

UNIT II--FUELS CLASSIFICATION

This unit is about fuels in the fire environment. In order to make reliable estimates of fire behavior, we must understand the relationship of fuels to the fire environment and be able to recognize the variations in these fuels. Before starting this unit, read the instructions to the student on page 1 of your workbook. On page 2, you will find the objectives on which you will be tested at the end of this unit. Please study these objectives. When you have finished, return to this text.

In fire control language, fuel is any organic material--living or dead, in the ground, on the ground, or in the air--that will ignite and burn. Fuels are found in almost infinite combinations of kind, amount, size, shape, position, and arrangement. The fuel on a given acre may vary from a few hundred pounds of sparse grass to 100 or more tons of large and small logging slash. It may consist of dense conifer crowns, heavy and deep litter and duff, or underground peat. Any one composite fuel system is referred to as a fuel complex and has built-in flammability potential.

We can predict fire behavior to a large extent by analyzing the physical properties and characteristics of fuels. Topographic and weather factors must also be considered before rate of spread and general behavior of fires can be determined.

A systematic approach to looking at the fuel complex is to divide it into three broad groups or levels--ground, surface, and aerial fuels. Look at figure 1 on page 3, Fuel Components and Levels.

Since most wildfires are carried by the surface fuels, this fuel level receives the most emphasis. Aerial fuels must also be considered because they may be consumed by fire under certain conditions and can contribute to extreme fire behavior. Ground fuels are important in relation to line construction and mop-up operations. Each level must be evaluated according to characteristics that affect ignition and combustion.

On page 4, figure 2, we take our discussion of fuel groups or levels a step further and generalize on typical fire behavior under normal fire season conditions. Ground fuels will usually be compacted, and fire spread will be slowest, typically smoldering or creeping.

Surface fuels will be less compacted with other characteristics more favorable for faster rates of spread. If no aerial fuels are present, we essentially have an open environment subject to stronger winds and more heating and drying by solar radiation. Thus, fires often run through this fuel complex with higher rates of spread than if aerial fuels were present.

If aerial fuels are present, we should be concerned with crown or canopy closure. Timber stands with an open canopy will probably have a faster spreading surface fire than closed canopy stands, and torching of individual trees with possible spotting could occur. Unless very strong winds are present, crowning is unlikely without a closed canopy. Closed canopy stands, whether timber or tall shrubs, offer the best opportunity for a running crown fire.

Now please do question 1, mark your choice or choices, then return to the text.

For question 1, you should have marked statements 1, 2, and 4. These are all good-reasons why fire usually travels faster through surface fuels that have no over story or aerial fuels.

Our analysis of fuel complexes and their potential to support combustion and spread fire requires a more detailed study of individual fuel components. On page 5, we introduce the principal characteristics of fuel components that can give us an indication of potential fire behavior within a fuels complex.

Under item A, please list the seven principal fuel characteristics that affect fire behavior: loading, size and shape, compactness, horizontal continuity, vertical arrangement, moisture content, and chemical properties. We will spend considerable time discussing these seven characteristics, and they should be well fixed in your mind by the end of this unit.

Each of these seven characteristics contributes to one or more fire behavior processes. In figure 3, we have diagramed the primary relationships. Let's take a few minutes to study these relationships. First, we're concerned with whether ignition will result in a sustaining fire. There are five fuel characteristics that most affect ignition. These are compactness, loading, chemical content, size and shape, and moisture content.

Our next concern is how fast the fire will spread. Here six primary characteristics are involved. How hot or intense will the fire be? What are the possibilities of spotting, torching, or crowning? We can relate individual fuel characteristics to each of these. Since we have not given you the definition for each of the seven characteristics yet, we will move on at this point but return later to study the diagram in more detail.

The first principal characteristic is fuel loading. Loading is defined as the oven dry weight of fuels in a given area, usually expressed in tons per acre. Natural fuel loadings vary greatly by vegetative or fuel types. Figure 4 on page 6 gives you some examples of total fuel loadings. Grassland areas may produce fuel loadings of 1 to 5 tons per acre. Brush species such as chaparral, may produce 20 to 40 tons per acre; logging slash, 30 to 200 tons per acre; and timber, 100 to 600 tons per acre. These are all typical ranges but will not fit every fuels complex. Often fuel loading refers only to surface fuels that are less than 3 inches in diameter. If this is the case, the loading for the timber stand in the above example would be 4 to 12 tons per acre.

You can see that fuel loadings involve different size classes of fuel particles, various fuel arrangements, and particle distribution over a specific area. Fuel loading descriptions may not only state the total weight or mass per acre, but give weights by fuel size classes and describe their distribution vertically and horizontally. For example, it is important to know the amount of fuels in various size classes, whether the fuels are standing or lying on the ground, and whether the fuels are scattered or in piles.

Now see question 2: Please mark your choice or choices, and then return to the text.

Let's look at each of the statements in question 2. Fuel loading and volume of fuels are not used synonymously, since there is not always a direct relationship between mass and volume. The

density of various natural fuels varies considerably depending on vegetative types. The second statement is not true. The relationship between fuel loading and available fuels varies with many factors. Number 3 is true. Grass types vary considerably by year, since seasonal climatic factors influence the height and density of grass stands. This is more true in drier regions of the country. Of course, the harvesting of such grasslands will affect fuel loadings. Number 4 is generally not true. There are some seasonal variations in understory grasses and shrubs, and in the amount and disposition of foliage in deciduous timber stands; however, overall fuel loading remains about the same throughout the season.

See page 7. Our next principal fuel characteristic is size and shape. Size and shape affects the surface area to volume ratio of fuels. Small fuels and flat fuels have a greater surface-area-to-volume ratio than larger fuels. Figure 5 illustrates the relationship between fuel size and surface area. The cube or block of fuel on the left is 1 foot on each side and contains 1 cubic foot. The surface area of this cube is 6 square feet. If that same cube is divided up into 16 pieces as shown on the right, we have the same volume of fuel, but now there is much more surface area to the 16 pieces. Calculations will show 18 square feet for the same cubic foot of fuel. This is three times the surface area of the cube on the left.

Why is this important to fire behavior? We know from our experiences in starting campfires, wood stoves, or fireplaces that small fuels ignite and sustain combustion easier than large blocks of fuel. Less heat is required to ignite the small particles.

Now please do question 3. Mark your choice or choices, then return to the text.

We will discuss each of the statements in question 3. The first one is false. The burnout time required for small fuels is shorter than for large fuels. Statement 2 is true. The heat required to reach ignition in small fuels is less. Number 3 is true. Fuel moisture content changes more rapidly in small fuels. Statements 1 through 3 are all related to small fuels having a greater surface-area-to-volume ratio.

Statement 4 is not necessarily true. The size and shape of the firebrands can affect the amount and distance of spotting, but firebrands can be produced from fuels of various sizes. Small embers ordinarily produce short range spotting only, since they cannot sustain combustion for the period of time required in long-range spotting. Firebrands consisting of burning tree branches have been lifted into convection columns and then deposited miles downwind from the fire.

Fuel shape is a significant factor in the problem of spotting. Figure 6 on page 8 illustrates some fuels that are likely candidates as aerial firebrands. Each of these has been found to have traveled distances of 10 miles or more downwind from a large, raging forest fire. In these cases, their flatness and greater surface-area-to-volume ratios have increased the aerodynamic qualities of the particles, thus making it easier for convection columns to lift them to greater altitudes.

The shape of fuels is also important to spotting downslope by rolling fire-brands. Pine cones, round logs, and round yucca plants are particularly troublesome in their respective areas.

We've been using the terms large fuels versus small fuels in a relative sense. To be more specific for fuels analysis purposes, we normally break dead fuels into four size classes. Under item B, please note the following diameter sizes: Grass, litter, duff--less than 1/4-inch diameter; twigs and small stems--1/4-inch to 1-inch diameter; branches--1-inch to 3-inches diameter; large stems and branches--more than 3-inches diameter. We will give these fuel-size classes more significance later.

Please turn to page 9. The next principal fuel characteristic we need to discuss is compactness. Compactness can be simply defined as the spacing between fuel particles. This affects the rate of combustion. Figure 7 illustrates how the closeness and physical arrangement of the fuel particles affects both ignition and combustion. Those that are closely compacted have less surface area exposed and less air circulation between particles, thus requiring more heat or time for ignition.

It's time now for another question. Mark your choice or choices in question 4, then return to the text

In question 4, you should have marked all four choices. These are all good reasons why loosely compacted fuels usually burn faster.

On page 10, let us look at horizontal continuity as a principal fuels characteristic. Horizontal continuity is the extent of horizontal distribution of fuels at various levels or planes. This characteristic influences where a fire will spread, how fast it will spread, and whether the fire travels through surface fuels, aerial fuels, or both.

Figure 8 shows an area of continuous fuels and an area of patchy or discontinuous fuels. If the open areas in the right-hand illustration are barren and void of any fuels, it will obviously be difficult for fire to travel from one fuel island to another. It would probably require a strong wind with spotting for fire to travel through such patchy fuels. Such fire situations do occur, and what might appear to be natural firebreaks or barriers may not stop a fire's spread.

Now do question 5. Mark your choice or choices, then return to the text. You should have marked statements 2 and 3 as being true. Number 1 is false, since horizontal continuity applies to all levels of the fuels complex. In number 4, the continuity of fine fuels is especially important to the spread of surface fires, since fire intensity can be much less in this fuel level. Before leaving horizontal continuity, we should consider other effects of a closed versus open timber canopy. Figure 9 on page 11 illustrates that a forest canopy not only shades surface fuels and prolongs moisture retention but also greatly reduces wind speeds from levels above the canopy to levels near the surface. Generally, the greater the crown closure, the greater the wind speed reduction. This certainly does have an effect on surface fires burning in these closed environments. If torching out of individual trees occurs, however, we have an entirely new fire environment with which to be concerned.

We've discussed some aspects of surface fires versus torching out and crown fires. A very important fuels characteristic involved here is the vertical arrangement of fuels. We define vertical arrangement as the relative heights of fuels about the ground as well as their vertical continuity, both of which influence fire reaching various fuel levels or strata.

In some mature timber situations, we need to be concerned with several levels of fuels which may help transport fire from the surface to the crowns. Figure 10 suggests four levels. Surface fuels mostly consist of grass and litter of various sizes. Low fuels may consist of shrubs, low limbs, and small young trees called regeneration. A subcanopy might consist of understory trees and larger regeneration. The canopy is made up of mature tree crowns perhaps over 100 feet tall. Fire may burn through one or more levels without burning the canopy. Regardless of the maximum height of the fuels and the number of fuel levels involved, we are concerned with the vertical continuity. When fuels are mostly vertically continuous, we call this a fuel ladder, or a ladder to transport fire into the forest canopy.

On page 12, please do question 6: Mark your choice or choices, then return to the text.

All of the statements given in question 6 are true. As implied in number 4, surface fire intensity is an important factor in whether torching out may actually occur through ladder fuel situations.

A very important fuel characteristic is fuel moisture content. It can vary in different fuel levels and thus influence whether those levels become involved with fire. We define fuel moisture content as the amount of water in fuels, expressed as a percent of the oven-dry weight of that fuel. In nature, dead-fuel moisture very seldom gets below 3 or 4 percent. Dead fuel moisture fluctuates considerably over time due to several environmental factors, as shown in figure 11. Live fuel moistures run much higher, perhaps 300 percent or more, but they change less rapidly than dead fuels. This is an interesting area of study that we will resume in Unit 5 of this course, which is entitled "Fuel Moisture."

See question 7 on page 13. Mark your choice or choices, then return to the text.

We'll now discuss each statement in question 7. The first statement is true, as the moisture content of all fuels, dead or live, affects rate of spread both vertically and horizontally. Number 2 is not true. Live fuels are frequently consumed by fire when there are enough dead, dry fuels to support fire, which can dry and ignite the live fuels. Statement 3 is true since heat is required to drive out the moisture in fuels before they will burn. The higher the fuel moisture content, the greater the heat required for combustion. The last statement is also true. Fine fuels which are very small fuels, such as grass, are most responsible for the spread of fire. The moisture content of these fine fuels is very important to the spread of the fire.

We also know that the moisture content in fine, dead fuels can change very rapidly, depending on the relative humidity of the air and precipitation. Moisture content changes in larger fuels, but at a much slower rate. How much slower? How do we predict what fuel moisture changes will occur in various fuels over periods of time? Well, fire scientists have determined drying times for different size fuels and have designed a system to determine and record fuel moisture percents. They use the term time lag and have placed various sizes of fuels into convenient time lag categories or classes. See item C. Time lag, which is a measure of the rate at which a given dead fuel gains or loses moisture, is related to fuel size. The time lag categories are as follows: 1-hour time lag fuels--less than 1/4-inch diameter; 10-hour time lag fuels--1/4-inch to 1-inch diameter; 100-hour time lag fuels-1-inch to 3-inches diameter; 1000-hour time lag fuels--more than 3-inches diameter.

Do these fuel sizes look familiar? Well, they should, because we made the same entries in item B on page 8. So, our four size classes of fuels correspond to the four time lag categories for fuels. In Unit 5 of this course, we will study the time lag concept more and make estimates of fuel moisture percents from tables.

We noted earlier the wide range in fuel moisture percents from dead to live fuels. Since the fine fuels are the primary carrier of fire, we should be concerned with the amount of dead versus live fine fuels. We know that this proportion changes throughout the year with the seasonal growth and then with the curing of herbaceous vegetation.

Let's move now to item D. For convenience, fire personnel use three general stages in the life cycle of herbaceous vegetation. Note the following: Live or green, mature or curing, and dead or cured. The dead or cured grasses and other fine fuels burn easily under average fire season conditions. The mature or curing fine fuels may burn but with difficulty. If all fuels are live or green, they will ordinarily not burn at all.

On page 14, we have the last principal fuel characteristic for discussion, the chemical properties of fuels. Chemical properties include the presence of volatile substances such as oils, resins, wax, and pitch in the fuels. These affect the rate of combustion. There are certain fuels having rather high amounts of these volatile substances that can contribute to rapid rates of spread and high fire intensities. On the other hand, certain fuels may be high in mineral content, which can reduce fire spread and intensity. A firefighter is primarily concerned with the volatile substances that make his job more difficult.

See item E. Some well known fuels in which volatile substances contribute greatly to fire intensity and fire spread are the following: Chaparral in the southwest, gall berry bushes in the southeast, sand pine during varnish stage in southeast, fountain grass in Hawaii, pitchy stumps from some conifers.

Now try question 8. Mark your choice or choices, then return to the text. You should have marked statements 1, 3, and 4 as being true. Statement 2 is false, since we find that volatile substances often prolong the burnout time. There is much more that can be said about the chemical properties of fuels; however, we recommend that you investigate and become acquainted with problem fuels in your locality.

We have just covered in some detail the seven principal fuel characteristics that affect fire behavior. Please turn back to page 5, figure 3, and take a few moments to study the diagram again. When you have finished, return to the text.

What does the diagram mean to you? It should emphasize the fuel characteristics that can make fuels available for each of the fire behavior processes. The bottom line, we want you to understand, is fuels availability. Now turn to page 15. We've devoted the next section to that topic.

Available fuels are those that will ignite and support combustion at the flaming front under specific burning conditions. Do all the fuels burn during the passage of a fire? The answer is no. Ordinarily only a portion of them burn, depending on factors of fuels availability. In figure 12,

we give some examples of the consumption of various fuels by fire. In a cured grass stand, we might get nearly 100 percent of the fuels consumed by fire. These indeed have a very high degree of availability. A stand of brush is seldom completely burned, but perhaps 5 to 95 percent is consumed. The stumps, logs, and larger limbs of logging slash rarely are totally burned; thus, consumption in slash might be 10 to 70 percent. In timber, standing trees are only partially burned, and overall fire consumption might be 5 to 25 percent.

What does this suggest to you? One assumption might be that the larger the fuels, the less likely it is that they will be totally consumed by fire. But more important is the assumption that some specific characteristics of the fuels made them unavailable for combustion. Certainly size, arrangement, moisture content, and other fuel characteristics played an important part in their availability to burn.

Now go to question 9. Mark two of the choices, and then return to the text.

You should have selected 3 and 6. Needles and small litter on the ground and cured grasses, if present, are usually most available and are the components that usually sustain a surface fire in timber.

Turn to page 16. We'll discuss some other aspects of fuels availability. A major concern of the firefighter is; will fuels ignite if subjected to heat or burning firebrands? For example, he needs to be able to recognize fuel conditions that are receptive to spotting. Under item F, list the following fuels that ignite most readily from embers: Rotten wood in snags or on ground; dead foliage, moss, and lichens in trees; slash compacted in a tight arrangement; needle or leaf accumulations on ground; and cured grasses, especially annuals.

Let's see what you remember about fuels availability. Please work question 10. When you have finished, return to the text.

You should have placed a 1 in front of uniform grass cover, cured. This fuel can have up to 100-percent availability. The second most available is the logging slash, 1-year-old. There may still be needles on the branches or they may have recently fallen. The large amount of fine, dead fuels makes these situations very available for combustion.

The third most available would be the heavy brush, scrub oak. Since it is still midsummer, the live moisture content of the brush would reduce the chances of a complete burn. We would rate the mature timber, pine, last. Only a small percent of the total fuels would burn, and these would probably be confined to the surface level. You may have rated them as we gave the percents of fuels consumed in figure 12 on page 15, thus putting brush ahead of slash. The point to be made here is that you must look at all the characteristics to determine how available fuels will be for combustion.

Before we leave fuels availability, we should examine the fuel conditions that influence the probability and character of crown fires. Under item G, please note the following: Vertical positioning of fuels above surface; character and availability of surface fuels; presence of fine dry aerial fuels; continuity of aerial or canopy fuels. Again, these all relate to determining fuels availability by examining the various fuels characteristics.

We may have been somewhat repetitious in our discussions up to this point, but the fact is, you will have a difficult job in your first efforts to analyze actual fuel complexes to determine potential fire behavior, and we want to give you every tool that we can to make your job easier.

As you recall from Unit I, a description of the fuel is required as input to the mathematical fire spread model. In the next section, starting on page 17, you will learn how this can be done easily using fuel models.

A fuel model is defined as a simulated fuel complex for which all the fuel descriptors required for the solution of the fire spread model have been specified. The specific descriptors that make up a fuel model are shown in figure 13. Since the fire model only applies to surface fires, ground fuels and aerial fuels are not included in the fuel descriptors. The components that are described include needles or leaf litter, dead and down woody material, grasses and forbs, shrubs, and regeneration. Various combinations of these components make up the fuel models.

There are 13 stylized fuel models that are used to make fire behavior predictions. These must represent a wide variety of fuel conditions. Choosing the appropriate fuel model requires experience and personal judgment.

The 13 fuel models can be divided into four major fuel community groups. Under item H, please list the following: grass, brush, timber, and slash. On page 18, figure 14, we have fuel model descriptions for the grass group. There are three fuel models in this group. Common types or species and typical fire behavior is also given for each fuel model.

On page 19 and 20, figure 15 gives us the fuel model descriptions for the brush group. There are four fuel models in this group. On page 21, figure 16 gives fuel model descriptions for the timber group. This group is represented by three fuel models. On page 22, figure 17 gives fuel model descriptions for the slash group. Again, we have three fuel models in this group. We are merely introducing these fuel model descriptions to you at this time. You will be referring back to them as you complete exercises later in the unit.

On pages 23 and 24, you will find the fire behavior fuel model key. It is presented as a guide to help you select an appropriate fuel model for the type of fuel that will carry the fire. This key is only a guide. You must always go to the fuel model descriptions on pages 18 through 22 to check your choice.

Here's how the key works. There are four primary divisions or choices in the key. These correspond to the four major fuel community groups -grass, brush, timber, and slash. Under division 1, you are given three choices, A, B, and C. The brief descriptions will guide you to a fuel model selection. We want you to become better acquainted with the fuel model key. On page 25, exercise 1 is intended for that purpose. Please read the instructions; then do the exercises. When you have finished, return to the text.

You should have checked your answers with those on page 29. On page 26, we have a table which consolidates certain information about the 13 fire behavior fuel models. Figure 18 identifies the fuel classes that are present and considered in the development of each fuel model. Note that fuel model 1 includes only fine dead fuels and that fuel model 2 includes live fuel and

all three dead size classes. Please take a few moments to look over the table and to note the information at the bottom of the page. When you have finished, return to the text.

Before we go on, we should clarify some important points about fuel models. You may be acquainted with the series of 20 fuel models that are used with the National Fire Danger Rating System. These 20 fire danger fuel models are referred to by letters, while the 13 fire behavior fuel models are referred to by numbers. These two sets of fuel models were developed for different purposes and cannot be interchanged. Only the 13 fuel models that we have covered in this lesson can be used in making predictions with the mathematical fire spread model.

We also want to stress that we are dealing only with fuels here and their potential fire behavior under moderate burning conditions. In actual field situations, we would include the specific onsite values of weather and topography in our calculations and predictions.

The final two exercises are designed to prepare you for meeting specific objectives for this unit. Briefly, they are to identify the important fuels characteristics that will influence fire behavior and to determine appropriate fuel models for given fuel complex information.

These are very important exercises, so take your time and study the given fuel complexes well. Now do exercise 2 on page 27. When you have finished, check your answers; then proceed to exercise 3. When you have finished with the unit, prepare yourself for the unit test by going back and reviewing the objectives for this unit.