UNIT I--THE FIRE ENVIRONMENT

Fire behavior, which is the subject of this course, can be defined as the manner in which fuels ignite, flames develop, and fire spreads and exhibits other phenomena. Our analysis o£ what fire does recognizes the complexity of the variable factors that influence it. Whether you are concerned with the suppression of wildfires, or you wish to use fire as a management tool, a healthy respect for, and a basic understanding of, the natural forces or processes related to fire are required. The safety and effectiveness of fire management operations usually are dependent on sound judgments made on what the fire can and will do. Such judgments often are required of firefighters on the fireline, as well as the fire overhead organization. Decisions made based on those judgments frequently reflect success or failure in meeting management objectives, reasonable or excessive costs of suppression, low or high accident rates, and reasonable or high losses to resources.

This unit is about the fire environment. You will be introduced to the most important variables that affect fire behavior. You will see how the interactions of fire with its environment must influence our assessments of fire behavior. This unit will also introduce you to mathematical fire models available to help us predict fire behavior.

Before starting the unit, be sure you have carefully read the instructions to students on page 1 of your workbook. On page 2, you will find the unit objectives on which you will be tested at the end of this unit. Please study these objectives; then, when you have finished, return to this text.

On page 3, figure 1 illustrates the three major components making up the fire environment. The current state of each of the environmental components--fuels, topography, and weather or airmass--and their interactions with each other and with fire itself, determine the characteristics and behavior of a fire at any given moment. Changes in fire behavior in space and time occur in relation to changes in the environmental components.

Note the seven factors listed under fuels. At the head of the list is moisture content. One unit of this course will be devoted just to fuel moisture content. Another unit will be devoted to fuel models, which will help you to analyze the rest of the fuels factors and make some important estimations.

Under weather, windspeed and direction are our most critical factors. One unit has been devoted to winds and their effects on fire behavior. A large part of this course concentrates on fire weather, as this is the most variable and most difficult of the environmental components to predict.

Topography is the most constant of the three major components making up the fire environment. The most important factor under topography is steepness of slope, since changes in slope have very direct and profound effects on fire behavior. One unit of the course will discuss topography and how to measure slope.

Firefighters soon realize that fires seldom behave exactly the same way from time to time or place to place. This complexity of variable factors indeed offers a challenge to any fireman and to his ability to predict what a fire will do in the next 24 hours or after it has spread into new terrain.

Now let's briefly note how each o£ the three major components can change and influence fire behavior. Please turn to page 4. Under Item A, note these changes that take place in time and in space: First, topography. With time, no change. Terrain is generally constant. Regarding space, changes can be considerable, especially in mountainous terrain.

Next, fuels: With time, fuel moisture changes on a short-time basis. Other changes occur due to man or nature. With space, very significant changes occur due to region and site characteristics.

Last, weather: With time, temperature, relative humidity, and wind change almost continuously. In space, significant changes occur with terrain and general weather patterns.

Let's go back to topography and point out just how it does affect the job of predicting fire behavior. We will see in this course how topography directly modifies general weather patterns to produce local weather variations. Because of these variations in weather, topography indirectly causes variations in fuel loadings and in local fuel moisture conditions. As a result topography strongly affects the direction and rate of spread of fire.

On page 5, we'll look at how fuels change over time. First of all, changes occur due to seasonal variations. Depending on time and the character of season, we have differing proportions of dead to live fuels. The amount of curing of annual growth varies, and the moisture content in dead and live fuels changes.

In addition, we must recognize other natural or man-made forces at work. These are disease or insect infestations, wind or flood damage, drought or frost damage, the harvesting or manipulation of vegetation, and prescribed fires or wildfires that have recently occurred. Each of these can produce changes in fuel loading, arrangement, and/or moisture content.

How about the influence of weather on the fire environment? Please do question 1 on page 5 of the workbook; then return to the text.

Choices 1 and 3 are true. Unfortunately, the elements of weather are not easily forecasted. Diurnal changes are significant and have a profound effect on fire behavior.

Another force of nature which must be considered here is the fire itself and how it affects its own environment. On page 6, we see how fire as a local heat source affects its environment. First, fire can directly modify local weather, the extent depending upon fire size and intensity. This is done in several ways. Intense heat can modify or produce local winds in the vicinity of the fire. It can also contribute to atmospheric instability, cumulus cloud development, and sometimes even precipitation. And, of course, fire directly affects temperatures and moisture contents of adjacent fuels. The effects of fire on its own environment will be discussed in more detail later.

Now let's note in item B some natural processes or features related to wildfire that concern firefighters. Under item B, the first factor is combustion. This is defined as the rapid oxidation of combustible materials that produces heat energy. The second factor is ignition temperature. This is the point to which a combustible material must be heated to produce self-sustaining combustion. The third factor is fire intensity, which is the rate of heat energy released during combustion. The fourth factor is rate of spread. This is the relative activity of fire in extending its horizontal dimensions. Rate of spread is usually expressed in chains per hour of forward spread or chains per hour of perimeter increase. As the course progresses, you will see how we must analyze and tie all the many variables together to predict whether ignition of new fuels will occur, what the fire intensity will be, and how fast the fire will spread.

Our first concern should be: Will new fuels ignite? On page 7, under item C, note these factors on which the ignition of vegetative fuels depends. First, size and shape of fuels; second, fuel moisture content; third, compactness or arrangement of fuels; and fourth, fuel temperature. These are pretty much listed in order of importance, but all interact to determine whether ignition will occur if a firebrand is introduced into a natural fuel bed.

Figure 2 illustrates rates of spread and their relationship to fire growth. The dashed lines depict fire perimeters by time periods, which in this example are 1-hour intervals. The fire started at point X, at 1400 hours, or 2:00 p.m.

We see that this fire is spreading primarily in one direction, which is also the direction the wind is blowing. This we call the head of the fire. Spread is also occurring to the sides or flanks, and to the rear, but at lesser rates. We are most concerned with forward rate of spread, or spread at the fire's head, as this is generally the most dangerous and difficult type of spread to control. The fire has spread at a rate of 8 chains per hour over a 3-hour period. Note that the perimeter o£ the fire has also increased at a fixed rate; that is, 24 chains per hour. At the end of the 2 hours, the perimeter is 48 chains; at 3 hours, 72 chains, and so on. If all factors remain constant, the fire will continue to grow at 8 chains per hour of forward spread, and 24 chains per hour of perimeter increase.

How about area increase per hour? During the first hour, the fire burned 4 acres. After 2 hours, the area increased to 16 acres; and after 3 hours, the area is 37 acres. From this we can see that there are no fixed rates of area increase per hour as long as the fire continues to spread freely in all directions. Calculations of rate of spread, then, should be in terms of forward spread at the head, sideways spread on the flanks, and fire perimeter increase.

Assuming that fuels are mostly continuous in the fire illustrated in figure 2, what are the primary factors that will affect rate of spread? Well, they normally are fine fuel moisture, windspeed, fuel loading, steepness of slope, and the occurrence of spotting. In later units, you will see the extent to which these factors affect rate of spread and how these inputs are used to calculate fire spread.

In figure 2, we diagrammed the perimeter and area relationship to rate of spread from a point source. Page 8, figure 3, illustrates some variations in the elliptical or egg-shaped patterns of fire spread, depending on windspeeds. As windspeeds increase, the fire shapes elongate. Note that these patterns are not drawn to scale, and merely illustrate fire shapes.

The fire shapes in figure 3 can be used for planning purposes, particularly on the initial attack of fires. These shapes may not fit your fire situation, as conditions in the field can cause variations in fire shapes. These conditions are the following: heterogenous fuel complexes that produce fingering, barriers that stop or partially stop the spread, the effect of slope that reduces or increases fire spread at the head or flanks, and spotting ahead of or downslope from a fire. All of these serve to complicate the task of estimating where the fire perimeter will be after times number o£ hours.

Together with ignition and rate of spread, fire intensity is a third feature of wildfires of great concern to firefighters. Under item D, note these factors that fire intensity is dependent upon: Fuel loading, compactness or arrangement of fuels, moisture content of fuels, and atmospheric instability. These are important factors to remember, and you will be expected to know them later.

The listing of these factors at this point in the course is intended primarily to acquaint you with the variables that must be analyzed and considered when making fire behavior predictions. Near the end of this unit, we will pull together the most important fire environmental factors and show what inputs are required to make fire behavior calculations and predictions.

To better understand when and how ignition and combustion occur in a wildfire, we need to discuss the physical processes involved. The next part of this unit, starting on page 9, will deal with heat transfer and how the various methods of heat transfer affect fire behavior.

First of all, note that heat transfer refers to the physical processes by which heat energy moves to and through unburned fuel.

The three common methods of heat transfer should be listed under item E. The first is conduction. Conduction is the transfer of heat from one molecule of matter to another. An example of this is fire smoldering through a solid piece of fuel. Since wood is generally a poor conductor of heat, conduction is the least important method of the three.

Next is convection. This is the transfer of heat resulting from the motion of air (or fluid). It is the natural buoyant rise of warm air over a heat source that induces an automatic circulation within an airmass. Examples of forced convection are fire spreading from surface fuels to aerial fuels, and columns of smoke rising high into the atmosphere. Convection also includes direct flame contact, a powerful heat transfer process, especially in a head fire.

The third method is radiation. Radiation is the transmission of heat energy by rays passing from a heat source to an absorbing material. Examples are the heat received from the sun, and the preheating of fuels ahead of a 10 flaming front. Radiation from glowing char or flames is very strong. This is why firefighters often must shield exposed skin. Radiation is the chief source of heat transfer in a backing fire.

Do the examples given for the three heat transfer methods suggest a relationship among ignition, fire intensity, and rate of spread? Well, they should, because fire behavior is the result of, and is affected by, the method and the amount of heat energy transfer within the fire environment.

Please turn to page 10. We've illustrated the various heat transfer methods in figure 4. Branches above the fire are receiving heat by convection and radiation. Tree trunks and shrubs are receiving heat by radiation from the fire. Fuels on the ground are being preheated by conduction and radiation. Preheating of fuels may be occurring by all of these methods at the same time, depending on the arrangement or loading of the fuels.

We've stressed the importance of radiant heat transfer in the preheating of fuels and spread of the fire. How much heat will be received by fuels ahead of the fire? Well, this depends on the fire intensity and the distance, but how much?

Figure 5 states that radiant heat decreases inversely with the square of the distance from a point source. For example, if 100 heat units are received at 1 foot ahead of the source, only 25 heat units will be received at 2 feet. If we double the distance from 2 to 4 feet, the heat units received are reduced to one-sixteenth that of the 1 foot level, or 6.25. At 10 feet, the heat units have been reduced to only one one-hundredth of the radiated value at 1 foot. You can see how rapidly radiant heat drops off with distance.

It should be emphasized that, in fireline work, a point source is rarely encountered. Here, the source is better described as a wall, and radiant energy from it obeys somewhat more complicated physical laws. In this course, however, we will deal only with the basic point source relationships.

On page 11, see question 2. Mark your selection, then return to the text.

The answer to question 2 is number 2. Radiant heat is decreased by 4 times. If you have problems in understanding this process, please go back and study figure 5.

In continuing our discussion of radiant heat process, see figure 6. We know that fire generally travels faster upslope than down. We know that fire travels faster when there is wind. And we know that a pile of wood burns hotter than scattered wood. Why? Well, at least part of the answer is increased radiant heat from the fire to the adjacent fuels. Fuels upslope or downwind from the flames are preheated at a faster rate; thus fire spread is increased. In these two situations, increased preheating by convection can also increase rate of spread upslope or downwind. In the third situation, the higher fire intensity in concentrated fuels is definitely a function of radiant heat transfer.

On page 12, do question 3. Mark your choice or choices, then return to the text.

The answer to question 3 is number 3. Convected heat can be angled by the wind to help increase preheating of fuels ahead of the fire. Fuels upslope from a fire receive the same effect, as we mentioned in our discussion of figure 6.

There is a fourth method by which fire spreads that is of great concern to firefighters. This is the mass transport of firebrands which can occur as a result of convection, wind, or gravity. We call this spotting. Small embers of burning material can be lifted in a convection column and be carried some distance ahead of a fire. Wind, in addition to strong convective currents, can carry embers or firebrands considerable distances downwind from the fire. Wind without convective lifting will result in shorter range spotting of firebrands.

Gravity also is responsible for spotting of firebrands, but always down slope. Usually, the steeper the slope, the greater the spotting problems from burning materials of various sizes rolling down slope. In each of these cases, we are dealing with new ignitions outside the fire perimeter, and not the normal growth of the fire.

Now see page 13. It's time for the first exercise. This unit has used some fire terminology that you must learn if you are to understand the basic concepts of fire behavior. You will see these and other terms used again and again in later units of the course. Being able to describe exactly what a fire is doing is a first step toward understanding fire behavior. Increase of your fire vocabulary is the purpose of the first exercise. Remember that there is a glossary in the back of the student guide. Please do this exercise now.

You should have checked your answers for exercise 1 on page 22. Remember, the glossary of terms is available to you in the Student Guide when you wish to check a definition.

In the next part, starting on page 14, we want to discuss a wildfire's potential behavior. Why do some fires remain small while others get large very rapidly? What happens when a fire gets large in size and intensity? How does fire interact with its environment?

Let's first consider the extent of the fire's environment. For a very small fire, the fire environment is limited to a few feet horizontally and vertically. As a fire grows in size, so does the extent of the environment affected. In a large fire, the fire environment may extend many miles horizontally and thousands of feet vertically. High intensity wildfires, whether large or small in size, usually have considerable effect on the atmosphere vertically. This is evidenced by their convection columns. There are generally three factors that determine the extent of vertical development of a fire's convection or smoke column. These are the heat energy generated from the fire, the instability of the lower atmosphere, and the winds aloft. Stable air and/or strong winds tend to discourage vertical development of convection columns.

Figure 7 illustrates the vertical dimensions of a fire. Low intensity fires will create weak indrafts at the fire's edge that will feed a low, weak smoke or convection column over the fire. This we sometimes refer to as a two-dimensional fire.

In contrast, a high intensity fire will create much stronger indrafts that can help feed convection columns to many thousands of feet into the atmosphere. This is sometimes called a three-dimensional fire.

Figure 8 illustrates an open and a closed fire environment. On the left side, we see a fire burning through all levels of the vegetation and exposed to various winds and other weather elements. It will be readily affected by any atmospheric changes, and fire behavior can change drastically as a result of wind shifts, etc.

On the right side, the fire is burning under a forest canopy. This is somewhat similar to a structural fire burning inside a building. Conditions outside the building have relatively little effect on the fire inside. Such fires usually remain low in intensity. However, once the fire breaks out o£ the building or out through the forest canopy, fire intensity and spread can increase drastically as outside atmospheric conditions then influence the fire.

Remember that any wildfire is a heat source that can and will interact with its natural environment. The size of that sphere of influence will depend on the size and intensity or heat energy output of the fire. The physical location of the fire, and the sheltering effect from surrounding terrain and vegetation is often a contributing factor to the potential behavior of that fire.

Let's once again compare low intensity fires to high intensity fires. See page 15. We can generalize by saying that with low intensity fires, the environment mostly controls the fire. The sphere of influence is very small, and the fire causes only slight modification of weather elements in the immediate proximity of the fire.

On the other hand, high intensity fires can control the environment to a marked extent. The sphere of influence becomes much greater, and high intensity fires can significantly modify weather elements near and adjacent to the fire.

Now for a change of pace, we'd like you to try answering question 4. This includes some statement that we have not thoroughly discussed. Mark your choice or choices, then return to the text..

We'll discuss each item in question 4. The first statement is not true, as grass fires in light fuel loadings can reach very high intensities or blowup conditions. To do this, rate of spread must be very high with large amounts of available fuels being consumed in short periods of time. Statement ? is true. Smoke columns from high intensity fires have been measured at over 30,000 feet. Statement 3 is not necessarily true. Watch out for that word "always", as there usually are exceptions. There are situations where ground fires may be burning deep into organic materials where heat intensities are very high, but there is little influence on the surrounding 13
environment. The last statement is not true. As we mentioned for the first statement, a high rate of spread is necessary to produce high fire intensities in light fuels. Where large quantities of fuel are available for combustion, fire intensity can be high with low rates of spread, but intensity does increase as rate of spread increases.

We hope that all of this discussion has impressed you, as a firefighter, with the need to know what a fire is doing and what it can do in the future. Many times firefighters have been surprised by wind shifts and other weather changes which suddenly contribute to extreme fire behavior. If you are to do your job safely and effectively, it, is essential that you be able to anticipate what your fire will do next.

There are four primary areas of concern to firefighters in predicting fire behavior: Forward rate of spread of fires, the future perimeter of the fires, the fireline intensities or flame lengths, and any unusual or extreme fire behavior such as crowning and spotting.

Note that we are now using the term "fireline intensity," rather than fire intensity. It's important that you understand that this is not the same as fire intensity. Fire intensity is a somewhat general term, referring to the entire heat release of a fire at a given time. It is very difficult to measure or to relate overall fire intensity to fire control activities.

In contrast, fireline intensity is a measurable and useful term that is related to flame length. In turn, flame length can be related to fire control jobs. We will explain fireline intensity and its relationship to flame length a little later.

The job of predicting fire behavior is indeed a complex one. How does one even start to analyze the many variables? Well, this course is intended to help you gain the basic knowledge required to assess fire behavior. It will also brief you about systems available to make fire behavior calculations or estimations.

On page 16, we would like to introduce you to fire behavior prediction systems. See figure 9. Before predictions can be made, we must make some preliminary observations. What is the fire doing, and under what environmental conditions? How are fireline conditions expected to change with respect to weather,. fuels, and terrain? This information can be entered into tables, graphs, and hand held calculators or computers, and, with the help of mathematical fire models, fire behavior output is obtained. Using this output, plus the firefighter's own experience with this fire and with other fires, enables the firefighter to make the best predictions or estimations.

Figure 10 delineates the process of using a fire behavior prediction system. First, we must assess the fire situation and determine the inputs essential to using the system. There are four: The fuel moisture content, primarily of fine fuels; second, physical descriptions of the fuels, which can be categorized into fuel models; third, the steepness of slope, measured in percent; and finally, wind speed and direction at points of calculations. These values are processed by entry into fire behavior models, which are now available for use in several forms.

Fire behavior outputs are received from the models and recorded as follows: Rate of spread in chains per hour, fireline intensity in BTUs/foot/second, and flame length in feet. Area and perimeter, and probability of ignition, can also be obtained from simple tables. The last steps in figure 10 are to interpret those outputs for various points on the fire perimeter; to estimate spotting and crowning potential, and size and fire perimeter location at various times; and finally, to use these estimations to determine control force requirements for the fire.

A mathematical model can never account for all of the many variable factors that govern wildfire behavior. In addition, it is very difficult to exactly assess all these factors on a specific fire and to determine exact inputs for the model. However we can do a reasonably good job, and can expect model answers that give better judgment aids than ever before in this inexact science. Personal experience, interpretation and feedback are essential to the fire predictions modeling process.

On page 17, we want to take a closer look at the mathematical fire behavior prediction model. The model processes fuel and environmental conditions to give expected fire behavior. Methods of estimating the input values and interpreting the output values will be covered throughout the course.

In the final unit of this course, Unit XI--Predicting Fire Behavior, you will go through the entire process of assigning input values, using the model in the form of tables and graphs to obtain output values, and interpreting these output values.

An entire unit will be devoted to each of the following basic input values: Fuel bed description, fuel moisture, slope, and wind speed. These units will cover both the general information required for a firefighter to assess the fire situation and also the specific information that is required as input to the model.

In order to express the many interactions that occur during a forest fire in mathematical terms, certain simplifying assumptions have been made. Among these are the following: The model describes fire behavior only at the leading edge of a 'free burning fire; the fuels are assumed to be continuous, uniform and in a single layer contiguous to the ground; wind, slope, and fuel moisture content all are constant for the time period of the calculation; the fire is not spreading by spotting or crowning; and firewhirls and other fire-induced atmospheric disturbances are not occurring.

It is important that you understand the implications of these assumptions. You know, of course, that fire does not occur in a continuous, uniform and constant environment. But predictions from the model can be used successfully in many situations. The closer actual conditions are to the model assumptions, the better the predictions will be. This is why human judgment is always used along with the model. Even though the model does not describe extreme fire behavior, you will see in later units that it can predict the potential for spotting and crowning.

Now please do question 5 on page 17, then return to the text.

You should have selected all of the choices, since all the statements apply.

Now please turn to page 18. Figure 11 presents a diagram of fireline intensity to further clarify this term. Fireline intensity is the heat released in 1 second by a foot-wide slice of the flaming front. This represents the heat that would impact a firefighter just ahead of the front. Since it has a direct relationship to flame length, it can be related to the kind of control actions and size of fireline that must be planned for on the fire.

The relationships between fireline intensity and flame length will be explained in more detail in latex units. Flame length is also an output of the mathematical fire model. It should not be confused with flame height. Figure 12 illustrates how each measurement is taken. Flames usually bend forward at the head of a fire, depending on wind slope factors. Researchers have determined that flame length is a better parameter for describing fire behavior than flame height.

As mentioned earlier, fire behavior predictions are useful for planning fire control actions. Such planning includes the location of firelines, use of direct or indirect attack methods, the type of control forces which will be effective, and the standards for fireline construction. Certainly, good planning in each of these areas will make the suppression effort more safe and effective.

On page 19, the second exercise is on wildfire and its environment. Please complete this exercise now; then return to the text.

You should have checked your answers on page 22. These decisions and choices are representative of those that are made on most fires by knowledgeable and experienced fireman.

This unit has introduced you to the many factors that influence the way a fire burns, how a fire can interact with its environment, and how fire behavior predictions can be made. The remaining units of the course will take you into much more detail. The diagram on page 20 is a training "road map" to achieving the skills necessary to meet the performance objectives of this course. Unit numbers refer to units of this course. With patience and diligence, you will meet those objectives.

Finally, we would like to summarize this unit by using a page from a publication entitled The Fire Environment Concept. Please read this summary on page 21; then prepare yourself for the unit test that follows.