Fuels

HOW FUELS ARE DESCRIBED

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

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

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

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

SELECTING FUEL MODELS

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

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

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

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

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

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

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

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

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

Considerations in Selecting a Fuel Model

I. Determine the general vegetation type, i.e., grass, brush, timber litter, or slash.

2. Estimate which stratum of surface fuel is most likely to carry the spreading fire. For instance, the fire may be in a timbered area, but the timber is relatively open and dead grass, not needle litter, is the stratum carrying the fire. In this case, fuel model 2, which is not listed as a timber model, should be considered. In the same area if the grass is sparse and there is no wind or slope, the needle litter would be the stratum carrying the fire and fuel model 9 would be a better choice.

3. Note the general depth and compactness of the fuel. This information will be needed when using the fuel model key. These are very important considerations when matching fuels, particularly in the grass and timber types.

4. Determine which fuel classes are present and estimate their influence on fire behavior. For instance, green fuel may be present, but will it play a significant role in fire behavior? Large fuels may be present, but are they sound or decaying and breaking up? Do they have limbs and twigs attached or are they bare cylinders? You must look for the fine fuels and choose a model that represents their depth, compactness, and to some extent, the amount of live fuel and its contribution to fire. Do not be restricted by what the model name is or what its original application was intended to be.

5. Using these observations, proceed through the fuel model key and the descriptions provided by Anderson (1982) to select a fuel model.

6. Record the selected fuel model on line 3 of the fire behavior worksheet.

NFFL Fuel Model Key'

1. PRIMARY CARRIER OF THE FIRE IS GRASS. Expected rate of spread is moderate-to-high, with lowto-moderate fireline intensity (flame length). A. Grass is fine structured, generally below knee level, and cured or primarily dead. Grass is essentially continuous.

   SEE THE DESCRIPTION OF MODEL 1.

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

   SEE THE DESCRIPTION OF MODEL 3.

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

   SEE THE DESCRIPTION OF MODEL 2.

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

A. Vegetative type is southern rough or low pocosin. Brush is generally 2 to 4 ft high.

   SEE THE DESCRIPTION OF MODEL 7.

B. Live fuels are absent or sparse. Brush averages 2 to 4 ft in height. Brush requires moderate winds to carry fire.

   SEE THE DESCRIPTION OF MODEL 6.

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

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

   SEE THE DESCRIPTION OF MODEL 5.

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

   SEE THE DESCRIPTION OF MODEL 4.

3. Vegetative type is high pocosin.

   SEE THE DESCRIPTION OF MODEL 4.

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

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

1. Dead foliage is **tightly compacted,** short needle (2 inches or less) conifer litter or hardwood litter.

   SEE THE DESCRIPTION OF MODEL 8.

2. Dead foliage litter is **loosely compacted** long needle pine or hardwoods.

   SEE THE DESCRIPTION OF MODEL 9.

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

   SEE THE DESCRIPTION OF MODEL 10.

C. Fuels are nonuniform, the area is mostly covered with litter interspersed with accumulations of dead and downed material (jackpots).

   SEE THE TWO-FUEL-MODEL CONCEPT.

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

IV. PRIMARY CARRIER OF THE FIRE 1S LOGGING SLASH. Spread rates are low-to-high, fireline intensities (flame lengths) are low-to-very high.

A. Slash is aged and overgrown.

1. Slash is from hardwood trees. Leaves have fallen and cured. Considerable vegetation (tall weeds) has grown in amid the slash and has cured or dried out.
   SEE THE DESCRIPTION OF MODEL 6.
2. Slash is from conifers. Needles have fallen and considerable vegetation (tall weeds and some shrubs) has overgrown the slash.
   SEE THE DESCRIPTION OF MODEL 10.

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

1. Slash is not continuous. Needle litter or small amounts of grass or shrubs must be present to help carry the fire, but primary carrier is still slash. Live fuels are absent or do not play a significant role in fire behavior. The slash depth is about 1 ft.
   SEE THE DESCRIPTION OF MODEL 11.
2. Slash generally covers the ground (heavier loadings than Model 11), though there may be some bare spots or areas of light coverage. Average slash depth is about 2 ft. Slash is not excessively compacted. Approximately one-half of the needles may still be on the branches but are not red. Live fuels are absent, or are not expected to affect fire behavior.
   SEE THE DESCRIPTION OF MODEL 12.
3. Slash is continuous or nearly so (heavier loadings than Model 12). Slash is not excessively compacted and has an average depth of 3 ft. Approximately one-half of the needles are still on the branches and are red, OR all the needles are on the branches but they are green. Live fuels are not expected to influence fire behavior.
   SEE THE DESCRIPTION OF MODEL 13.
4. Same as 3, EXCEPT all the needles are at tached and are red.
   SEE THE DESCRIPTION OF MODEL 4.

NFFL Fuel Model Descriptions

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

Grass Group

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

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

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

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

Shrub Group

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

Fire behavior fuel model 5. Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs, and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the shrubs are young with little dead material, and the foliage contains little volatile material. Shrubs are generally not tall, but have nearly total coverage of the area. Young, green stands such as laurel,[1] vine maple, alder, or even chaparral, manzanita, or chamise with no deadwood would qualify.

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

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

Timber Group

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

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

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

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

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

Logging Slash Group

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

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

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

The Two-Fuel-Model Concept

If nonuniformity of the fuel makes it impossible to select a fuel model from part 1, then the two-fuel-model concept may be useful.

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

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

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

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

The process is begun with four steps: . 1. Select a fuel model from the key that represents the dominant cover-50 percent or more of the area.

2. From the key, select a fuel model that represents fuel concentrations within the area that interrupt the dominant cover.

3. Estimate the percentage of cover for the two fuels. The sum of the two should equal 100 percent.

4. Record the.selected fuel models on fine 3 of the fire behavior worksheet in two separate columns. Record the estimated proportional coverage of each model on line 2. This completes the information needed as inputs to the two-fuelmodel concept. Calculating spread rate and interpreting intensity are explained in chapter III.