten, shaggy-barked snags, such as broken-topped hemlock snags, and large quantities of ground fuels, such as those found in heavy logging slash, are the fuels most likely to cause spot fires. Spot fires are frequently started by crown fires. Crown fires in single trees or small groups of trees can start spot fires a short distance ahead. Widespread crown fires with their intense heat and strong convection currents can throw burning embers far out ahead.

Fuels which ignite most readily from embers thrown out ahead of the main fire, listed in the order of their susceptibility, include:

1. Rotten wood on the ground, on logs, and in snags.
2. Moss and lichens in tree tops.
3. Slash, particularly when compacted in tight piles.
4. Duff.
5. Cured grass.

Spot fires become more frequent and severe with lower fuel moisture and increased wind. On an average dry August afternoon the smallest sparks will ignite rotten wood or tree moss quickly. In compacted slash, in duff, and in cured grass larger burning embers are required to start spot fires unless there is sufficient wind to fan smoldering material into flames.

Crown Fires

Many forests contain a combination of aerial and ground fuels that favor the development of crown fires. Fuel conditions which influence the probability and character of crown fires include:

1. Volume and arrangement of timber canopy.
2. Volume and arrangement of fine dry aerial fuels such as moss and dead twigs.
3. Position of aerial fuels above ground fuels.
4. Character of ground fuels.

In open forests where single trees or small clumps of trees are well isolated from each other, crown fires are usually confined to single trees or small groups of trees. Crowning in such cases increases rate of spread by intensifying heat and by causing spot fires, but it will not result in racing crown fires like those which sometimes occur in dense forests.

When the timber canopy is sufficiently dense and continuous to carry broadcast crown fires, the severity of the crown fire is influenced by the quantity, character, and arrangement of dry fuels in the air and on the ground.

In most forests tree moss and dead aerial fuels, such as small twigs, have the greatest influence on crown fires. Trees loaded with moss and lichens that extend from the tips of the trees to the ground present the worst conditions, but severe crown fires can start when fine aerial fuels are situated high above the ground if a sufficient amount of ground fuels are present to create intense heat. The influence of distance from ground to aerial fuels varies with the volume and inflammability of ground fuels. When the ground is covered by the heaviest cedar logging slash, crowning will occur when aerial fuels are a maximum height of 100 feet or more above ground. Crown fires seldom develop above light ground fuels where duff is the principal material unless tree branches or moss extend continuously down to within 2 or 3 feet of the ground.

An important consideration in evaluating fuel conditions is the likelihood of reburns in tree crowns over previously burned ground fuels. A combination of fuel, weather, and topographic conditions may confine a fire to ground fuels for a considerable period of time. While the fire is burning on the ground, the aerial fuels may be scorched, singed, and become critically dry. Finally conditions change and a crown fire develops which sweeps back over the area. Fuel conditions, where a crown fire of this type may get its start, are similar to those influencing any other crown fire. However, this type of crown fire may develop easier and burn more explosively because of the drying of aerial fuels caused by the surface fire.

FUEL RATE-OF-SPREAD CLASSIFICATION

In the foregoing, individual fuel elements influencing fire behavior were analyzed. If a firefighter is to rate the inflammability of a particular fuel body, he must consider the effects of each element and of the combined effects of the various elements on each other. The end result of such an analysis is to express fuel inflammability in terms of rate of spread. The objective is to provide a yardstick which subdivides fuels into relative rate-of-spread groups.

Fuel Types

Long established procedure in the northern Rocky Mountains calls for the classification of fuels according to rate of spread and resistance to control (8). Rate of spread indicates the speed at which a fire will gain perimeter. Resistance to control indicates the difficulty of the fire-fighting job. In fire behavior analyses the rate-of-spread classification is the dominant factor.

Forest fire research has shown that fuels may be grouped into five rate-of-spread types (1). These types are described as low, medium, high, extreme, and flash. Actual rate of spread of fires in each type depends

upon the weather and topographic factors at the site. However, under the same weather and topographic conditions fires in medium rate-of-spread fuels will gain perimeter faster than in low fuels, and in high rate-of-spread fuels the fire perimeter increase will be faster than in medium fuels, etc. The general characteristics of each rate-of-spread type are shown in table 3. Representative examples are shown in figures 48 through 52.

Rate-of-Spread Classification Keys

Studies of forest and range conditions in the northern Rocky Mountains have enabled fuel rate-of-spread classification keys to be prepared (tables A-1 to A-7, inclusive, in appendix). These keys are intended as general guides in determining fuel rate-of-spread classification based upon what an observer sees in examining a particular forest or range area. A separate key is used for each of the following situations:

Grass and Range Land
Brush and Reproduction
Dense Coniferous Forests
Open Coniferous Forests
Subalpine and Spruce Forests
Logging Slash
Cut-Over Forests With Slash Disposal Work Completed

Use of the keys in determining fuel rate-of-spread classification requires the following steps:

1. Select the key in the above list which is most representative of the area being classified.

2. Select the appropriate description of ground fuels from the guides contained in key.

3. Under the appropriate description of ground fuels select the aerial fuel description contained in the key that is most representative of the area (or in the case of grass fuels select the proper curing condition).

4. Read the rate-of-spread classification.

Use of Fuel Rate-of-Spread Types in Fire Behavior Analysis

Once a given fuel body has been properly classified according to rate-of-spread type the firefighter is interested in an accurate estimate of how fast the fire will gain perimeter and in any special fire behavior characteristics that are common in the type. A method for estimating perimeter increase according to fuel type, aspect, position of fire on slope, steepness of slope, and burning index is discussed in Chapter VI. Special fire behavior characteristics of each type are as follows:

Table 3. General characteristics of five fuel rate-of-spread types in the northern Rocky Mountains

Rate-of-Spread Classification	Average Initial Rate of Spread at BI 70 1/	Maximum Rate of Spread for 85% of Fires at BI 70 2/	Type Characteristics
	---chains per hour---		
Low	4.5	8.0	Sparse fine dead ground fuels. Very few snags. Ground fuels generally protected from sun and wind. Type usually found in dense timber.
Medium	6.0	10.0	Moderate amounts of fine dead ground fuels. Occasional concentration of down logs and limbs. Few snags. Tree moss may be present. Crown fires likely. Ground fuels generally protected from sun and wind. Type usually found in dense timber or reproduction.
High	13.0	28.0	Large amounts of fine dead ground fuels only partially protected from wind and sun. Many shaggy-barked snags often present. Type may be found in open ponderosa pine forests, single burns in heavily timbered forests, brush fields containing many dead stems, bug-killed forests, heavy windthrow areas, and sparsely covered cured grass fields.
Extreme	18.0	35.0	Very heavy concentration of fine dead ground fuels largely exposed to wind and sun. Very large numbers of shaggy-barked snags may be present. Type usually found in heavy logging slash, the worst single burns, and moderate stands of cured grass.
Flash	33.0	65.0	Type generally confined to dense stands of cured cheatgrass and bunchgrass or heavy logging slash with dry needles remaining on limbs.

1/ Rate of spread from discovery to first attack.
2/ 15% of fires will spread faster.

Figure 48. Low rate-of-spread fuel type. Ground fuels are sparse and well shaded. There is little opportunity for a fire to become established in the aerial fuels.

Figure 49. Medium rate-of-spread fuel type. Ground fuels are shaded, but include a moderate amount of fine dead material. A fire in the ground fuels may spread into aerial fuels.

Figure 50. High rate-of-spread fuel type. Ground fuels are largely exposed to sun and wind. A large amount of fine dead material is present. Aerial fuels are primarily snags.

Figure 51. Extreme rate-of-spread fuel type. Very large amounts of fine dead ground fuels are the main characteristic of this type.

Figure 52. Flash rate-of-spread fuel type. Dense stands of cured cheatgrass or bunchgrass form the flashiest ground fuel in the northern Rocky Mountain region.

Low rate-of-spread fuels. Most ground fuels in this type are densely shaded and protected from wind. Under extreme drouth conditions ground fuels may become highly inflammable. Crown fires are not common; but when crowning does occur, much higher than average rates of spread may be expected. Spot fires are not common except where crown fires occur.

Medium rate-of-spread fuels. Rate of perimeter increase of fires burning in ground fuels is only slightly higher than in low rate-of-spread fuels. The big difference is the probability of crown fires. A higher percentage of crown fires develop in medium rate-of-spread fuels than in any other type.

High rate-of-spread fuels. Fires in snags are often a major problem in this type. Spot fires are common, and when they occur much higher than average rates of spread may be anticipated.

Extreme rate-of-spread fuels. Except for the grass types, this fuel classification usually has a combination of large amounts of fine and heavy materials. Very hot fires result. Spot fires are common and are a major factor contributing to rate of spread. Because of the intense heat and tendency of fires to spot ahead, normal barriers, such as roads and streams, will seldom stop a running fire in this type.

Flash rate-of-spread fuels. Critical factor in this type is state of curing of vegetation. Rate-of-spread classification within the type can actually vary from low to flash depending upon whether vegetation is green or cured. Fires will burn clean and hangover fires are rare. Spot fires are not common unless logging slash is present.

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Figure 53. Teamwork by all members of the fire control organization in rating fire behavior is necessary to prevent "blowups" like this or to handle such situations safely when they do occur.

CHAPTER VI. FIRE BEHAVIOR RATING

A fire behavior rating is an evaluation of the combined effects of all pertinent weather, topographic, and fuel conditions. In the initial size-up of a fire each major factor may be evaluated separately, but in reaching a decision on what the fire is going to do it is necessary to consider the interrelationship of all factors. The objective of all fire behavior ratings is to provide the following information:

1. Rate of spread. Estimate the number of chains per hour that the fire will gain perimeter.

2. Special behavior. Determine the probability of crown fires and spot fires.

3. Safety factors. Determine when and where the probable behavior of the fire may call for special safety measures by the firefighting personnel.

ESTIMATE OF THE SITUATION

Fire behavior predictions are based upon information of weather, topography, and fuel at the site of the fire. To insure that all pertinent information is obtained and properly evaluated, an estimate of the situation is made on each fire. The estimate of the situation is a continuing process beginning with the discovery of the fire and carrying on through the dispatching, initial attack, and follow-up stages of the fire suppression operations.

The Weather Estimate

The weather estimate is an evaluation of the effects on fire behavior of past, present, and future weather conditions. The weather estimate should specifically be based on:

1. Cumulative drying

   a. Do soil and vegetative conditions in the fire area indicate prolonged drouth?

   b. How many days have elapsed since the last rain of 0.2 inch or more at the nearest weather station?

   c. Is there evidence in the fire area of recent light rains?

2. Burning index

   a. What is the burning index at the nearest fire weather station?

   b. What is the current burning index at the site of the fire?

   c. Can burning index be expected to increase or decrease in the hours immediately ahead?

3. Wind direction and velocity

   a. What is the prevailing wind direction in the fire area?

   b. What is the current wind velocity in the fire area?

   c. Is the fire area freely exposed to wind?

   d. Is the fire approaching a topographic site where a change in wind direction or velocity may be expected?

   e. What changes in wind velocity and direction may be anticipated in the hours immediately ahead?

4. Special weather conditions

   a. Does cloud cover in fire area indicate possibility of turbulent or stable air?

   b. Have dust devils been observed in fire area?

5. Weather forecast

   a. Does the weather forecast indicate the probability of more severe or less severe burning conditions?

   b. Does the weather forecast indicate the probability of a major change in burning index rating?

The Topography Estimate

The topography estimate should specifically include an evaluation of:

1. Aspect

   a. What direction does the slope face at the present position of the fire?

   b. As the fire progresses will it burn on a slope facing in a different direction?

2. Position of fire on slope

   a. Is the fire on the lower, middle, or upper one-third of a slope?

   b. On what part of the slope will the main fire front be during the night? During the day?

3. Steepness of slope

   a. What is the slope steepness in percent in the fire area?

b. As the fire progresses will there be a major change in slope steepness?

c. Will the steepness of the slope cause material to roll out of the fire area?

4. Special topographic features

a. Will wind direction and general air movement be influenced by canyons, ridges, and other major topographic features?

b. Does the proximity of adjacent slopes make spot fires on those slopes likely?

c. Do any of the major topographic features provide fire barriers?

The Fuel Estimate

The fuel estimate is an analysis of the inflammability of all fuels in the fire area. The fuel estimate should specifically include an evaluation of:

1. Condition of herbaceous vegetation

a. Is the grass and other herbaceous vegetation green, curing, or cured in the fire area?

b. Is there a sufficient quantity of grass present to make it the dominant ground fuel?

2. Fuel types

a. What is the rate-of-spread classification of the fuel in the area where the fire is burning?

b. As the fire progresses will different fuel types be encountered?

c. Does the combination of aerial and ground fuels make crown fires or spot fires likely?

d. Are there significant breaks or especially dangerous jackpots in the fuel type?

ESTIMATING RATE OF SPREAD OF SMALL FIRES

Rate-of-spread estimates provide an evaluation of how fast a fire will gain perimeter. Such estimates provide the most important basis for reaching decisions on general fire behavior. In addition they provide the basis for determining suppression force requirements and suppression methods.

Initial Rate of Spread

A rate-of-spread estimate should be made as soon as a fire is discovered. This estimate is usually made by the dispatcher or the person responsible for planning initial action on the fire. The first objective of the estimate is to determine the rate at which the fire will gain perimeter between discovery and first attack. Preparation of the initial rate-of-spread estimate requires the following information:

1. Weather

   Average burning index at the site of the fire during the period from discovery to first attack (as determined from B.I. conversion tables).

2. Topography

   Aspect. (Is the fire on a north or south slope?)

   Position of fire on slope. (Is the fire on the lower, middle, or upper one-third of a slope?)

   Steepness of slope. (Estimated in percent.)

3. Fuel

   The fuel rate-of-spread type at the site of the fire. (Is it low, medium, high, extreme, or flash?)

Aids for Estimating Initial Rate of Spread

The many complex factors influencing fire behavior and the inability to measure some of these factors precisely make it difficult to obtain exact computations of rate of spread. No mechanical instrument or slide rule can be expected to present exact rate-of-spread figures for every fire. Keen observation of key factors and good judgment in the interpretation of these factors is the main and essential requirement in estimating rate of spread. However, as an aid to judgment, several guides are available for dispatchers and fire suppression personnel.

Burning Index Conversion Tables are available for estimating hourly changes in burning index and for converting ratings at a valley-bottom or mountain-top station to some other position on a mountain slope (tables A-8 through A-14 in appendix). These tables are especially useful to dispatchers in estimating average burning index at the site of a fire from discovery to first attack.

A Rate-of-Spread Table is available for estimating perimeter increase according to fuel type, slope steepness, and burning index at the site of a fire (table A-16 in appendix).

A Sample Problem in Estimating Initial Rate of Spread

At 1 p.m. on July 20 the observer at Pine Mountain Lookout Station discovers a fire and immediately reports its location and the following information to the dispatcher at the Bear Lake Ranger Station:

Aspect: South

Slope position: Middle of slope (thermal belt)

Slope steepness: Moderate (26 to 50%)

Size of fire: Spot

Type of forest: Dense mature

Visible fuels: Medium

Wind: Light, southwest

Precipitation: None since very light rain during electrical storm last night

The dispatcher knows that clear weather has prevailed over all the district since the brief electrical storm of the previous evening. During the noon hour burning index measured at the ranger station is 59. The weather forecast does not indicate any major change in wind, temperature, or relative humidity. From his knowledge of the situation and from the lookout observer's report the dispatcher believes that the weather in the fire area is generally the same as at the ranger station except for differences caused by local site and topographic conditions. Therefore, he believes that he can make a reliable estimate of the burning index at the site of the fire.

The dispatcher takes the following action:

1. He plots the location of the fire on a map. The fuel type map for the area, plus the lookout observer's report, indicates that the fuels are medium in rate of spread.

2. He estimates that an initial attack force can reach the fire in 3 hours.

3. Through use of a burning index conversion table (table A-9) he estimates that the average burning index at the site of the fire will be 63 during the next 3 hours.

4. Applying the converted burning index to a rate-of-spread table (table A-16) he estimates that during the next 3 hours the fire will gain perimeter at a rate of 5 chains per hour in medium fuels on a moderately steep slope.

5. From the above calculations he estimates that the fire will have a perimeter of 15 chains at 4 p.m.

Follow-Up Estimates of Rate of Spread

Upon arrival at a fire the forest officer in charge should make a new estimate of the rate of spread. He is in a good position to make a reliable estimate because he has a direct view of the influencing factors. In addition he can calculate how fast the fire has spread in the past under the observed conditions and can use these calculations as a guide in making an estimate of future spread.

BEHAVIOR OF LARGE FIRES

Large fires are capable of spreading at much faster rates than small fires. During a dry August afternoon a 50-acre fire with a perimeter of 120 chains may spread in 2 hours to 3000-acre size with a perimeter of more than 900 chains, or an average rate of spread of about 400 chains per hour. Under very severe conditions even faster rates of spread have occurred on large fires.

In forest areas high rates of spread on large fires are nearly always the result of crowning or spotting. Therefore, the first requirement in judging general behavior and rate of spread is to determine whether fuel, weather, and topographic conditions make crown fires and spot fires likely.

Wind is a major factor in the spread of crown fires. At a burning index of 60 to 80 with gentle to moderate winds, fires of 100 chains perimeter or more which are crowning or spotting ahead may be expected to double their perimeter each hour during the peak afternoon burning period. On very steep slopes or under very severe wind conditions long stringers of fire may extend out from the main perimeter. However, if the fuel body is continuous, the intervening areas may be expected to burn out later.

Definite breaks in the rate of spread of large fires are often governed by topography. Running crown fires or fires in single burns that are spotting ahead and traveling from snag to snag generate great speed and heat and may be expected to burn out an entire drainage during a hot, dry afternoon. However, a major reduction in rate of spread may be anticipated when such fires reach a ridge top, unless high winds or critically dry and inflammable fuels are causing spot fires far ahead of the main flame front.

In mountainous areas the various sectors of a large fire will vary widely in behavior at night. Fires in sectors at lower elevations and in valley bottoms will quiet down early in the evening. Shortly after shadows fall on the lower slopes of a mountain a noticeable break in the violence of fires may be observed. At upper elevations, and especially in the thermal belt, fires in heavy fuels may not quiet down until well after dark. Under critically dry conditions crowning and spotting may continue well into the night.

BEHAVIOR OF BACKFIRES

Backfires started at the proper time and place provide an effective means of combating the main fire. However, great care must be taken in such operations to insure that existing conditions will enable the backfires

to assist rather than aggravate the suppression task. A careful estimate must be made of all factors which will influence the behavior of both the main fire and the backfires.

A distinction must be made between backfiring and burning out small strips between the fire line and the edge of the burn. Burning-out is a common operation in fire suppression wherever the fire line is not located directly on the edge of the main fire. The intervening area of unburned material between the fire line and the edge of the main fire is normally only a few feet wide. Deliberate burning of this strip cleans up inflammable material and has the effect of widening the control line.

Violent or erratic behavior of fires in the burn-out strip should be extremely rare because the suppression personnel can plan the operation so as to avoid danger points. The heat from the main fire will pull the burn-out fire inward, away from the control line. The burning of narrow strips should continue even when critically dry conditions exist. If conditions are too severe to start a burn-out fire, then it may be anticipated that the constructed fire line will not stop the main fire. The main danger areas in a burn-out strip are snags, concentrations of heavy ground fuels, and live trees with branches extending to the ground or with moss which may cause crown fires. In all of these cases the dangerous fuels should be removed or broken up or a control line built to prevent either the burn-out fire or the main fire from reaching the trouble spots.

Backfiring refers to an indirect method of fire control in which a fire is intentionally set on the fire side of a control line located a considerable distance away from the main burn. The method differs from burning-out chiefly because of the greater area to be consumed by the intentionally set fire. Backfiring is strictly an emergency measure and is used only when more direct methods are totally unsuccessful. Backfiring should be employed only by experienced fire control personnel.

The initial behavior of a backfire is the same as any other fire burning under similar conditions. In the initial stages the backfire usually will not be pulled inward by the heat from the main fire because of the distance between the two fires. For this reason it is necessary to select a time and place for setting the backfire which will insure its travel toward the main fire. As the backfire approaches the main fire the heat from the main fire will pull the two together.

Very slow rates of spread are not desired for backfires. The area to be burned out should be cleaned up before moist night air reduces the fires to a smoldering condition. Usually the best time to set a backfire is about 1 or 2 hours after the peak afternoon burning index. Early morning backfires are almost always unsuccessful. During those hours work should be attempted directly on the edge of the main fire. Wherever there is a choice, heavy ground fuels and snags should be avoided in backfires. Light, flashy fuels are desirable.

DUTIES OF PERSONNEL IN FIRE BEHAVIOR RATING

Successful fire behavior rating requires participation by all members of the fire control organization. Teamwork by all members of the organization is necessary to identify, report, and evaluate the pertinent factors influencing fire behavior. Important duties of various personnel in making fire behavior ratings are as follows:

Lookout observers

1. Observe and maintain a daily record of pertinent weather conditions in the area seen from the lookout station. Make a special effort to observe areas covered by thundershowers and light rains.

2. On each fire observe and report the factors which will assist in making the initial estimate of rate of spread, including position of fire on slope, aspect, slope steepness, type of forest, visible fuels, wind direction and velocity, precipitation, color of smoke, and initial size and general behavior of fire.

3. After submitting initial report make follow-up observations and report any major changes in behavior or in conditions in the fire area.

Aerial observers

1. On initial discovery of each fire observe and report all factors listed in duty number 2 above for lookout observers.

2. While flying over fire area, observe and report special factors which can be noticed from aircraft, such as air turbulence, direction fire is traveling, fuel conditions, barriers, and special topographic features.

3. On follow-up or scouting flights make detailed observations of area already burned, sketch size and shape of fire, carefully study fuels and topography in the path of the fire, determine probable direction of spread, look for spot fires, and identify danger spots.

Dispatchers

1. Maintain ready for instant use all available aids in rating fire behavior, including fuel type maps, burning index conversion tables, and rate-of-spread tables and computers.

2. Observe, record, and plot daily weather conditions. Wherever possible maintain rainfall maps of the district. Watch weather trends and be alert to prolonged periods of drouth and high burning index. Know the current burning index at all times. During especially dangerous periods or periods of changing weather obtain as many daily readings from fire weather stations as necessary to keep currently informed on burning index ratings. Carefully study and evaluate weather forecasts. Anticipate changes. From the current information and the weather forecast estimate tomorrow's burning index.

3. Make a daily evaluation and estimate of the district fire situation, and especially of the weather situation. Keep all fire control personnel informed of the situation, and especially of the current burning index and the weather forecast.

4. Estimate the initial rate of spread on every fire. Make follow-up estimates wherever possible. Check your estimates with the rate of spread which actually occurred.

5. When dispatching the initial attack force, give them your estimate of the burning index at the site of the fire, the probable changes during the next several hours, and your estimate of the initial rate of spread.

Smokechasers and smokejumpers

1. Before leaving for the fire obtain pertinent fire behavior information, especially current burning index, estimated burning index at the site of the fire, probable changes in burning index during the next several hours, and the weather forecast.

2. Upon arrival at the fire anticipate its probable behavior. Make an estimate of the situation based upon keen observation of fuel, weather, and topographic factors.

3. Observe how fast the fire has spread between discovery and your arrival. Make your own estimate of future rate of spread.

4. Make careful observations of both aerial and ground fuels. Look for combinations that may cause spot fires or crown fires.

5. Look for special factors that may influence fire behavior, including movement of clouds, especially thunderheads over fire area, dust devils, and outstanding topographic features.

6. Anticipate when and where major changes in fire behavior will occur based upon your continuing estimate of the fuel, topographic, and weather situation.

Smokejumper spotters

1. Before leaving for the fire obtain pertinent fire behavior information. It is desirable that this information include current burning index at the nearest fire weather station, estimated burning index at the site of the fire, probable changes in burning index during the next several hours, and the weather forecast.

2. Upon arrival over fire area make a brief estimate of the fire behavior situation. Look especially for position of fire on slope, aspect, wind direction on ground, and dangerous fuels.

3. Before the smokejumpers leave the aircraft inform them of your estimate of the situation. If a large crew of smokejumpers is to jump, coordinate your estimate with the squad leader or foreman.

4. Inform the forest dispatcher of your fire behavior observations.

Fire boss

1. Before leaving for the fire make necessary arrangements to receive pertinent fire behavior information, and especially fire weather information and weather forecasts. Obtain all possible information on the current situation.

2. Equip yourself with necessary maps, a burning index meter, burning index conversion tables, rate-of-spread tables, relative humidity charts, and a pocket, sling psychrometer.

3. Upon arrival at the fire establish the means for obtaining current information on fuels and topography on all sectors of the fire. Establish a scouting procedure and brief scouts and aerial observers on the fire behavior information that you desire.

4. On large and dangerous fires make arrangements for the employment of a mobile fire weather unit or for the receipt of special fire weather forecasts. On all other fires obtain current burning index from the nearest fire weather station. Estimate burning index on the critical sectors of the fire. Correct your estimates by local measurement of relative humidity with a sling psychrometer and careful observation of wind velocity. Anticipate changes in burning index at various topographic positions and at various periods of the day and night.

5. Before each burning period make a detailed estimate of the fuel, topographic, and weather situation. Compute rate of spread on each major sector during the previous burning period. Estimate rate of spread during the next burning period. Estimate the number of chains of fire line which must be worked. Anticipate when and where crown fires and spot fires may occur.

6. Make sure that the sector bosses and crew foremen understand the fire behavior situation and that they pass this information on to crew members.

Sector boss

1. Become thoroughly acquainted with the fire behavior situation in your sector. Study the fuels that are burning and the fuels in the path of the fire. Study the topography. Know the general situation on adjacent sectors.

2. From general weather information available on the fire area estimate the probable burning index in your sector and the probable hourly changes during the day and night.

3. Identify the possible danger spots in your sector. Estimate when and where crown fires and spot fires may occur. Look for points where wind direction may change. Anticipate periods when wind velocity may increase.

4. Brief your foremen on the fire behavior situation in the sector and any possible changes that may occur from fire activity in adjacent sectors. Ask foremen to keep you informed of important factors or changes which they observe. Make sure that foremen brief their crews on the fire behavior situation.

Crew foreman

1. Become thoroughly acquainted with the fire behavior situation in the area where your crew is to work. Know the general situation in adjacent areas within the sector.

2. Observe all pertinent fuel and topographic factors in your crew's area. Identify the danger spots. Wherever possible locate your fire line so that the fire will not reach dangerous fuel concentrations. Cool down fires and break up fuels in areas where crown fires may start. Look for fuels that may cause spot fires and treat these fuels promptly.

3. Plan your work so that dangerous areas on the line are manned during the most critical part of the burning period. Patrol areas outside the fire line where spot fires may occur.

4. Inform your crew of the probable fire behavior situation. Point out areas where high rates of spread, crown fires, or spot fires may occur. Give your crew explicit instructions on procedures to be followed in handling dangerous spots or in making withdrawal from the area. Point out the location of safe areas where the crew may retreat to if necessary.

5. Keep your sector boss informed of the fire behavior situation. Assist him in evaluating the probable behavior and rate of spread of fires in the sector.

FIRE SAFETY MEASURES

A thorough understanding of fire behavior is essential to the promotion of safety in firefighting operations. Accidents often occur when so-called "unexpected fire behavior" develops. To avoid these "unexpected events," the first and most important safety measure on every fire, regardless of size, is to make the estimate of the fire behavior situation which has been emphasized throughout this chapter. Fires behave according to certain laws. Runaway fires do not just happen. When keen observations and evaluations are made of weather, topography, and fuels, there are very slim chances for firefighters to be surprised suddenly by an unexpected blowup.

Every fire behavior situation calls for special safety measures. In most cases the best safety measure is aggressive and intelligent firefighting aimed at abating the danger spot. For use as a general guide, the following are a few important fire behavior situations and appropriate safety measures for those situations:

Fire Behavior Situation	Safety Measures
Spot Fires	
Convection currents from a hot fire in a group of shaggy-barked snags are carrying burning embers into unburned fuels.	1. Cool down fires at base of snags and break up or remove dangerous ground fuels. 2. Patrol for spot fires and promptly control all fires discovered. 3. Keep all men away from burning snags except a small squad performing the control job around the snags. 4. Fall the snags as soon as possible. Follow standard snag-falling safety procedures.
During the early afternoon of a dry August day a crew is building line on the lower side of a fire lying about midway up a moderately steep mountain slope. The fire is burning in ground fuels in a type classified medium in rate of spread. The forest is dense and a few trees have hanging moss. A hot spot fire is discovered about 200 feet below the main fire.	1. Anticipate the probability that both the main fire and the spot fire may crown. 2. Promptly devote major attention to control of the spot fire. Recognize that it may move rapidly upslope into the main fire. 3. Make immediate plans for movement of the crew to a safer position below the spot fire.
Grass Fires	
At 8 a.m. on a clear morning following a day when peak burning index was 68, a fire near the base of a long, moderately steep slope has an uncontrolled perimeter of 15 chains. The area in the path of the fire is an open ponderosa pine forest with a uniform understory of dense, cured bunchgrass and scattered pine needles. At the present time the fire is quiet.	1. Recognize that the flashy fuels will dry out rapidly during the next 2 or 3 hours and that about 10 a.m. the burning index will increase significantly. 2. Take aggressive control action immediately. 3. Anticipate that the fire may develop a high rate of spread before noon. Plan work so that fire is flanked by control lines from the back toward the head. Patrol flanks for spot fires. Plan an escape route for use if necessary.

Fire Behavior Situation	Safety Measures
Grass Fires (cont'd)	
A fire is burning in a mixed stand of Douglas-fir and ponderosa pine about 100 yards above the base of a steep slope in a narrow canyon. The opposite south slope of the canyon is covered with a uniform stand of cured cheatgrass. The route to and from the fire, including the route used by the water boy, follows a rough trail along the south slope. It is 1 p.m. and the estimated burning index at the fire is 65.	1. Recognize that if a fire becomes established on the south slope, the rate of spread may be over 100 chains per hour. 2. Take aggressive action to control the north slope fire. Prevent any material from rolling down to the base of the slope. Treat any areas in the fire which may cause crown fires or spot fires. 3. Establish an alternate route to and from the fire.
A small crew is making good progress beating out the edges of a grass fire. They are working up a steep, south slope on the flanks of the fire and have already covered about 25 chains of line. It is 11 a.m. and the peak afternoon burning index is expected to be about 70 in the thermal belt.	1. Anticipate that a smoldering fire might cross into unburned fuel below the crew and race up the slope flanking their position. 2. Send 1 or 2 men back down the edge of the worked line to patrol and handle any smoldering fires. 3. Instruct the crew to get into the burned area if a flanking fire should threaten their position.
Crown Fires	
A small, hot fire is burning in a tangle of windfall underneath a dense forest of lodgepole pine and a few Engelmann spruce. Some of the trees have hanging moss and the lodgepole pine overstory is partially killed from insect attacks. The fire is approaching a part of the windfall which runs into a thicket of spruce reproduction. It is a hot, windy afternoon. The ground in the area is very dry.	1. Recognize that the conditions are ideal for the development of a crown fire. 2. Take aggressive action to cool down the fire in the windfall. Remove reproduction. Limb up trees over and around the fire. Prevent fire from becoming established in snags. 3. Observe wind direction. For possible emergency use select a safe place of retreat where the wind will blow the fire away from your position.

Fire Behavior Situation	Safety Measures
Crown Fires (cont'd)	
During the night a fire in heavy ground fuels lying under a pole-sized stand of Douglas-fir and larch has slowly backed downhill. A control line has been placed across the upper edge of the fire and men are now mopping up along that line. Only a few trees in the fire area have crowned out, but many others have been singed and lower branches browned by the hot fire in heavy ground fuels. At 1 p.m. a crew building line on the lower side of the fire encounters several very hot fires burning directly under scorched trees.	1. Recognize the danger of a crown fire developing on the lower sector and sweeping uphill over the area where ground fuels have already burned. 2. Take aggressive action to cool down hot spots on the lower side of the fire. Break up fuel concentrations and remove lower limbs from trees. 3. Warn the upper crew of the possibility of a crown fire. Advise them to select a route of retreat and caution them that they cannot safely retreat into the burn because of the possibility of a reburn in the tree crowns.

Each of the foregoing fire safety examples has been patterned after an actual fire. Each of the examples emphasizes that the warning signs of some new action by a fire are present. Keen observation and interpretation of weather, topography, and fuels lead to a good understanding of fire behavior and to safe, efficient firefighting.

APPENDIX

FUEL RATE-OF-SPREAD CLASSIFICATION KEYS

Table A-1 Grass and Range Land
Table A-2 Brush and Reproduction
Table A-3 Dense Coniferous Forests
Table A-4 Open Coniferous Forests
Table A-5 Subalpine and Spruce Forests
Table A-6 Logging Slash
Table A-7 Cut-Over Forests With Slash Disposal Work Completed

BURNING INDEX CONVERSION TABLES

Table A-8 Valley Bottom to Lower One-Third of Mountain Slope
Table A-9 Valley Bottom to Middle One-Third of Mountain Slope
Table A-10 Valley Bottom to Upper One-Third of Mountain Slope
Table A-11 Mountain Top to Middle One-Third of Slope
Table A-12 Mountain Top to Lower One-Third of Slope
Table A-13 Mountain Top to Valley Bottom
Table A-14 Mountain Top to North Aspect on Upper One-Third of Mountain Slope
Table A-15 Cumulative Hourly Change in Burning Index

RATE-OF-SPREAD TABLE

Table A-16 Average Initial Rate of Spread According to Fuel Type, Slope Steepness, and Burning Index at Site of Fire

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Table A-1. Fuel Rate-of-Spread Classification Key
for
GRASS AND RANGE LAND

Definition: Non-forested areas where grass and small plants form the dominant vegetative cover. Scattered trees or brush may be present, but not in sufficient density to shade more than 5 to 10% of ground fuels.

Ground Fuels		Rate-of-Spread Classification	
Specific Kind of Fuel (Select description most representative of area)	Fuel Continuity 1/	Grass Green (About 75% or more of plants are green, moist and succulent)	Grass Cured (Brown, yellow or red color predominates. Stems are generally dry and brittle)
Cheatgrass (Bromus spp.) (Moderate to dense stands.)	Patchy	Low	Flash
	Uniform 2/	Low	Flash
Range Type - Good to Excellent Condition (Moderate to dense stands with mat of dead stems and leaves lying on ground.)	Patchy	Low	Extreme
	Uniform	Low	Flash
Range Type - Fair to Poor Condition (Plants clipped short over much of area, but little bare soil is exposed. Usually is moderately to heavily grazed.)	Patchy	Low	High
	Uniform	Low	Extreme
Depleted Range (Much bare soil exposed due to overgrazing or poor site; very shallow or no litter of dead stems and leaves.)	Patchy	Low	Medium
	Uniform	Low	Medium
Alpine Parks and Meadows (Moderate to dense stand of grass and flowers. Stands remain green and wet except in periods of prolonged drouth.)	Patchy	Low	Medium
	Uniform	Low	High

1/ Fuel continuity represents the arrangement of dry grass, rotten material, and the litter of dead leaves and stems.

2/ Uniform continuity includes not only the arrangement of fuels distributed evenly over the fire area, but also those arranged in a network fashion where stringers or blocks of fuel are connected with each other forming a continuous path for spread of fires.

Notes: Green grass is normally a fire barrier. However during the curing stage grass that appears green may be dry enough to permit medium to high rates of spread. Spotting in grass fires is uncommon except where rotten wood or exposed dry vegetative matter is present. Dense stands of cured cheatgrass and bunchgrass will cause fires to spread faster than any ground fuel found in the region.

Table A-2. Fuel Rate-of-Spread Classification Key
for
BRUSH AND REPRODUCTION

Definition: Areas where trees over 20 feet in height are widely scattered singly or in small groups and where woody shrubs and/or reproduction exist in either scattered or dense uniform stands. Includes areas of multiple burn as well as solid fields of dense ceanothus.

Ground Fuels			Rate-of-Spread Classification		
Specific Kind of Fuel (Select description most representative of area.)	Fuel Volume 1/	Fuel Continuity 2/	Few Snags (Less than 4 rotten or shaggy-barked snags per acre.)	Numerous Snags	
				4 or more rotten or shaggy-barked snags per acre of any species less than cedar, hemlock or fir.	4 or more rotten or shaggy-barked cedar, hemlock, or grand fir snags per acre.
Sage Brush - Sparse Ground Fuel (Very thin and scattered stands of grass; much bare soil exposed.)	Any quantity	Patchy	Low		
		Uniform 3/	Medium		
Sage Brush - Grass (Moderately dense to very dense stands of grass; dead twigs and branches may be scattered on ground. Use this classification only when grass is cured.)	Any quantity	Patchy	High		
		Uniform	Extreme		
Scattered Brush or Reproduction (Sparse dead ground fuels. Typical of multiple burns or plantations where fire has consumed or charred most of the logs and dead branchwood.)	Sparse dead ground fuels	Patchy	Medium	Medium	High
		Uniform	High	High	Extreme
Dense Brush Fields - Few Logs (Typical of dense ceanothus or mixed brush fields where fire has consumed most of the logs and snags.)	Sparse dead branchwood. Healthy shrubs.	Patchy	Low		
		Uniform	Medium		
	Moderate to large quantity of dead branchwood. Sickly shrubs.	Patchy	Medium		
		Uniform	High		
Brush and Reproduction With Numerous Logs (Typical of single burns in white pine timber zone where there are many snags.)	Fine dead branchwood and loose bark sparse	Patchy	Medium	High	High
		Uniform	High	High	Extreme
	Moderate to large quantity of dead branchwood and loose bark.	Patchy	Medium	High	Extreme
		Uniform	High	Extreme	Extreme

1/ Fuel volume refers to the relative quantity of dead branchwood, dead brush stems, rotten material, loose bark and grass.

2/ Fuel continuity refers to the combined arrangement of dead branchwood, dead brush stems, rotten material, loose bark and grass.

3/ Uniform continuity includes not only the arrangement of fuels distributed evenly over the fire area, but also those arranged in a network fashion where stringers or blocks of fuel are connected with each other forming a continuous path for spread of fire.

Notes: A wide variety of brush types occur in the Northern Rocky Mountains. The descriptions given cover only the more important fire types. In brush and reproduction the quantity and arrangement of fine dead fuels has the most significant influence on rate of spread. Crown-to-crown fire spread through brush and reproduction may occur where there is a large quantity of dead brush stems or other dead fuels. In scattered brush types grass is usually the most important rate-of-spread factor.

Table A-3. Fuel Rate-of-Spread Classification
for
DENSE CONIFEROUS FORESTS

Definition: Continuous stands of medium to large conifers; very few openings; major part of ground fuels shaded; majority of trees over 25 feet in height.

Ground Fuels		Rate-of-Spread Classification		
Specific Kind of Fuel (Select description most representative of fire area)	Fuel Continuity 1/	Few Snags - No Moss (less than five shaggy-barked snags per acre)	Many Snags - No Moss (five or more shaggy-barked snags per acre)	Moss on Trees (with or without snags, about 1/5 of trees have moss hanging on lower limbs)
Mainly Duff (Tightly compacted on ground; very little dead branchwood.)	Patchy	Low	Low	Low
	Uniform 2/	Low	Medium	Medium
Needles and Twigs (Large volume of loosely compacted needles mixed with dead twigs and moderate amount of fine branchwood.)	Patchy	Low	Medium	Low
	Uniform	Medium	Medium	Medium
Branchwood and Limbs (Large volume of branchwood and small limbs lying over duff and needles.)	Patchy	Low	Medium	Medium
	Uniform	Medium	High	High
Down Logs (Many down logs lying over limbwood, needles, and duff.)	Patchy	Low	Medium	Medium
	Uniform	Medium	Medium	High
Grass and Small Shrubs (Small shrubs and bushes occur in sufficient volume to make travel in area difficult; grass clumps scattered through other ground fuels.)	Patchy	Low	Low	Medium
	Uniform	Low	Medium	Medium

1/ Fuel continuity represents the arrangement of dead branchwood, rotten material, loose bark, dry grass, and, where present, ponderosa pine duff.

2/ Uniform continuity includes not only the arrangement of fuels distributed evenly over the fire area, but also those arranged in a network fashion where stringers or blocks of fuel are connected with each other forming a continuous path for spread of fire.

Notes: In dense green forests most ground fuels are shaded and usually do not dry out sufficiently to cause high initial rate of spread. However, aerial fuels such as shaggy-barked snags and moss may contribute measurably to rate of spread, especially where ground fuels provide sufficient heat to ignite them easily. Crown fires may occur when tree branches cover lower trunks over medium to heavy ground fuels.

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Table A-4. Fuel Rate-of-Spread Classification Key
for
OPEN CONIFEROUS FORESTS

Definition: Trees generally not close enough to completely shade ground fuels; includes seedling and sapling, pole and mature stands.

Ground Fuels		Rate-of-Spread Classification	
Specific Kind of Fuel (Select description most representative of fire area)	Fuel Continuity 1/	Few Snags (less than four shaggy-barked snags per acre)	Many Snags (four or more shaggy-barked snags per acre)
Very Sparse Ground Fuels (Thin layer of duff, needles and twigs with much bare ground exposed.)	Patchy	Low	Low
	Uniform 2/	Low	Medium
Needles and Twigs (Large volume of loosely compacted needles mixed with moderate amount of branchwood.)	Patchy	Low (Medium in Ponderosa Pine)	Medium
	Uniform	Medium (High in Ponderosa Pine)	High
Branchwood and Limbs (Large volume of branchwood and limbs lying over duff and needles.)	Patchy	Low	Medium
	Uniform	Medium	High
Down Logs (Many down logs lying over limb wood, needles, and duff.)	Patchy	Low	Medium
	Uniform	Medium	High
Grass (Most of forest floor covered with grass mixed with other fine fuels.)	Patchy	Low (Medium when grass is cured)	Medium (High when grass is cured)
	Uniform	Low (High when grass is cured)	Medium (Extreme when grass is cured)

1/ Fuel continuity represents the arrangement of dead branchwood, rotten material, loose bark, dry grass, and, where present, ponderosa pine duff.

2/ Uniform continuity includes not only the arrangement of fuels distributed evenly over the fire area, but also those arranged in a network fashion where stringers or blocks of fuel are connected with each other forming a continuous path for spread of fire.

Notes: Most mature ponderosa pine forests will fit this key except where mixture of Douglas-fir and larch shade ground fuels. In such cases use key for DENSE GREEN FORESTS. In open forests crown fires are infrequent except where heavy ground fuels are arranged under groups of trees. Grass and other herbaceous vegetation normally will cure earlier in the season in open forests than in dense forests.

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Table A-5. Fuel Rate-of-Spread Classification Key
for
SUBALPINE AND SPRUCE FORESTS

Definition: Open to dense stands of Engelmann spruce, alpine fir, limber pine, and white bark pine. Except for some spruce stands, this type generally occurs at elevations of 6,000 to 10,000 feet. Associated species may include mountain hemlock, alpine larch, and lodgepole pine.

Ground Fuels		Rate-of-Spread Classification		
Specific Kind of Fuel (Select description most representative of fire area)	Fuel Continuity 1/	Few Snags - No Moss (less than four shaggy-barked snags per acre)	Many Snags - No Moss (four or more shaggy-barked snags per acre; may include live trees with shaggy-broken tops and limbs)	Moss on Trees (with or without snags about 1/5 of trees have moss hanging on lower limbs)
Spruce Bottoms (Deep duff, much loose bark, many down logs, ferns scattered through area.)	Patchy	Low	Low	Medium
	Uniform 2/	Low	Medium	High
Sparse Ground Fuels (Scattered small limbs and very thin layer of duff; much bare soil and rock exposed; scattered clumps of grass and flowers.)	Patchy	Low	Low	Medium
	Uniform	Low	Medium	Medium
Limbwood (Moderate to heavy layer of limbwood, especially around base of mature trees; scattered down logs.)	Patchy	Low	Medium	Medium
	Uniform	Medium	Medium	High
Heavy Windfall (Many trees on ground and leaning above ground; heavy accumulation of limbs and tops.)	Patchy	Medium	Medium	High
	Uniform	Medium	High	Extreme

1/ Fuel continuity represents the arrangement of dead branchwood, rotten material, loose bark, dry grass, and duff.

2/ Uniform continuity includes not only the arrangement of fuels distributed evenly over the fire area, but also those arranged in a network fashion where stringers or blocks of fuel are connected with each other forming a continuous path for spread of fires.

Notes: Fuels are difficult to classify according to rate of spread in subalpine forests. Because the ground is free of snow for only a short period of the year, these areas are in a moist condition and are characterized by clumps of green, succulent grass and flowers. However, many factors may contribute to serious fire conditions. Wind is common and assists in drying out fuels. Snow breakage, windfall and moss may often cause dangerous fuel conditions. Tree-to-tree fire spread may occur where there are tangles of dead limbs and tops. Spot fires are common where rotten wood occurs on the ground or on logs and shaggy stumps. In spruce stands fires will burn very deep, especially where squirrel caches occur at the base of old trees.

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Table A-6. Fuel Rate-of-Spread Classification Key
for
LOGGING SLASH

Definition: Areas where untreated logging slash forms the dominant fuel.

Ground Fuels		Rate-of-Spread Classification					
		Partially Cut Stands				Clear-Cut Stands (Only scattered green trees remain)	
		60 to 90% of ground surface shaded by remaining trees		30 to 59% of ground surface shaded by remaining trees			
Specific Kind of Fuel (Select description most representative of fire area)	Fuel Continuity 1/	Little moss on trees and rotten or shaggy-barked snags fewer than four per acre	Considerable moss on trees or four or more rotten shaggy-barked snags per acre	Little moss on trees and rotten or shaggy-barked snags fewer than four per acre	Considerable moss on trees or four or more rotten shaggy-barked snags per acre	Few Snags (Less than four rotten or shaggy-barked snags per acre	Many Snags (Four or more rotten or shaggy-barked snags per acre
Larch-Douglas Fir or Lodgepole Pine Slash	Patchy	Low	Medium	Medium	High	Medium	High
	Uniform 2/	Medium	High	High	High	High	Extreme
White Pine Slash (Normally includes debris from several other species. If about 25% of debris is cedar, use cedar classification.)	Patchy	Medium	High	High	High	High	Extreme
	Uniform	Medium	High	High	Extreme	Extreme	Extreme
Cedar Slash (In most cases cedar slash will include debris from other species.)	Patchy	Medium	High	High	Extreme	Extreme	Extreme
	Uniform	High	Extreme	Extreme	Extreme	Extreme	Extreme
Ponderosa Pine Without Grass (Only scattered or very thin stands of grass present. This type may include some mixture of larch and Douglas-fir.)	Patchy	Medium	High	Medium	High	High	Extreme
	Uniform	High	High	High	Extreme	Extreme	Extreme
Ponderosa Pine With Grass (Grass stands moderately dense to very dense. When grass is green use classification for ponderosa pine without grass.)	Patchy	High	Extreme	High	Extreme	Extreme	Extreme
	Uniform	Extreme	Extreme	Extreme	Flash	Flash	Flash

1/ Fuel continuity represents the arrangement of dead branchwood, rotten material, loose bark, dry grass, and where present, ponderosa pine duff.

2/ Uniform continuity includes not only the arrangement of fuels distributed evenly over the fire area, but also those arranged in a network fashion where stringers or blocks of fuel are connected with each other, forming a continuous path for spread of fire. Slash windrowed in lodgepole pine clear-cutting is classed as uniform.

Notes: When dry needles are still attached to 25% or more of the branchwood, use the next higher classification, i.e., raise Medium to High, etc., but do not use a higher classification than extreme unless there are cured grass stands of moderate or greater density.

When wind velocity is less than 8 or 10 miles per hour, the great heat generated by fires in heavy slash may actually retard rate of spread because of the tendency of convection currents to force flames and heat inward and upward from the perimeter. Spotting is common in slash fires during dry summer weather, especially if rotten or shaggy-barked snags are present.

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Table A-7. Fuel Rate-of-Spread Classification Key
for
CUT-OVER FORESTS WITH SLASH DISPOSAL WORK COMPLETED

Definition: Areas where 20 to 100% of merchantable timber has been removed and reproduction is not yet fully shading openings; slash accumulations have been burned or broken up so that slash is no longer the dominant ground fuel in which a fire will spread from one area to another.

Ground Fuels			Rate-of-Spread Classification					
Specific Kind of Fuel (Select description most representative of fire area)		Fuel Continuity 1/	Partially Cut Stands				Clear-Cut Stands (Only scattered green trees remain)	
			60 to 90% of ground fuels shaded by remaining trees		30 to 59% of ground fuels shaded by remaining trees		Few Snags (Less than four rotten or shaggy-barked snags per acre)	Many Snags (Four or more rotten or shaggy-barked snags per acre)
Fuel Description	Species of Dead Ground Fuel		Little moss on trees and rotten or shaggy-barked snags fewer than four per acre	Considerable moss on trees or four or more rotten or shaggy-barked snags per acre	Little moss on trees and rotten or shaggy-barked snags fewer than four per acre	Considerable moss on trees or four or more rotten or shaggy-barked snags per acre		
Sparse Dead Branchwood and Loose Bark (Usually occurs where slash has been nearly 100% piled and burned or where hot fires have consumed most all the slash without leaving numerous snags.)	Dead ground fuels of any species	Patchy	Low	Low	Low	Medium	Low	High
		Uniform 2/	Low	Low	Low	Medium	Low	High
Moderate to Large Quantity of Small Dead Branchwood and Loose Bark (Typical of areas where partial slash disposal has been undertaken or where hot fire has killed numerous residual trees that have or will become rotten or shaggy-barked snags. Grass is sparse or absent.)	Less than 35% of dead ground fuels are cedar	Patchy	Medium	Medium	Medium	High	Medium	High
		Uniform	Medium	Medium	Medium	High	High	Extreme
	35% or more of dead ground fuels are cedar	Patchy	Medium	Medium	Medium	High	High	Extreme
		Uniform	Medium	High	High	Extreme	High	Extreme
Grass (Moderately dense to very dense stands of grass with or without dead branchwood and logs.) 3/	Dead ground fuels of any species	Patchy	Medium	Medium	Medium	High	High	Extreme
		Uniform	High	High	Extreme	Extreme	Flash	Flash

1/ Fuel continuity represents the arrangement of dead branchwood, rotten material, loose bark, dry grass, and, where present, ponderosa pine duff.

2/ Uniform continuity includes not only the arrangement of fuels distributed evenly over the fire area, but also those arranged in a network fashion where stringers or blocks of fuel are connected with each other forming a continuous path for spread of fire.

3/ When grass is green drop the medium classification to low and drop all other ratings by two classifications, i.e., lower High down to Low, Extreme to Medium, and Flash to High.

Notes: The finer ground fuels in exposed cut-over areas will dry out easily until reproduction shades openings. Where tractors have been used in slash disposal, numerous patches of low or medium rate-of-spread classification may result from scarification of ground and mixture of soil with fine fuels. In areas of partial slash disposal rate-of-spread classification will vary widely in cut-over stands according to volume and arrangement of the slash left.

Table A-8. Correction to Valley Bottom burning index which will give average burning index in the lower one-third of a mountain slope for a given number of hours after measurement.

Time of B.I. Measurement	Correction Factor According to Time and Aspect																	
	0 hour		1 hour		2 hours		3 hours		4 hours		5 hours		6 hours		7 hours		8 hours	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Morning																		
0600-0659	- 4	+ 4	- 6	+ 4	- 7	+ 3	- 8	+ 3	-10	+ 3	-11	+ 3	-12	+ 3	-12	+ 3	-13	+ 3
0700-0759	- 7	+ 3	- 9	+ 3	-10	+ 3	-11	+ 3	-12	+ 3	-13	+ 3	-13	+ 3	-14	+ 3	-14	+ 3
0800-0859	-10	+ 3	-12	+ 3	-13	+ 3	-14	+ 3	-14	+ 3	-14	+ 3	-15	+ 3	-15	+ 3	-15	+ 3
0900-0959	-13	+ 3	-14	+ 3	-15	+ 3	-15	+ 3	-15	+ 3	-16	+ 3	-16	+ 3	-16	+ 3	-16	+ 3
Day																		
1000-1059	-15	+ 3	-16	+ 3	-16	+ 3	-16	+ 3	-16	+ 3	-16	+ 3	-16	+ 3	-16	+ 3	-16	+ 3
1100-1159	-16	+ 3	-16	+ 3	-16	+ 3	-16	+ 3	-16	+ 3	-17	+ 3	-17	+ 3	-17	+ 2	-16	+ 2
1200-1259	-16	+ 3	-16	+ 3	-16	+ 3	-17	+ 3	-17	+ 3	-17	+ 3	-17	+ 2	-17	+ 2	-16	+ 2
1300-1359	-16	+ 3	-17	+ 3	-17	+ 3	-17	+ 3	-17	+ 3	-17	+ 2	-17	+ 2	-16	+ 2	-16	+ 2
1400-1459	-17	+ 3	-17	+ 3	-17	+ 3	-17	+ 2	-17	+ 2	-17	+ 2	-16	+ 2	-16	+ 2	-16	+ 2
1500-1559	-17	+ 3	-17	+ 2	-17	+ 2	-17	+ 2	-17	+ 2	-16	+ 2	-16	+ 1	-16	+ 1	-16	+ 1
1600-1659	-17	+ 2	-17	+ 2	-17	+ 2	-17	+ 2	-16	+ 1	-16	+ 1	-15	+ 1	-15	+ 1	-14	+ 1
1700-1759	-17	+ 2	-17	+ 2	-16	+ 1	-16	+ 1	-15	+ 1	-15	+ 1	-14	+ 1	-14	+ 1	-13	+ 1
Evening																		
1800-1859	-16	+ 1	-16	+ 1	-16	+ 1	-15	+ 1	-15	+ 1	-14	0	-13	+ 1	-13	+ 1	-12	+ 1
1900-1959	-16	+ 1	-16	+ 1	-15	+ 1	-14	+ 1	-14	+ 1	-13	+ 1	-12	+ 1	-12	+ 1	-11	+ 1
2000-2059	-15	+ 1	-15	+ 1	-14	+ 1	-13	+ 1	-12	+ 1	-12	+ 1	-11	+ 1	-10	+ 1	- 9	+ 1
2100-2159	-14	+ 1	-13	+ 1	-12	+ 1	-12	+ 1	-11	+ 1	-10	+ 1	- 9	+ 1	- 9	+ 2	- 8	+ 2
Night																		
2200-2259	-12	+ 1	-12	+ 1	-11	+ 1	-10	+ 1	- 9	+ 1	- 9	+ 1	- 8	+ 2	- 7	+ 2	- 7	+ 2
2300-2359	-11	+ 1	-11	+ 1	-10	+ 1	- 9	+ 1	- 8	+ 1	- 7	+ 2	- 7	+ 2	- 6	+ 2	- 6	+ 2
2400-2459	-10	+ 1	- 9	+ 1	- 8	+ 1	- 7	+ 2	- 7	+ 2	- 6	+ 2	- 6	+ 3	- 6	+ 2	- 6	+ 3
0100-0159	- 8	+ 1	- 7	+ 2	- 6	+ 2	- 6	+ 2	- 5	+ 2	- 6	+ 3	- 6	+ 3	- 7	+ 3	- 8	+ 3
0200-0259	- 6	+ 2	- 6	+ 2	- 5	+ 2	- 5	+ 3	- 4	+ 3	- 5	+ 3	- 6	+ 3	- 7	+ 3	- 7	+ 3
0300-0359	- 5	+ 2	- 5	+ 2	- 4	+ 3	- 4	+ 3	- 5	+ 3	- 6	+ 3	- 7	+ 3	- 8	+ 3	- 9	+ 3
0400-0459	- 4	+ 3	- 4	+ 4	- 4	+ 4	- 5	+ 4	- 6	+ 3	- 7	+ 3	- 8	+ 3	- 9	+ 3	-10	+ 3
0500-0559	- 3	+ 4	- 4	+ 4	- 5	+ 4	- 6	+ 4	- 7	+ 3	- 9	+ 3	-10	+ 3	-11	+ 3	-11	+ 3

TO USE TABLE:

1. Select time of burning index measurement in valley bottom.
2. To estimate burning index at another location at same time measurement is taken, read correction for proper aspect in 0 hour column. Example: At 1600 B.I. in valley bottom is 59. At the same time estimated B.I. on lower south slope is +2 or 61.
3. To estimate average burning index for a given number of hours at another location, read correction for proper aspect in column showing length of estimate in hours. Example: At 1600 B.I. in valley bottom is 55. Average B.I. for the next 3 hours on a lower north slope will be -17 or 38.

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Table A-9. Correction to Valley Bottom burning index which will give average burning index in the middle (Thermal Belt) one-third of a mountain slope for a given number of hours after measurement.

Time of B.I. Measurement	Correction Factor According to Time and Aspect															
	0 hour		1 hour		2 hours		3 hours		4 hours		5 hours		6 hours		7 hours		8 hours	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Morning																		
0600-0659	+ 5	+14	+ 4	+14	+ 3	+14	0	+14	- 1	+13	- 3	+12	- 4	+12	- 5	+11	- 5	+10
0700-0759	+ 3	+14	+ 2	+14	- 1	+13	- 3	+12	- 5	+12	- 6	+11	- 6	+10	- 7	+10	- 7	+ 9
0800-0859	0	+14	- 3	+13	- 5	+12	- 7	+11	- 7	+10	- 8	+10	- 8	+ 9	- 9	+ 8	- 9	+ 8
0900-0959	- 6	+12	- 8	+11	- 8	+10	- 9	+ 9	-10	+ 9	-10	+ 8	-10	+ 7	-10	+ 7	-10	+ 6
Day																		
1000-1059	- 9	+10	-10	+ 9	-10	+ 9	-11	+ 8	-11	+ 8	-11	+ 7	-11	+ 6	-11	+ 6	-10	+ 6
1100-1159	-11	+ 8	-11	+ 8	-11	+ 7	-11	+ 6	-11	+ 6	-11	+ 6	-11	+ 5	-10	+ 5	-10	+ 5
1200-1259	-11	+ 7	-11	+ 6	-11	+ 6	-11	+ 6	-11	+ 5	-11	+ 5	-10	+ 4	-10	+ 4	- 9	+ 4
1300-1359	-11	+ 6	-11	+ 6	-11	+ 5	-11	+ 4	-11	+ 4	-10	+ 4	-10	+ 3	- 9	+ 4	- 8	+ 4
1400-1459	-11	+ 5	-11	+ 4	-11	+ 4	-11	+ 4	-10	+ 4	- 9	+ 4	- 9	+ 4	- 8	+ 4	- 7	+ 4
1500-1559	-11	+ 4	-11	+ 4	-10	+ 3	-10	+ 3	- 9	+ 3	- 8	+ 3	- 7	+ 3	- 7	+ 4	- 6	+ 4
1600-1659	-10	+ 3	-10	+ 3	- 9	+ 3	- 9	+ 3	- 8	+ 3	- 7	+ 3	- 6	+ 4	- 5	+ 4	- 4	+ 4
1700-1759	-10	+ 3	- 9	+ 3	- 8	+ 3	- 7	+ 3	- 6	+ 3	- 5	+ 4	- 4	+ 4	- 4	+ 4	- 3	+ 5
Evening																		
1800-1859	- 8	+ 3	- 7	+ 3	- 6	+ 3	- 5	+ 4	- 4	+ 4	- 4	+ 4	- 3	+ 4	- 2	+ 5	- 2	+ 5
1900-1959	- 6	+ 3	- 5	+ 4	- 4	+ 4	- 3	+ 4	- 3	+ 4	- 2	+ 4	- 1	+ 5	- 1	+ 5	- 1	+ 6
2000-2059	- 4	+ 4	- 3	+ 4	- 2	+ 4	- 2	+ 4	- 1	+ 5	- 1	+ 6	0	+ 6	0	+ 6	+ 1	+ 7
2100-2159	- 2	+ 4	- 2	+ 4	- 1	+ 5	- 1	+ 5	0	+ 5	0	+ 6	+ 1	+ 6	+ 1	+ 7	+ 1	+ 8
Night																		
2200-2259	- 1	+ 5	- 1	+ 5	0	+ 5	+ 1	+ 6	+ 1	+ 6	+ 1	+ 7	+ 2	+ 8	+ 2	+ 8	+ 2	+ 9
2300-2359	0	+ 5	+ 1	+ 6	+ 1	+ 6	+ 1	+ 6	+ 2	+ 7	+ 2	+ 8	+ 2	+ 9	+ 3	+ 9	+ 3	+10
2400-2459	+ 1	+ 6	+ 2	+ 6	+ 2	+ 7	+ 2	+ 8	+ 2	+ 9	+ 3	+ 9	+ 3	+10	+ 3	+10	+ 3	+11
0100-0159	+ 2	+ 7	+ 2	+ 8	+ 2	+ 8	+ 3	+ 9	+ 3	+10	+ 3	+11	+ 3	+11	+ 3	+12	+ 2	+12
0200-0259	+ 2	+ 8	+ 3	+ 9	+ 3	+10	+ 3	+11	+ 4	+11	+ 4	+12	+ 3	+12	+ 2	+12	+ 1	+12
0300-0359	+ 3	+10	+ 4	+11	+ 4	+12	+ 4	+12	+ 4	+13	+ 3	+13	+ 2	+13	+ 1	+12	- 1	+12
0400-0459	+ 4	+12	+ 4	+12	+ 4	+13	+ 4	+13	+ 3	+13	+ 2	+13	0	+13	- 1	+12	- 2	+12
0500-0559	+ 4	+13	+ 5	+14	+ 4	+14	+ 3	+14	+ 1	+14	- 1	+13	- 2	+12	- 3	+11	- 4	+11

TO USE TABLE:

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2. To estimate burning index at another location at same time measurement is taken, read correction for proper aspect in 0 hour column. Example: At 1600 B.I. in valley bottom is 59. At the same time estimated B.I. on middle south slope is +3 or 62.
3. To estimate average burning index for a given number of hours at another location, read correction for proper aspect in column showing length of estimate in hours. Example: At 1600 B.I. in valley bottom is 55. Average B.I. for the next 3 hours on a middle north slope will be -9 or 46.

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Table A-10. Correction to Valley Bottom burning index which will give average burning index in the upper one-third of a mountain slope for a given number of hours after measurements.

Time of B.I. Measurement	Correction Factor According to Time and Aspect															
	0 hour		1 hour		2 hours		3 hours		4 hours		5 hours		6 hours		7 hours		8 hours	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Morning																		
0600-0659	+ 5	+ 8	+ 4	+ 8	+ 3	+ 8	+ 1	+ 7	- 1	+ 6	- 3	+ 5	- 4	+ 4	- 5	+ 3	- 5	+ 3
0700-0759	+ 3	+ 8	+ 2	+ 8	- 1	+ 6	- 3	+ 5	- 4	+ 4	- 5	+ 3	- 6	+ 2	- 6	+ 2	- 7	+ 1
0800-0859	0	+ 7	- 3	+ 6	- 5	+ 4	- 6	+ 3	- 7	+ 2	- 7	+ 2	- 8	+ 1	- 8	0	- 9	0
0900-0959	- 6	+ 4	- 8	+ 2	- 8	+ 2	- 9	+ 1	- 9	0	- 9	0	- 9	- 1	- 9	- 1	- 9	- 1
Day																		
1000-1059	- 9	+ 1	-10	0	-10	0	-10	- 1	- 9	- 1	- 9	- 2	- 9	- 2	- 9	- 2	- 9	- 2
1100-1159	-10	0	-10	0	-10	- 1	-10	- 2	- 9	- 2	- 9	- 2	- 9	- 2	- 9	- 2	- 9	- 2
1200-1259	-10	- 1	-10	- 2	- 9	- 2	- 9	- 2	- 9	- 3	- 9	- 3	- 9	- 3	- 9	- 3	- 8	- 3
1300-1359	- 9	- 2	- 9	- 2	- 9	- 3	- 9	- 3	- 9	- 3	- 9	- 3	- 8	- 3	- 8	- 3	- 8	- 2
1400-1459	- 9	- 3	- 9	- 3	- 9	- 3	- 9	- 3	- 8	- 3	- 8	- 3	- 8	- 3	- 7	- 2	- 7	- 2
1500-1559	- 9	- 3	- 9	- 4	- 8	- 3	- 8	- 3	- 8	- 3	- 8	- 3	- 7	- 2	- 7	- 2	- 6	- 2
1600-1659	- 8	- 4	- 8	- 4	- 8	- 3	- 8	- 3	- 7	- 3	- 7	- 2	- 6	- 2	- 6	- 1	- 5	- 1
1700-1759	- 8	- 3	- 8	- 3	- 8	- 3	- 7	- 2	- 7	- 2	- 6	- 2	- 5	- 1	- 5	0	- 4	0
Evening																		
1800-1859	- 8	- 3	- 8	- 2	- 7	- 2	- 6	- 2	- 5	- 1	- 5	- 1	- 4	0	- 3	0	- 3	+ 1
1900-1959	- 7	- 2	- 7	- 2	- 6	- 1	- 5	- 1	- 4	0	- 3	0	- 3	+ 1	- 2	+ 1	- 2	+ 2
2000-2059	- 6	- 2	- 5	- 1	- 4	0	- 3	0	- 3	+ 1	- 2	+ 1	- 1	+ 2	- 1	+ 2	- 1	+ 3
2100-2159	- 4	0	- 3	0	- 2	+ 1	- 2	+ 2	- 1	+ 2	- 1	+ 2	0	+ 3	0	+ 3	+ 1	+ 4
Night																		
2200-2259	- 2	+ 1	- 2	+ 2	- 1	+ 2	- 1	+ 2	0	+ 3	0	+ 4	+ 1	+ 4	+ 1	+ 4	+ 2	+ 5
2300-2359	- 1	+ 2	- 1	+ 2	0	+ 3	+ 1	+ 4	+ 1	+ 4	+ 1	+ 4	+ 2	+ 5	+ 2	+ 5	+ 2	+ 5
2400-2459	0	+ 3	+ 1	+ 4	+ 1	+ 4	+ 1	+ 4	+ 2	+ 5	+ 2	+ 5	+ 2	+ 6	+ 3	+ 6	+ 2	+ 6
0100-0159	+ 1	+ 4	+ 2	+ 4	+ 2	+ 5	+ 2	+ 5	+ 2	+ 6	+ 3	+ 6	+ 3	+ 6	+ 3	+ 6	+ 2	+ 6
0200-0259	+ 2	+ 5	+ 2	+ 6	+ 2	+ 6	+ 3	+ 6	+ 3	+ 6	+ 3	+ 7	+ 3	+ 7	+ 2	+ 6	0	+ 6
0300-0359	+ 2	+ 6	+ 3	+ 6	+ 3	+ 6	+ 4	+ 7	+ 3	+ 7	+ 3	+ 7	+ 2	+ 7	0	+ 6	- 1	+ 5
0400-0459	+ 3	+ 6	+ 4	+ 7	+ 4	+ 7	+ 4	+ 7	+ 3	+ 7	+ 2	+ 7	0	+ 6	- 1	+ 5	- 2	+ 4
0500-0559	+ 4	+ 7	+ 5	+ 8	+ 4	+ 8	+ 3	+ 8	+ 1	+ 7	- 1	+ 6	- 2	+ 5	- 3	+ 4	- 4	+ 4

TO USE TABLE:

1. Select time of burning index measurement in valley bottom.
2. To estimate burning index at another location at same time measurement is taken, read correction for proper aspect in 0 hour column. Example: At 1600 B.I. in valley bottom is 59. At the same time estimated B.I. on upper south slope is -4 or 55.
3. To estimate average burning index for a given number of hours at another location, read correction for proper aspect in column showing length of estimate in hours. Example: At 1600 B.I. in valley bottom is 55. Average B.I. for the next 3 hours on an upper north slope will be -8 or 47.

Table A-11. Correction to Mountain Top burning index which will give average burning index on the middle one-third of a mountain slope for a given number of hours after measurement.

Time of B.I. Measurement	Correction Factor According to Time and Aspect															
	0 hour		1 hour		2 hours		3 hours		4 hours		5 hours		6 hours		7 hours		8 hours	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Morning																		
0600-0659	- 3	+ 6	- 4	+ 6	- 5	+ 6	- 6	+ 7	- 7	+ 7	- 8	+ 7	- 8	+ 7	- 8	+ 8	- 8	+ 8
0700-0759	- 5	+ 6	- 6	+ 6	- 7	+ 7	- 8	+ 8	- 9	+ 8	- 9	+ 8	- 9	+ 8	- 9	+ 8	- 9	+ 8
0800-0859	- 7	+ 7	- 9	+ 8	- 9	+ 8	-10	+ 8	-10	+ 8	-10	+ 8	- 9	+ 8	- 9	+ 8	- 9	+ 8
0900-0959	-10	+ 8	-10	+ 8	-10	+ 8	-10	+ 8	-10	+ 8	-10	+ 8	- 9	+ 8	- 9	+ 8	- 9	+ 8
Day																		
1000-1059	-10	+ 9	-10	+ 8	-10	+ 8	-10	+ 8	-10	+ 8	- 9	+ 8	- 9	+ 8	- 9	+ 8	- 8	+ 7
1100-1159	-11	+ 8	-10	+ 8	-10	+ 8	- 9	+ 8	- 9	+ 8	- 9	+ 8	- 8	+ 7	- 8	+ 7	- 8	+ 7
1200-1259	-10	+ 8	-10	+ 8	- 9	+ 8	- 9	+ 8	- 8	+ 8	- 8	+ 7	- 8	+ 7	- 7	+ 7	- 7	+ 7
1300-1359	- 9	+ 8	- 9	+ 8	- 8	+ 8	- 8	+ 8	- 8	+ 7	- 7	+ 7	- 7	+ 7	- 6	+ 7	- 6	+ 6
1400-1459	- 8	+ 8	- 8	+ 8	- 8	+ 7	- 8	+ 7	- 7	+ 7	- 7	+ 6	- 6	+ 6	- 6	+ 6	- 5	+ 6
1500-1559	- 8	+ 7	- 7	+ 7	- 7	+ 7	- 6	+ 6	- 6	+ 6	- 5	+ 6	- 5	+ 6	- 4	+ 6	- 4	+ 5
1600-1659	- 6	+ 7	- 6	+ 6	- 6	+ 6	- 6	+ 6	- 5	+ 6	- 4	+ 6	- 4	+ 5	- 4	+ 5	- 4	+ 5
1700-1759	- 7	+ 6	- 6	+ 6	- 5	+ 6	- 4	+ 6	- 4	+ 5	- 4	+ 5	- 3	+ 5	- 3	+ 5	- 3	+ 4
Evening																		
1800-1859	- 5	+ 6	- 4	+ 6	- 4	+ 6	- 3	+ 5	- 3	+ 5	- 3	+ 5	- 3	+ 4	- 3	+ 4	- 3	+ 4
1900-1959	- 4	+ 5	- 3	+ 6	- 3	+ 5	- 2	+ 5	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 2	+ 4
2000-2059	- 2	+ 6	- 2	+ 5	- 2	+ 5	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 2	+ 4
2100-2159	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 2	+ 3	- 2	+ 3	- 2	+ 3	- 2	+ 4	- 2	+ 4
Night																		
2200-2259	- 2	+ 4	- 3	+ 4	- 2	+ 3	- 2	+ 3	- 2	+ 3	- 2	+ 3	- 2	+ 4	- 2	+ 4	- 3	+ 4
2300-2359	- 2	+ 3	- 2	+ 3	- 2	+ 3	- 2	+ 3	- 2	+ 3	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 3	+ 4
2400-2459	- 2	+ 3	- 2	+ 2	- 2	+ 3	- 2	+ 4	- 2	+ 4	- 2	+ 4	- 3	+ 4	- 3	+ 4	- 3	+ 5
0100-0159	- 2	+ 3	- 2	+ 3	- 2	+ 3	- 2	+ 4	- 3	+ 4	- 3	+ 5	- 3	+ 5	- 4	+ 5	- 4	+ 5
0200-0259	- 3	+ 3	- 3	+ 4	- 3	+ 4	- 3	+ 5	- 3	+ 5	- 3	+ 5	- 4	+ 5	- 4	+ 6	- 5	+ 6
0300-0359	- 3	+ 4	- 2	+ 5	- 3	+ 5	- 3	+ 5	- 3	+ 6	- 4	+ 6	- 5	+ 6	- 5	+ 6	- 6	+ 7
0400-0459	- 2	+ 6	- 2	+ 6	- 3	+ 6	- 3	+ 6	- 4	+ 6	- 5	+ 6	- 6	+ 7	- 6	+ 7	- 7	+ 7
0500-0559	- 3	+ 6	- 3	+ 6	- 4	+ 6	- 5	+ 6	- 6	+ 7	- 6	+ 7	- 7	+ 7	- 7	+ 7	- 8	+ 7

TO USE TABLE:

1. Select time of burning index measurement on mountain top.
2. To estimate burning index on a middle slope at the same time the mountain top measurement is taken, read correction opposite selected time in 0 hour column for aspect desired. Example: At 1600 burning index on mountain top is 50. The estimated 1600 correction for middle south slopes is +7, and the burning index therefore is 57.
3. To estimate average burning index on a middle slope for a given number of hours after measurement at a mountain top station, read correction opposite time of measurement and in column headed by number of hours for which average burning index is desired. Example: At 1100 burning index on mountain top is 40. The estimated 1100 correction to give average burning index for the next five hours on a middle north slope is -9; hence, average burning index will be 31.

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Table A-12. Correction to Mountain Top burning index which will give average burning index on the lower one-third of a mountain slope for a given number of hours after measurement.

Time of B.I. Measurement	Correction Factor According to Time and Aspect															
	0 hour		1 hour		2 hours		3 hours		4 hours		5 hours		6 hours		7 hours		8 hours	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Morning																		
0600-0659	-12	- 4	-14	- 4	-15	- 4	-15	- 3	-15	- 2	-16	- 2	-16	- 1	-15	0	-15	+ 1
0700-0759	-15	- 5	-16	- 4	-16	- 3	-16	- 2	-16	- 1	-16	0	-16	+ 1	-16	+ 1	-15	+ 2
0800-0859	-17	- 4	-17	- 2	-17	- 1	-16	0	-16	+ 1	-16	+ 2	-16	+ 2	-15	+ 3	-15	+ 3
0900-0959	-17	- 1	-16	0	-16	+ 1	-16	+ 2	-16	+ 3	-15	+ 3	-15	+ 4	-15	+ 4	-15	+ 4
Day																		
1000-1059	-16	+ 2	-16	+ 2	-16	+ 3	-15	+ 4	-15	+ 4	-15	+ 4	-15	+ 5	-14	+ 5	-14	+ 5
1100-1159	-16	+ 3	-16	+ 4	-15	+ 4	-15	+ 4	-15	+ 5	-14	+ 5	-14	+ 5	-14	+ 5	-14	+ 5
1200-1259	-15	+ 4	-14	+ 5	-14	+ 5	-14	+ 5	-14	+ 5	-14	+ 5	-14	+ 5	-14	+ 5	-13	+ 5
1300-1359	-14	+ 5	-14	+ 6	-14	+ 6	-14	+ 6	-14	+ 6	-14	+ 5	-14	+ 5	-14	+ 5	-14	+ 4
1400-1459	-14	+ 6	-14	+ 6	-14	+ 6	-14	+ 6	-14	+ 5	-14	+ 5	-14	+ 5	-14	+ 4	-14	+ 4
1500-1559	-14	+ 6	-14	+ 6	-14	+ 6	-14	+ 5	-14	+ 5	-14	+ 4	-14	+ 4	-14	+ 4	-13	+ 3
1600-1659	-13	+ 6	-14	+ 6	-13	+ 5	-13	+ 4	-13	+ 4	-13	+ 4	-13	+ 3	-13	+ 2	-13	+ 2
1700-1759	-14	+ 5	-14	+ 5	-14	+ 4	-14	+ 4	-14	+ 3	-14	+ 3	-13	+ 2	-13	+ 2	-13	+ 1
Evening																		
1800-1859	-13	+ 4	-14	+ 4	-14	+ 3	-14	+ 3	-13	+ 2	-13	+ 2	-13	+ 1	-13	+ 1	-13	0
1900-1959	-14	+ 3	-14	+ 3	-14	+ 2	-14	+ 2	-13	+ 1	-13	+ 1	-13	0	-13	0	-13	- 1
2000-2059	-13	+ 3	-14	+ 2	-13	+ 1	-13	+ 1	-13	0	-13	0	-13	- 1	-12	- 1	-12	- 1
2100-2159	-14	+ 1	-14	0	-13	0	-13	0	-13	- 1	-13	- 1	-12	- 2	-12	- 2	-12	- 2
Night																		
2200-2259	-13	0	-13	0	-13	- 1	-13	- 2	-12	- 2	-12	- 2	-12	- 2	-12	- 2	-12	- 3
2300-2359	-13	- 1	-13	- 2	-13	- 2	-12	- 2	-12	- 3	-12	- 3	-11	- 3	-12	- 3	-12	- 3
2400-2459	-13	- 2	-12	- 2	-12	- 3	-12	- 3	-11	- 3	-11	- 3	-11	- 3	-12	- 3	-12	- 3
0100-0159	-12	- 3	-12	- 3	-11	- 3	-11	- 3	-11	- 3	-11	- 3	-12	- 4	-12	- 4	-13	- 3
0200-0259	-11	- 3	-11	- 4	-11	- 3	-10	- 3	-11	- 3	-12	- 4	-12	- 4	-13	- 3	-13	- 3
0300-0359	-11	- 4	-10	- 4	-10	- 3	-11	- 4	-12	- 4	-12	- 4	-13	- 3	-13	- 3	-14	- 2
0400-0459	-10	- 3	-10	- 3	-11	- 3	-12	- 4	-13	- 4	-14	- 3	-14	- 3	-14	- 2	-14	- 1
0500-0559	-10	- 3	-11	- 4	-12	- 4	-14	- 4	-14	- 3	-14	- 2	-15	- 2	-15	- 1	-15	0

TO USE TABLE:

1. Select time of burning index measurement on mountain top.
2. To estimate burning index on a lower slope at the same time the mountain top measurement is taken, read correction opposite selected time in 0 hour column for aspect desired. Example: At 1600 burning index on mountain top is 50. The estimated 1600 correction for lower south slopes is +6, and the burning index therefore is 56.
3. To estimate average burning index on a lower slope for a given number of hours after measurement at a mountain top station, read correction opposite time of measurement and in column headed by number of hours for which average burning index is desired. Example: At 1100 burning index on mountain top is 40. The estimated 1100 correction to give average burning index on a lower north slope for the next five hours is -14; hence, average burning index will be 26.

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Table A-13. Correction to Mountain Top burning index which will give average burning index in valley bottoms for a given number of hours after measurement.

Time of B.I. Measurement	Correction Factor According to Time and Aspect								
	0 hour	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	8 hours
Morning									
0600-0659	-8	-8	-8	-7	-6	-5	-4	-3	-2
0700-0759	-8	-8	-6	-5	-4	-3	-2	-2	-1
0800-0859	-7	-6	-4	-3	-2	-2	-1	0	0
0900-0959	-4	-2	-2	-1	0	0	+1	+1	+1
Day									
1000-1059	-1	0	0	0	+1	+1	+2	+2	+2
1100-1159	0	0	+1	+2	+2	+2	+2	+2	+2
1200-1259	+1	+2	+2	+2	+3	+3	+3	+3	+3
1300-1359	+2	+2	+3	+3	+3	+3	+3	+3	+2
1400-1459	+3	+3	+3	+3	+3	+3	+3	+2	+2
1500-1559	+3	+4	+3	+3	+3	+3	+2	+2	+2
1600-1659	+4	+4	+3	+3	+3	+2	+2	+1	+1
1700-1759	+3	+3	+3	+2	+2	+2	+1	0	0
Evening									
1800-1859	+3	+2	+2	+2	+1	+1	0	0	-1
1900-1959	+2	+2	+1	+1	0	0	-1	-1	-2
2000-2059	+2	+1	0	0	-1	-1	-2	-2	-3
2100-2159	0	0	-1	-2	-2	-2	-3	-3	-4
Night									
2200-2259	-1	-2	-2	-2	-3	-4	-4	-4	-5
2300-2359	-2	-2	-3	-4	-4	-4	-5	-5	-5
2400-2459	-3	-4	-4	-4	-5	-5	-6	-6	-6
0100-0159	-4	-4	-5	-5	-6	-6	-6	-6	-6
0200-0259	-5	-6	-6	-6	-6	-7	-7	-6	-6
0300-0359	-6	-6	-6	-7	-7	-7	-7	-6	-5
0400-0459	-6	-7	-7	-7	-7	-7	-6	-5	-4
0500-0559	-7	-8	-8	-8	-7	-6	-5	-4	-4

TO USE TABLE:

1. Select time of burning index measurement on mountain top.
2. To estimate burning index in the valley bottoms at the same time the mountain top measurement is taken, read correction opposite selected time in 0 hour column. Example: At 1600 burning index on mountain top is 50. The estimated 1600 correction for valley bottom is +4, and the burning index therefore is 54.
3. To estimate average burning index in valley bottoms for a given number of hours after measurement at a mountain top station, read correction opposite time of measurement and in column headed by number of hours for which average burning index is desired. Example: At 1100 burning index on mountain top is 40. The estimated 1100 correction to give average valley bottom burning index for the next five hours is +2; hence, average burning index will be 42.

Table A-14. Correction to Mountain Top burning index which will give average burning index on north aspects of the upper one-third of a mountain slope for a given number of hours after measurement. 1/

Time of B.I. Measurement	Correction Factor According to Time and Aspect								
	0 hour	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	8 hours
Morning									
0600-0659	-3	-4	-5	-6	-7	-8	-8	-8	-7
0700-0759	-5	-6	-7	-8	-8	-8	-8	-8	-8
0800-0859	-7	-8	-9	-9	-9	-9	-8	-8	-8
0900-0959	-10	-10	-10	-10	-9	-9	-8	-8	-8
Day									
1000-1059	-10	-10	-10	-9	-8	-8	-8	-7	-7
1100-1159	-10	-10	-9	-8	-8	-7	-7	-7	-6
1200-1259	-9	-8	-7	-7	-7	-6	-6	-6	-6
1300-1359	-7	-6	-6	-6	-6	-6	-6	-5	-5
1400-1459	-6	-6	-6	-6	-5	-5	-5	-5	-5
1500-1559	-6	-6	-5	-5	-5	-5	-5	-4	-4
1600-1659	-5	-5	-5	-5	-5	-5	-4	-4	-4
1700-1759	-5	-5	-5	-5	-5	-4	-4	-4	-4
Evening									
1800-1859	-5	-5	-5	-4	-4	-4	-4	-4	-4
1900-1959	-5	-4	-4	-4	-4	-4	-4	-4	-3
2000-2059	-4	-4	-4	-4	-3	-3	-3	-3	-3
2100-2159	-4	-4	-3	-3	-3	-3	-3	-3	-3
Night									
2200-2259	-3	-3	-3	-3	-3	-3	-3	-3	-3
2300-2359	-3	-3	-3	-3	-3	-3	-3	-3	-3
2400-2459	-3	-3	-3	-3	-3	-3	-3	-3	-4
0100-0159	-3	-3	-3	-3	-3	-3	-3	-4	-4
0200-0259	-3	-3	-3	-3	-3	-3	-4	-5	-5
0300-0359	-3	-3	-3	-3	-3	-4	-5	-6	-6
0400-0459	-3	-3	-3	-4	-4	-5	-6	-6	-7
0500-0559	-3	-3	-4	-4	-6	-6	-7	-7	-7

1/ No correction required for south aspects. Conditions essentially the same as at mountain top.

TO USE TABLE:

1. Select time of burning index measurement on mountain top.
2. To estimate burning index on an upper north slope at the same time the mountain top measurement is taken, read correction opposite selected time in 0 hour column. Example: At 1600 burning index on mountain top is 50. The estimated 1600 correction for upper north slopes is -5, and the burning index is therefore 45.
3. To estimate average burning index on an upper north slope for a given number of hours after measurement at a mountain top station, read correction opposite time of measurement and in column headed by number of hours for which average burning index is desired. Example: At 1100 burning index on mountain top is 40. The estimated 1100 correction to give average burning index on an upper north slope for the next five hours is -7; hence, average burning index will be 33.

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Table A-15. Cumulative Hourly Change in Burning Index 1/

Hour of B.I. Measurement	Hour for which B.I. is desired																						
	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
0000	-2	-3	-5	-8	-9	-10	-9	-6	-1	+4	+8	+10	+13	+15	+16	+15	+14	+12	+9	+7	+5	+4	+2	///
0100	///	-2	-4	-6	-8	-9	-8	-4	+1	+6	+9	+12	+15	+17	+18	+17	+15	+13	+10	+8	+7	+5	+3	+2
0200	+2	///	-2	-4	-6	-7	-6	-3	+2	+7	+11	+14	+17	+19	+20	+19	+17	+15	+13	+10	+8	+7	+5	+3
0300	+4	+2	///	-2	-4	-5	-4	-1	+5	+9	+13	+16	+19	+21	+22	+21	+19	+17	+15	+13	+11	+9	+7	+5
0400	+6	+4	+2	///	-2	-3	-2	+2	+7	+11	+15	+18	+21	+23	+24	+23	+21	+19	+17	+16	+12	+11	+9	+7
0500	+8	+6	+4	+2	///	-1	0	+4	+8	+13	+17	+19	+22	+25	+26	+25	+23	+21	+18	+16	+14	+13	+11	+9
0600	+9	+7	+5	+3	+1	///	+1	+4	+9	+14	+18	+20	+23	+26	+27	+26	+24	+21	+19	+17	+15	+14	+12	+10
0700	+7	+5	+3	+1	0	-1	///	+3	+8	+13	+16	+19	+22	+24	+25	+24	+23	+20	+18	+16	+14	+12	+10	+9
0800	+5	+3	+1	-1	-3	-4	-3	///	+5	+10	+13	+16	+19	+21	+23	+21	+19	+17	+15	+13	+11	+9	+7	+6
0900	-1	-2	-4	-7	-8	-9	-8	-4	///	+4	+8	+11	+14	+16	+17	+16	+14	+12	+10	+8	+6	+4	+2	+1
1000	-5	-7	-9	-11	-13	-14	-13	-10	-4	///	+3	+6	+9	+12	+12	+12	+9	+7	+5	+3	+1	0	-2	-4
1100	-9	-11	-13	-15	-17	-18	-17	-14	-8	-4	///	+3	+6	+8	+9	+8	+6	+4	+2	0	-2	-4	-6	-7
1200	-12	-14	-16	-18	-20	-21	-20	-17	-11	-7	-3	///	+3	+5	+6	+5	+3	+1	-1	-3	-5	-7	-9	-10
1300	-15	-17	-19	-21	-23	-24	-23	-20	-14	-10	-6	-3	///	+2	+3	+2	0	-2	-4	-6	-8	-10	-12	-13
1400	-17	-19	-21	-23	-25	-26	-25	-22	-16	-12	-8	-5	-2	///	+1	0	-2	-4	-6	-8	-10	-12	-14	-15
1500	-18	-20	-22	-23	-26	-27	-26	-23	-17	-13	-9	-6	-3	-1	///	-1	-3	-5	-7	-9	-11	-13	-15	-16
1600	-17	-19	-21	-22	-25	-26	-25	-22	-16	-12	-8	-5	-2	0	+1	///	-2	-4	-6	-8	-10	-12	-14	-15
1700	-15	-17	-19	-20	-23	-24	-23	-20	-14	-10	-6	-3	-1	+2	+3	+2	///	-2	-4	-6	-8	-10	-12	-13
1800	-13	-15	-17	-18	-21	-22	-21	-18	-12	-8	-4	-1	+1	+4	+5	+4	+2	///	-2	-4	-6	-8	-10	-11
1900	-10	-12	-14	-15	-18	-19	-18	-15	-9	-5	-1	+2	+4	+7	+8	+7	+5	+3	///	-1	-3	-5	-7	-8
2000	-8	-10	-12	-13	-16	-17	-16	-13	-7	-3	+1	+4	+6	+9	+10	+9	+7	+5	+2	///	-1	-3	-5	-6
2100	-7	-9	-11	-12	-15	-16	-15	-12	-6	-2	+2	+5	+7	+10	+11	+10	+8	+6	+3	+1	///	-2	-4	-5
2200	-5	-7	-9	-10	-13	-14	-13	-10	-4	0	+4	+7	+9	+12	+13	+12	+10	+8	+5	+3	+2	///	-2	-3
2300	-3	-5	-7	-8	-11	-12	-11	-8	-2	+2	+6	+9	+11	+14	+15	+14	+12	+10	+7	+5	+4	+2	///	0

1/ Based on average bi-hourly change during normal (settled) summer weather beginning on the fifth day in July on which burning index reached 30 or more. B.I. measured at 2300-foot clearcut station, Priest River Experimental Forest, July and August, 1936-1939.

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Table A-16. Average Initial Rate of Spread 1/ According To Fuel Type, Slope Steepness, and Burning Index at Site of Fire. 2/

Fuel Rate of Spread Type	Slope Steepness 3/ Percent	Burning Index									
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
		Perimeter Increase in Chains Per Hour									
Low	0-10	0	1	1	1	1	2	2	2	3	4
	11-25	0	1	1	1	2	2	3	3	4	6
	26-50	1	1	2	2	3	3	4	4	6	8
	51-75	1	2	3	3	4	5	6	7	9	13
	Over 75	2	3	4	5	6	7	8	10	15	20
Medium	0-10	0	1	1	1	2	2	2	3	4	5
	11-25	1	1	1	2	2	3	3	4	6	7
	26-50	1	2	2	3	3	4	5	6	8	10
	51-75	2	3	3	4	5	6	7	9	13	16
	Over 75	3	4	5	6	8	10	12	15	20	25
High	0-10	0	1	2	3	4	5	6	8	9	12
	11-25	1	1	3	4	6	7	9	11	13	17
	26-50	2	2	4	6	8	10	12	16	18	24
	51-75	3	3	6	9	13	16	19	25	28	38
	Over 75	4	5	10	15	20	25	30	40	45	60
Extreme	0-10	1	3	4	5	6	8	10	13	16	19
	11-25	1	4	6	7	9	11	14	19	22	27
	26-50	2	6	8	10	12	16	20	26	32	38
	51-75	3	9	13	16	19	25	32	41	50	60
	Over 75	5	15	20	25	30	40	50	65	80	95
Flash	0-10	1	5	12	15	19	24	30	37	46	57
	11-25	1	7	17	21	27	34	42	52	65	81
	26-50	2	10	24	30	38	48	60	74	92	114
	51-75	3	16	38	48	60	76	95	117	146	181
	Over 75	5	25	60	75	95	120	150	185	230	285

1/ Average Initial Rate of Spread refers to perimeter increase between discovery of fire and first attack. This rate of spread may be anticipated during the first 4 to 5 hours.

2/ Table based upon study of 2955 fires in national forests, R-1, 1936-1944. Values for very high and very low burning index have been estimated.

3/ General descriptions used in slope descriptions are: Level, 0-10%; Gentle, 11-25%; Moderate, 26-50%; Steep, 51-75%; Very Steep, over 75%.

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LITERATURE CITED

(1) BARROWS, J. S.
1951. Forest Fires in the northern Rocky Mountains. Northern Rocky Mountain Forest and Range Experiment Station. Station Paper No. 28, illus.

(2) GISBORNE, H. T.
1941. How the wind blows in the forest of northern Idaho. Northern Rocky Mountain Forest and Range Experiment Station. Progress Report, illus.

(3) _____
1936. Measuring fire weather and forest inflammability. USDA Circular No. 398, illus.

(4) HAYES, G. LLOYD
1941. Influence of altitude and aspect on daily variations in factors of forest fire danger. USDA Circular No. 541, illus.

(5) HORNBY, L. G.
1935. Fuel type mapping in Region One. Journal of Forestry, Vol. 33, No. 1.

(6) JEMISON, GEORGE M.
1935. Influence of weather factors on moisture content of light fuels in forests of the northern Rocky Mountains. Journal of Agricultural Research, Vol. 51, No. 10, illus.

(7) PRICE, DAVID J.
1939. How fires start and how they burn. Pennsylvania Firemen's Training Conference, State College, Pennsylvania. Mimeographed.

(8) U. S. FOREST SERVICE
1936. Fuel type standards, Region One. Northern Rocky Mountain Forest and Range Experiment Station.

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14		List of publications available for distribution or loan, 1910 through 1947. NRM station. June 1948.
15		Review of published information on the larch-Douglas fir forest type, by Russell K. LeBarron. Nov. 1948

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