UNIT XI--FIRE BEHAVIOR PREDICTIONS

In this final unit, you will acquire the tools necessary to make basic predictions of fire behavior from the environmental assessments and input data described in earlier units. Please note the instructions to students on page 1 are somewhat different from previous units. Here you are required to use the Fire Behavior Field Guide with the workbook. A small calculator is desirable, but not necessary, for the calculations.

The unit objectives on which you will be tested at the end of this unit are on page 2. Please read these objectives; then return to this text.

The materials in this unit may appear to be highly technical and over-whelming upon first inspection. This should not be the case, since the system presented is relatively simple, and we will take you through it slowly, step by step. The job aids in the field guide are designed to make your assignments as easy as possible. You should have little trouble meeting the unit and course objectives.

This unit will be confined primarily to initial attack fire problems. The predictions system can be applied to larger wildfires; however, the greater variety of fire environmental factors and input values on these fires complicates the process. We'll leave those calculations to the Fire Behavior Officer or the Plans Chief, both of whom have had much more intensive training and experience.

What is involved in the predictions system? Page 3 breaks the job of performing a fire behavior analysis into four phases. In the earlier units, you learned to gather and assess fire environmental data using forecasts, photos, local observations, descriptions, and maps. Then you were required to determine principal inputs using tables, formulas, keys, and descriptions. This was phase two.

Unit X jumped ahead to phase four, making fire behavior assessments using input and output data. This was done to give you a greater appreciation for making the calculations before actually doing them. You may never be required to do calculations on the job; however, you will be aware of their value and how to use them in fire suppression and other fire management efforts.

Phase three will be covered in this unit. Here you will calculate principal outputs for fire behavior using a worksheet, tables, and other processing aids.

You should note that the field guide contains all of the tables, formulas, keys, procedures, and other aids as introduced in the units for performing phases 2, 3, and 4. It is designed to give you a quick and easy reference for Unit XI, the final exam, and for future field use. Please take a few moments to study the diagram on page 3 of the workbook; then inspect the field guide. Notice how the field guide is organized into sections to help you in the various phases. When you have finished, return to the text.

Please turn to page 4. We will be dealing with the fire behavior predictions model developed at the Northern Forest Fire Laboratory at Missoula, Montana. The prediction model can be described as a set of mathematical equations that can be used to predict certain aspects of fire behavior when provided with an assessment of fuel and environmental conditions.

There are several considerations you should be aware of when using the fire behavior prediction model. First, it is not always possible to predict exactly what a fire will do, but it is possible and useful to obtain a reasonable estimate. Second, the accuracy of model predictions is dependent upon, and limited by, the accuracy of the input values. Third, the fire behavior models assume that the fuel strata carrying the fire is continuous and uniform; that the fire is spreading in surface fuel; and that the windspeed, slope, and fuel moisture values remain reasonably constant.

In order for predictions to be successful, the fire model must be used in applications for which it was designed. The model does not apply to smoldering combustion such as occurs in tightly packed litter, duff, or rotten wood. Predictions are for the flaming front of the fire and not for burnout that occurs after the front has passed. Complications of severe fire behavior due to crowning, spotting, and fire whirls are not predicted by the fire model, but the possible onset of severe fire behavior can be predicted.

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

In question 1, you should have marked statements 1 and 3. The fact that fire is occasionally torching in the canopy, but spotting is not common, means that the fire is basically a surface fire and conforms to the model. Fire spotting is somewhat more complicated and requires some explanation. Fires experiencing high winds frequently spread by very short range spotting. In such cases, the spotting may be considered in the model predictions, as the fire front may overtake the spot fires. Long-range spotting can start new fires far ahead of the main fire but not influence the main fire; thus the fire model may still fit the situation. Fires spreading by medium range spotting are least apt to be predicted by the fire model.

On page 5, we have several fire behavior calculation aids that are available to fire managers. Each of these allows you to process input data using the mathematical equations in the fire behavior prediction model. The program was originally available on computer. Later, a set of fire behavior nomograms were developed as a cheap and convenient field processor for Fire Behavior Officers. A special program chip was also developed for the TI-59 programmable calculator, that gives the same outputs as the nomograms, plus more. The Texas Instrument Model 59 with fire behavior program chip has been popular; however, its availability is limited. Not every student of fire behavior or field technician has access to the TI-59. As a result, a set of fire behavior tables were developed for this course. The tables are easy to use and give you most of the output values available from the TI-59. Output values from the tables will be reasonably close to those from a TI-59.

Turn to pages 6 and 7. Calculations using the tables can be accomplished in six steps.

1. Determine input values of dead and live fuel moisture, fuel model, midflame windspeed, and slope percent. These inputs were discussed in previous units and are covered in sections 1-5 of the field guide.

2. Determine the effective windspeed factor. This is important to later steps of the calculations. The effective windspeed factor is the sum of the wind factor and the slope factor.

3. Go to the tables to determine both rate of spread and fireline intensity values for a no wind, no slope situation. These fire behavior values came from tables in section 6.

4. Calculate adjusted fire behavior values for both wind and slope. This is done by a formula that considers the effective windspeed factor.

5. Determine fire behavior output values for flame length and probability of ignition through the use of simple tables.

6. Determine or predict fire size for point source fires. Area and perimeter tables are found in section 7.

You may wish to take more time to study pages 6 and 7 before moving on.

Turn to page 8. We'll make a distinction between two kinds of fire prediction methods. They vary by the complexity of the fire or by the stage of fire development. The first method is point source. Point source predictions apply to an initiating fire burning during a time when conditions have been relatively constant and where it can be assumed that the fire will maintain a basically elliptical shape.

The second method is line source. Line source predictions apply to a fire that has become large, that no longer has the basic elliptical shape, that could have significantly different burning conditions along the perimeter, and the growth of which must be considered from more than one point along the perimeter. The emphasis of this unit will be on point source fire situations.

Next we will introduce you to the formulas used for adjusting fire behavior values for wind and slope. Note the abbreviations for four input values into the formulas. ROS is rate of spread for no wind or slope. FI is fireline intensity for no wind or slope. WF is the wind factor, and SF is the slope factor.

Adjusted rate of spread equals rate of spread times wind factor, plus rate of spread times slope factor, plus rate of spread.

This formula can be simplified algebraically--adjusted rate of spread equals rate of spread times the sum of wind factor, plus slope factor, plus one. Since the wind factor plus the slope factor equals the effective windspeed factor, the formula can be worded as rate of spread times the sum of the effective windspeed factor plus one. The effective windspeed factor plus one becomes the total correction factor.

The formula for adjusted fireline intensity is essentially the same as for adjusted rate of spread and can be simplified in the same manner.

To assist you in performing the necessary calculations for the six steps given on pages 6 and 7, a worksheet is provided on page 9. The worksheet for predicting fire behavior has 36 lines for entries. Two columns allow two sets of calculations on the same sheet. The-first portion of the worksheet requires site and other input data needed for calculations. The second portion takes you through the fire behavior calculations and gives you the output values. References or instructions are made to field guide sections, tables, calculations, or repeat entries. The sequence of entries was designed to permit forward progression through the field guide when completing the worksheet. One column of the worksheet is filled out to provide an example of entries to be made. Refer to the example entries on this page as we go through the next portions of the workbook.

Turn to page 10. The six steps to performing fire behavior calculations will be presented using the worksheet and the field guide tables.

Step 1 requires entries on worksheet lines 1-14, and 16. These primary input values are covered in sections 1-5 of the field guide.

Step 2 requires the use of two tables to determine the effective windspeed factor. Table 4B in section 4 gives the correction factor for wind, or the wind factor. Enter fuel model and midflame windspeed into the table. Read the wind factor at the intersection. If the fuel model is 2, and the midflame windspeed is 4, the wind factor is 10. This is entered on lines 15 and 18 of the workbook.

Do the same for slope in table 5B. Enter fuel model 2 and slope percent 20 into the table. Read the slope factor of 1.0 at the intersection. Enter this value on line 17.

To calculate the effective windspeed factor, we simply add the wind factor to the slope factor and enter this on line 19.

Step 3 on page 11 determines fire behavior values for no wind or slope conditions. There are a series of tables in section 6 from which you must select the proper table for the fuel model. Some fuel models have both live and dead fuels, which are considered in the calculations, while others consider only dead fuels.

The 6A series of tables are for rate of spread for no wind or slope. Enter the dead fuel moisture of 3 percent and the live fuel moisture of 102 percent into the appropriate table, and read the rate of spread of 2.6 chains per hour at the intersection. Enter this value on line 22.

Next select the proper fireline intensity table from the 6B series. Enter dead fuel moisture of 3 percent and live fuel moisture of 120 percent into the table. Read fireline intensity in BTUs per foot per second at the intersection. Enter this value on line 25.

In step 4, you calculate the adjusted fire behavior values using the formulas. Complete worksheet lines 23 and 24 for adjusted rate of spread.

Multiply the rate of spread for no wind or slope by the total correction factor from line 21.

Turn to page 12. Adjusted fireline intensity is calculated in the same manner. Complete lines 26 and 27 on the worksheet.

Step 5 gives you two more important fire behavior outputs. Table 6C is used to obtain flame length from fireline intensity. This is a direct con-version. Enter the adjusted fireline intensity into the table and read the flame length to the nearest foot. A fireline intensity of 312 BTUs per foot per second is equivalent to an approximate 6-foot flame length. Enter this value on line 28 on the worksheet.

Table 6D gives the percent probability of ignition. Enter the percent shading less than 50 percent, the temperature of 82 degrees, and the dead - fuel moisture of 3 percent into the table. Read -90 percent probability of ignition at the intersection. Enter this value on line 29.

Step 6 on page 13 helps you to determine fire size for point source fires. You will need to determine two additional values to calculate fire size--these are the total forward spread distance and the effective windspeed.

Spread distance equals the adjusted rate of spread multiplied by projection time. Projection time is the period in hours you select for your predictions.

The example selects 2 hours, which gives a total forward spread distance of 62.4 chains.

Next you will use table 7A to obtain the effective windspeed. Enter fuel model 2 and the effective windspeed factor of 11 into the table. Read the effective windspeed on the right side of the table to the nearest mile per hour, which is 4.

Area estimations are determined from table 7B. Enter spread distance of 62.4 chains and effective windspeed of 4 miles per hour into the table. You will find 62 chains in the table, which is generally close enough for our calculations. Effective windspeeds of 3 and 5 appear at the top of the table, but not 4. The acreage value should lie about halfway between those for 3 and 5 miles per hour. If you average 329 and 245, you should get 287 as the acreage at 4 miles per hour.

If the spread distance was 63 chains, you would want to average the values between 62 and 64 chains then average those values between 3 and 5 miles per hour. This requires double interpolations between columns and lines.

Perimeter estimations can be made from table 7C that is in your field guide. This table works exactly the same as table 7B, but gives chains of perimeter. Its output values are entered on line 36 of the worksheet.

You may wish to go back through these steps and relate them to the worksheet example on page 9. Also go to the field guide sections and locate the various tables used in the steps. When you feel you understand the steps for fire behavior calculations, proceed to exercise 1 on page 14. Read the instructions and complete the exercise.

You should have checked your answers for exercise 1 with those on page 30. Now please turn to page 16. You have used effective windspeed values in predicting fire size for point source fires. Effective windspeed is the midflame windspeed adjusted for the effect of slope on uphill fire spread.

Figure 1 gives examples of effective windspeed. The fire on the left is burning on level ground. The effective windspeed is the same as the mid-flame windspeed, 5 miles per hour. The fire on the right is burning on a steep slope. Although the midflame windspeed is 3 miles per hour, the effects of slope will increase rate of spread. The combined effects of wind and slope are added together to give an effective windspeed of 5 miles per hour. In this example, the rates of spread of both fires should be about the same.

Fire patterns become elongated when wind drives the fire in one direction. Upslope usually has the same effect on burn patterns. When the two factors are combined and complement each other, the fire becomes even more elongated.

This deduction helps us to predict the shape, and area and perimeter growth of a fire. Figure 2 gives some examples of fire sizes and shapes depending on effective windspeed. The first fire is spreading with a 5 miles per hour effective windspeed. After 1 hour, its area is 15 acres. The second fire has 8 miles per hour effective windspeed. After 1 hour, its area is 26 acres. The third fire has 11 miles per hour effective windspeed. After 1 hour, its area is 38 acres.

On page 17, figure 3 gives approximate fire shapes for various effective windspeeds. The forward spread distances are constant here, so be concerned only with fire shapes. These elliptical shapes can be used to plot fire perimeters on maps by using the ratios between forward spread distance and side spread distance. Remember, these patterns apply to fires burning on slopes as well as level ground.

Now do question 2. Mark your choice or choices, then return to the text.

In question 2, you should have marked all the statements as being true. Remember these when you are plotting fire perimeters for point source fires on maps.

Turn to page 18. The fire model was designed to describe the behavior of a fire burning upslope with the wind as illustrated in situation 1. In this case the midflame windspeed and maximum slope value are used in the calculations. Other situations can also be handled by the model.

In the second situation, the wind is downslope but the fire is spreading upslope. Since it is not possible to use a negative wind-speed in-the model, you use zero windspeed and the maximum slope value in your calculations.

In the third situation, the spread is downslope, against the upslope wind. Use zero wind and zero slope in your calculations.

Situation four illustrates the fire burning downslope with the wind. In this case you use the midflame windspeed and zero slope in the calculations.

Try out some of the procedures just covered. Exercise 2 starts on page 19. Complete the exercise and check your answers; then return to the text.

Turn to page 21. What do you do if your calculations are not reasonably close to the actual conditions existing on the fire? Under item B, list the following four methods by which adjustments to calculations can be made. The first thing you should do is to re-examine the input values. Your assessments of environmental conditions and the input values may not be accurate.

Second, use an adjustment factor. This factor is determined by comparing calculations and actual values. This should be done only after you have had considerable experience with fire burning under the same local conditions.

Third, use the two fuel model concept. When one fuel model does not seem to fit your area, run calculations for two fuel models that represent the predominant fuels. Rate of spread is calculated by combining the output values according to the proportionate coverage of each fuel model in the area. This course will not require you to do calculations using the two fuel model concept.

The last method is to tailor a fuel model for the site. A procedure using a computer program is being developed by the Northern Forest Fire Laboratory and may be available for field use in 1982.

The procedures for using the fire behavior prediction model go on and on. If you're a Plans Chief on a large fire, you will want to know what to expect of fire behavior on all portions of the fire perimeter. This requires line source fire predictions. How far might firebrands travel to cause spot fires? What will be the maximum scorch height in a stand of timber? What is the potential for a free burning, continuous fire front?

These questions and many others are covered by procedures taught in advanced fire behavior courses. If you have special needs or interest in the fire behavior predictions area, note the publications listed in the reference bibliography in the student guide. You might also contact a qualified Fire Behavior Officer in your area for help.

The next portion of the unit starting on page 22 is on estimating actual fire behavior in the field. The documentation of actual fire behavior serves several useful purposes. How do you measure it? First let's consider rate of spread. It can be measured or estimated by the following four general methods:

1. Measure a distance ahead of the fireline, and time the fire spread over that distance. Calculate feet per minute or chains per hour from these observations.

2. Use a hand held rangefinder to determine distance of fire spread by time. This allows you to measure spread distance from a safe distance away.

3. Use high resolution maps or aerial photos, and observe and time the fire spread between two points which you can identify both in the field and on the map. Calculate spread distance from the map or photo.

4. Take aerial photos or infrared imagery at various times and note fire spread distance over time. This is done by specially equipped aircraft on larger fires where ground observations of fire spread is difficult. There may be other variations to these methods that are used locally to estimate rate of spread.

On small fires, the first method may be the most practical. See figure 4. If fire spread is relatively slow, this method works well. You might set stakes or hang flagging from the vegetation at measured intervals from the fire perimeter.

On page 23, figure 5 shows fire perimeters by times plotted on a topographic map. Rate of spread is easily determined for this fast spreading fire situation. When large fires are spreading rapidly over mountainous terrain, low flying aircraft are often used for fire perimeter recording missions.

Fireline intensity or flame length is another important fire behavior factor that can be observed and documented. Field methods for estimating fireline intensity or flame length are usually limited to comparing flame lengths to an object of known height near the fireline, and observing the ability of various control forces to make direct or indirect attack.

You then use the fire suppression interpretations of fireline intensity and flame length, table 8B, in reverse. For example, if handline crews are able to make direct attack on the fire, flame lengths are probably less than 4 feet. This is not a very accurate method, but it can give you a good indication of flame lengths by debriefing fire crews coming off the fireline.

The most practical means of estimating flame length is illustrated in figure 6. Use a firefighter, flagging hung from a tree, a fence post or a pole as a reference to estimate the length of the flames. This is relatively easy on the flanks of a fire where rate of spread is slower. The heads of fast-moving fires present a greater challenge.

On page 24, figure 7 illustrates flame length of a fire traveling upslope with a wind. The flames are angled, making flame height lower than flame length. From your perspective, you might be observing flame height rather than flame length. Remember, our observations should be of flame length and not flame height. Obviously, these can only be estimations, as it would be very difficult to accurately measure flame lengths under these conditions. Photographs taken at the fireline might be of some value in estimating flame lengths.

Now please do question 3, then return to the text.

You should have marked all the statements as reasons for taking field observations of fire behavior. A good fire behavior specialist will use the field observations for all of these.

The remainder of this unit contains exercises to help prepare you for the final exam. You will work through all four phases of the fire behavior predictions system, including assessing fire environment data, determining principal input, calculating principal output, and making fire behavior assessments and interpretations.

Read the instructions for exercise 3 on page 25. Do this exercise; then check your answers. Next proceed to exercise 4 on page 28. If you have any questions or problems with the materials in this unit, we suggest you contact your designated instructor or a qualified Fire Behavior Officer. Be sure you have a good understanding of the procedures used to predict fire behavior at this level before taking the final exam.