United States
Department
of Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-122

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Aids to Determining Fuel Models For Estimating Fire Behavior

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RESEARCH SUMMARY

This report presents photographic examples, tabulations, and a similarity chart to assist fire behavior officers, fuel management specialists, and other field personnel in selecting a fuel model appropriate for a specific field situation. Proper selection of a fuel model is a critical step in the mathematical modeling of fire behavior and fire danger rating. This guide will facilitate the selection of the proper fire behavior fuel model and will allow comparison with fire danger rating fuel models.

The 13 fire behavior fuel models are presented in 4 fuel groups: grasslands, shrublands, timber, and slash. Each group comprises three or more fuel models; two or more photographs illustrate field situations relevant to each fuel model. The 13 fire behavior fuel models are cross-referenced to the 20 fuel models of the National Fire Danger Rating System by means of a similarity chart. Fire behavior fuel models and fire danger rating fuel models, along with the fire-carrying features of the model and its physical characteristics, are described in detail.

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INTRODUCTION

During the past two decades in the United States, the USDA Forest Service has progressed from a fire danger rating system comprising two fuel models (USDA 1964), to nine models in 1972 (Deeming and others 1972), and to 20 models in 1978 (Deeming and others 1977). During this time the prediction of fire behavior has become more valuable for controlling fire and for assessing potential fire damage to resources. A quantitative basis for rating fire danger and predicting fire behavior became possible with the development of mathematical fire behavior models (Rothermel 1972). The mathematical models require descriptions of fuel properties as inputs to calculations of fire danger indices or fire behavior potential. The collections of fuel properties have become known as fuel models and can be organized into four groups: grass, shrub, timber, and slash. Fuel models for fire danger rating have increased to 20 while fire behavior predictions and applications have utilized the 13 fuel models tabulated by Rothermel (1972) and Albini (1976). This report is intended to aid the user in selecting a fuel model for a specific area through the use of photographic illustrations. A similarity chart allows the user to relate the fire behavior fuel models to the fire danger rating system fuel models. The chart also provides a means to associate the fire danger rating system fuel models with a photographic representation of those fuel types.

HOW FUEL MODELS ARE DESCRIBED

Fuels have been classified into four groups—grasses, brush, timber, and slash. The differences in fire behavior among these groups are basically related to the fuel load and its distribution among the fuel particle size classes. This can be illustrated by the shift in size class containing the maximum fraction of load when considering the four fuel groups shown in figure 1. Notice that the fraction of the total load in the less than ¼-inch (0.6-cm) size class decreases as we go from grasses to slash. The reverse is true for the 1- to 3- inch (2.5- to 7.6-cm) material. In grasses, the entire fuel load may be herbaceous material less than one fourth inch (0.6 cm), but grass may include up to 25 percent material between one-fourth and 1 inch (0.6 and 2.5 cm) and up to 10 percent material between 1 and 3 inches (2.5 cm and 7.6 cm). Each fuel group has a range of fuel loads for each size class, with maximum fuel load per size class approximately as shown in figure 1.

Fuel load and depth are significant fuel properties for predicting whether a fire will be ignited, its rate of spread, and its intensity. The relationship of fuel load and depth segregates the 13 fuel models into two distinctive orientations, with two fuel groups in each (fig. 2). Grasses and brush are vertically oriented fuel groups, which rapidly increase in depth with increasing load. Timber litter and slash are horizontally positioned and slowly increase in depth as the load is increased. Observations of the location and positioning of fuels in the field help one decide which fuel groups are represented. Selection of a fuel model can be simplified if one recognizes those features that distinguish one fuel group from another.

The 13 fuel models (table 1) under consideration are presented on page 92 of Albini's (1976) paper, "Estimating Wildfire Behavior and Effects." Each fuel model is described by the fuel load and the ratio of surface area to volume for each size class; the depth of the fuel bed involved in the fire front; and fuel moisture, including that at which fire will not spread, called the moisture of extinction. The descriptions of the fuel models include the total fuel load less than 3 inches (7.6 cm), dead fuel load less than one-fourth inch (0.6 cm), live fuel load of less than one-fourth inch (0.6 cm), and herbaceous material and fuel depth used to compute the fire behavior values given in the nomographs.

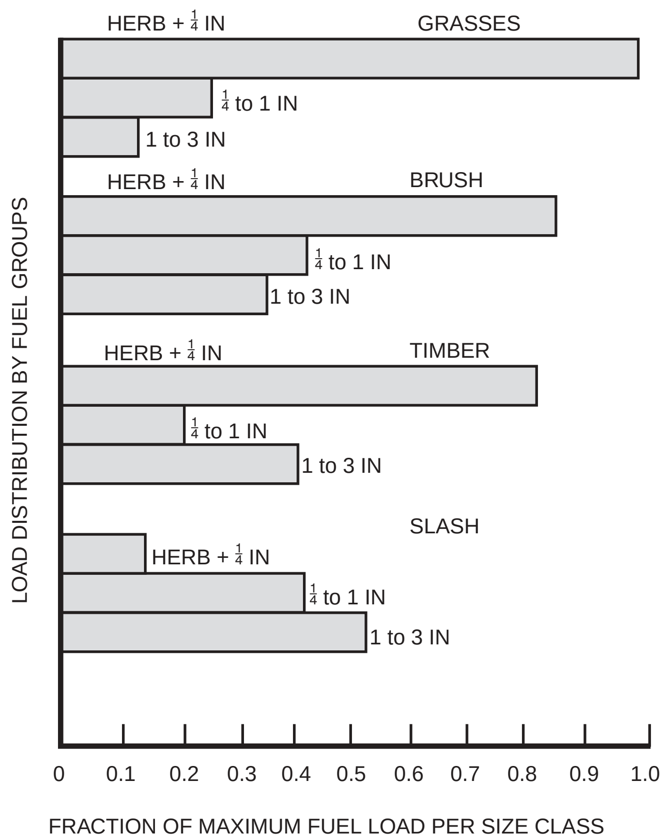

Figure 1. — Distribution of maximum fuel load by size class for each of the four general fuel groups. Note the shift in less than ¼-inch (0.6-cm) and 1- to 3-inch (2.5- to 7.6-cm) material

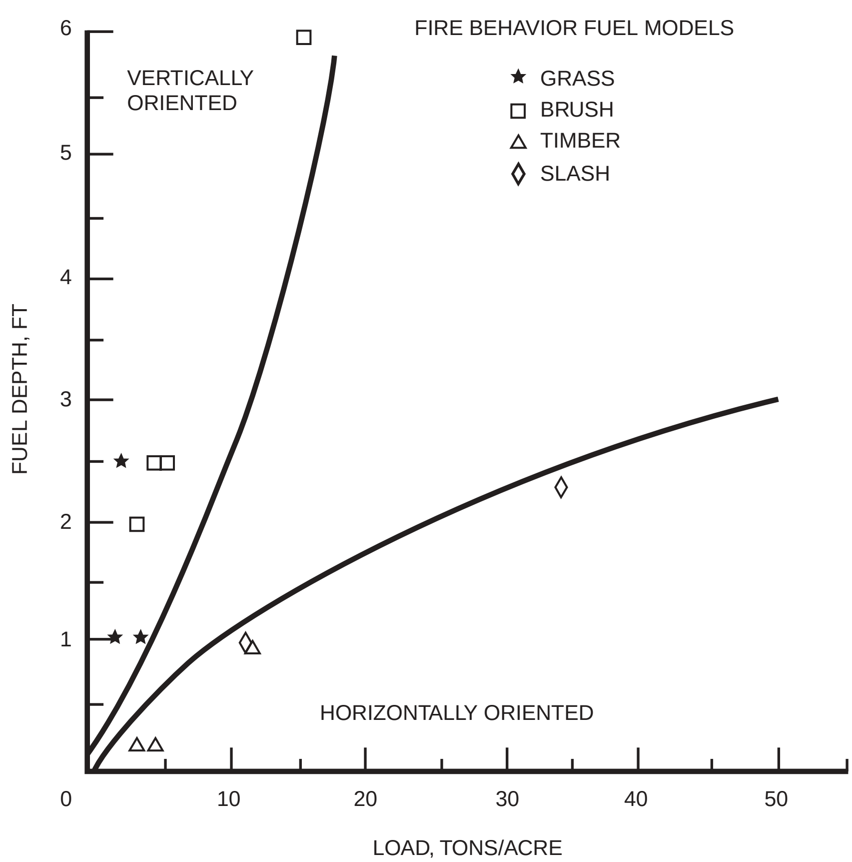

Figure 2. — The four general fuel groups are oriented in two basic directions: vertically, as in grasses and shrubs, and horizontally, as in timber, litter, and slash.

Table 1. — Description of fuel models used in fire behavior as documented by Albini (1976)

Fuel model	Typical fuel complex	Fuel loading 1 hour	Fuel loading 10 hours	Fuel loading 100 hours	Fuel loading Live	Fuel bed depth	Moisture of extinction dead fuels
		--------------------Tons/acre			-------------------	*Feet*	*Percent*
	Grass and grass-dominated						
1	Short grass (1 foot)	0.74	0.00	0.00	0.00	1.0	12
2	Timber (grass and understory)	2.00	1.00	.50	.50	1.0	15
3	Tall grass (2.5 feet)	3.01	.00	.00	.00	2.5	25
	Chaparral and shrub fields						
4	Chaparral (6 feet)	5.01	4.01	2.00	5.01	6 0	20
5	Brush (2 feet)	1.00	.50	.00	2.00	2.0	20
6	Dormant brush, hardwood slash	1.50	2.50	2.00	.00	2.5	25
7	Southern rough	1.13	1.87	1.50	.37	2.5	40
	Timber litter						
8	Closed timber litter	1.50	1.00	2.50	0.00	0.2	30
9	Hardwood litter	2.92	41	.15	.00	.2	25
10	Timber (litter and understory)	3.01	2.00	5.01	2.00	1.0	25
	Slash						
11	Light logging slash	1.50	4.51	5.51	0.00	1.0	15
12	Medium logging slash	4.01	14.03	16.53	.00	2.3	20
13	Heavy logging slash	7.01	23.04	28.05	.00	3.0	25

The criteria for choosing a fuel model includes the fact that the fire burns in the fuel stratum best conditioned to support the fire. This means situations will occur where one fuel model represents rate of spread most accurately and another best depicts fire intensity. In other situations, two fuel conditions may exist, so the spread of fire across the area must be weighted by the fraction of the area occupied by each fuel. Fuel models are simply tools to help the user realistically estimate fire behavior. The user must maintain a flexible frame of mind and an adaptive method of operating to totally utilize these aids. For this reason, the fuel models are described in terms of both expected fire behavior and vegetation.

The National Fire Danger Rating System (NFDRS) depends upon an ordered set of weather records to establish conditions of the day. These weather conditions along with the 1978 NFDRS fuel models are used to represent the day-to-day and seasonal trends in fire danger. Modifications to the fuel models are possible by changes in live/dead ratios, moisture content, fuel loads, and drought influences by the large fuel effect on fire danger. The 13 fuel models for fire behavior estimation are for the severe period of the fire season when wildfires pose greater control problems and impact on land resources. Fire behavior predictions must utilize on-site observations and short term data extrapolated from remote measurement stations. The field use situation generally is one of stress and urgency. Therefore, the selection options and modifications for fuel models are limited to maintain a reasonably simple procedure to use with fire behavior nomographs, moisture content adjustment charts, and wind reduction procedures. The NFDRS fuel models are part of a computer data processing system that presently is not suited to real time, in-the-field prediction of fire behavior.

FUEL MODELS DESCRIPTIONS
Grass Group

Fire Behavior Fuel Model 1

Fire spread is governed by the fine, very porous, and continuous herbaceous fuels that have cured or are nearly cured. Fires are surface fires that move rapidly through the 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 met the above area constraint. Annual and perennial grasses are included in this fuel model. Refer to photographs 1, 2, and 3 for illustrations.

This fuel model correlates to 1978 NFDRS fuel models A, L, and S.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	0.74
Dead fuel load, ¼-inch, tons/acre	.74
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	1.0

Photo 1. Western annual grasses such as cheatgrass, medusahead ryegrass, and fescues.

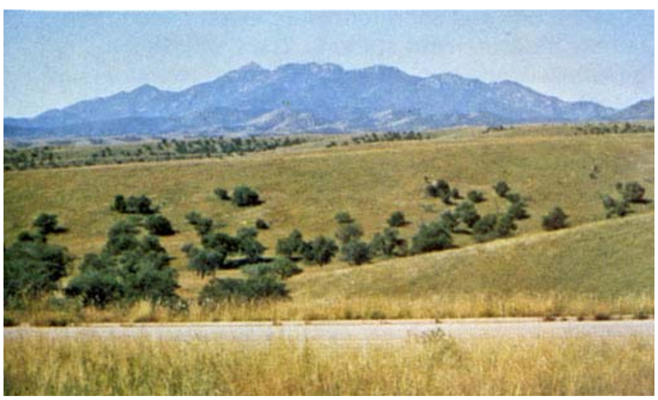

Photo 2. Live oak savanna of the Southwest on the Coronado National Forest.

Photo 3. Open pine—grasslands on the Lewis and Clark National Forest.

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, in addition to 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 to two-thirds of the area may generally fit this model; such stands may include clumps of fuels that generate higher intensities and that may produce firebrands. Some pinyon-juniper may be in this model. Photographs 4 and 5 illustrate possible fuel situations.

This fuel model correlates to 1978 NFDRS fuel models C and T.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	4.0
Dead fuel load, ¼-inch, tons/acre	2.0
Live fuel load, foliage, tons/acre	0.5
Fuel bed depth, feet	1.0

Photo 4. Open ponderosa pine stand with annual grass understory.

Photo 5. Scattered sage within grasslands on the Payette National Forest.

Fire Behavior Fuel Model 3

Fires in this fuel are the most intense of the grass group and dislay high rates of spread under the influence of wind. Wind may drive fire into the upper heights of the grass and across standing water. Stands are tall, averaging about 3 feet (1 m), but considerable variation may occur. Approximately one-thrid of 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. Refer to photographs 6, 7, and 8 for examples of fuels fitting this model.

This fuel correlates to 1978 NFDRS fuel model N.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	3.0
Dead fuel load, ¼-inch, tons/acre	3.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.5

Fires in the grass group fuel models exhibit some of the faster rates of spread under similar weather conditions. With a windspeed of 5 mi/h (8 km/h) and a moisture content of 8 percent, representative rates of spread (ROS) are as follows:

Model	Rate of spread *Chains/hour*	Flame length *Feet*
1	78	4
2	35	6
3	104	12

As windspeed increases, model 1 will develop faster rates of spread than model 3 due to fineness of the fuels, fuel load, and depth relations.

Photo 6. Fountaingrass in Hawaii; note the dead component.

Photo 7. Meadow foxtail in Oregon prairie and meadowland.

Photo 8. Sawgrass “prairie” and “strands” in the Everglades National Park, Fla.

Shrub Group

Fire Behavior Fuel Model 4

Fires 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 shrubs, 6 or more feet tall, such as California mixed chaparral, the high pocosin along the east coast, the pinebarrens of New Jersey, or the closed jack pine stands of the north-central States are typical candidates. Besides flammable foliage, dead woody material in the stands significantly contributes to the fire intensity. Height of stands qualifying for this model depends on local conditions. A deep litter layer may also hamper suppression efforts. Photographs 9, 10, 11, and 12 depict examples fitting this fuel model.

This fuel model represents 1978 NFDRS fuel models B and O; fire behavior estimates are more severe than obtained by models B or O.

Photo 9. Mixed chaparral of southern California; note dead fuel component in branchwood.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	13.0
Dead fuel load, ¼-inch, tons/acre	5.0
Live fuel load, foliage, tons/acre	5.0
Fuel bed depth, feet	6.0

Photo 10. Chaparral composed of manzanita and chamise near the Inaja Fire Memorial, Calif.

Photo 11. Pocosin shrub field composed of species like fetterbush, gallberry, and the bays.

Photo 12. High shrub southern rough with quantity of dead limbwood.

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. Usually shrubs are short and almost totally cover the area. Young, green stands with no dead wood would qualify: laurel, vine maple, alder, or even chaparral, manzanita, or chamise.

No 1978 NFDRS fuel model is represented, but model 5 can be considered as a second choice for NFDRS model D or as a third choice for NFDRS model T. Photographs 13 and 14 show field examples of this type. Young green stands may be up to 6 feet (2 m) high but have poor burning properties because of live vegetation.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	3.5
Dead fuel load, ¼-inch, tons/acre	1.0
Live fuel load, foliage, tons/acre	2.0
Fuel bed depth, feet	2.0

Photo 13. Green, low shrub fields within timber stands or without overstory are typical. Example is Douglas-fir–snowberry habitat type.

Photo 14. Regeneration shrublands after fire or other disturbances have a large green fuel component, Sundance Fire, Pack River Area, Idaho.

Fire Behavior Fuel Model 6

Fires carry through the shrub layer where the foliage is more flammable than fuel model 5, but this requires moderate winds, greater than 8 mi/h (13 km/h) at mid-flame height. Fire will drop to the ground at low wind speeds or at 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 be considered include intermediate stands of chamise, chaparral, oak brush, low pocosin, Alaskan spruce taiga, and shrub tundra. Even hardwood slash that has cured can be considered. Pinyon-juniper shrublands may be represented but may overpredict rate of spread except at high winds, like 20 mi/h (32 km/h) at the 20-foot level.

The 1978 NFDRS fuel models F and Q are represented by this fuel model. It can be considered a second choice for models T and D and a third choice for model S. Photographs 15, 16, 17, and 18 show situations encompassed by this fuel model.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	6.0
Dead fuel load, ¼-inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.5

Photo 15. Pinion-juniper with sagebrush near Ely, Nev.; understory mainly sage with some grass intermixed.

Photo 16. Southern harwood shrub with pine slash residues.

Photo 17. Low pocosin shrub field in the south.

Photo 18. Frost-killed Gambel Oak foliage, less than 4 feet in height, in Colorado.

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 flammability of live foliage and other live material. Stands of shrubs are generally between 2 and 6 feet (0.6 and 1.8 m) high. Palmetto-gallberry understory-pine overstory sites are typical and low pocosins may be represented. Black spruce-shrub combinations in Alaska may also be represented.

This fuel model correlates with 1978 NFDRS model D and can be a second choice for model Q. Photographs 19, 20, and 21 depict field situations for this model.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	4.9
Dead fuel load, ¼-inch, tons/acre	1.1
Live fuel load, foliage, tons/acre	0.4
Fuel bed depth, feet	2.5

The shrub group of fuel models has a wide range of fire intensities and rates of spread. With winds of 5 mi/h (8 km/h), fuel moisture content of 8 percent, and a live fuel moisture content of 100 percent, the models have the values:

Model	**Rate of spread** *Chains/hour*	**Flame length** *Feet*
4	75	19
5	18	4
6	32	6
7	20	5

Photo 19. Southern rough with light to moderate palmetto understory.

Photo 20. Southern rough with moderate to heavy palmetto-gallberry and other species.

Photo 21. Slash pine with gallberry, bay, and other species of understory rough.

Timber Group

Fire Behavior Fuel Model 8

Slow-burning ground fires with low flame lengths are generally the case, 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 fire hazards. Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and occasionally twigs because little undergrowth is present in the stand. Representative conifer types are white pine, and lodgepole pine, spruce, fir, and larch.

This model can be used for 1978 NFDRS fuel models H and R. Photographs 22, 23, and 24 illustrate the situations representative of this fuel.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	5.0
Dead fuel load, ¼-inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	0.2

Photo 22. Surface litter fuels in western hemlock stands of Oregon and Washington.

Photo 23. Understory of inland Douglas-fir has little fuel here to add to dead-down litter load.

Photo 24. Closed stand of birch-aspen with leaf litter compacted.

Fire Behavior Fuel Model 9

Fires run through the surface litter faster than model 8 and have longer flame height. Both long-needle conifer stands and hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are predictable, but high winds will actually cause higher rates of spread than predicted because of 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.

NFDRS fuel models E, P, and U are represented by this model. It is also a second choice for models C and S. Some of the possible field situations fitting this model are shown in photographs 25, 26, and 27.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	3.5
Dead fuel load, ¼-inch, tons/acre	2.9
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	0.2

Photo 25. Western Oregon white oak fall litter; wind tumbled leaves may cause short-range spotting that may increase ROS above the predicted value.

Photo 26. Loose hardwood litter under stands of oak, hickory, maple and other hardwood species of the East.

Photo 27. Long-needle forest floor litter in ponderosa pine stand near Alberton, Mont.

Fire Behavior Fuel Model 10

The fires burn 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 (7.6-cm) 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 are more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; examples are insect- or disease-ridden stands, wind-thrown stands, overmature situations with deadfall, and aged light thinning or partial-cut slash.

The 1978 NFDRS fuel model G is represented and is depicted in photographs 28, 29, and 30.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	12.0
Dead fuel load, ¼-inch, tons/acre	3.0
Live fuel load, foliage, tons/acre	2.0
Fuel bed depth, feet	1.0

The fire intensities and spread rates of these timber litter fuel models are indicated by the following values when the dead fuel moisture content is 8 percent, live fuel moisture is 100 percent, and the effective windspeed at midflame height is 5 mi/h (8 km/h):

Model	Rate of spread *Chains/hour*	Flame length *Feet*
8	1.6	1.0
9	7.5	2.6
10	7.9	4.8

Fires such as above in model 10 are at the upper limit of control by direct attack. More wind or drier conditions could lead to an escaped fire.

Photo 28. Old-growth Douglas-fir with heavy ground fuels.

Photo 29. Mixed conifer stand with dead-down woody fuels.

Photo 30. Spruce habitat type where succession or natural disturbance can produce a heavy downed fuel load.

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 (7.6-cm) material load is less than 12 tons per acre (5.4 t/ha). The greater-than-3-inch (7.6-cm) is represented by not more than 10 pieces, 4 inches (10.2 cm) in diameter, along a 50-foot (15-m) transect.

The 1978 NFDRS fuel model K is represented by this model and field examples are shown in photographs 31, 32, and 33.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	11.5
Dead fuel load, ¼-inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	1.0

Photo 31. Slash residues left after skyline logging in western Montana.

Photo 32. Mixed conifer partial cut slash residues may be similar to closed timber with down woody fuels.

Photo 33. Light logging residues with patchy distribution seldom can develop high intensities.

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 and much of it is less than 3 inches (7.6 cm) in diameter. The fuels total less than 35 tons per acre (15.6 t/ha) and seem well distributed. Heavily thinned conifer stands, clearcuts, and medium or heavy partial cuts are represented. The material larger than 3 inches (7.6 cm) is represented by encountering 11 pieces, 6 inches (15.2 cm) in diameter, along a 50-foot (15-m) transect.

This model depicts 1978 NFDRS model J and may overrate slash areas when the needles have dropped and the limbwood has settled. However, in areas where limbwood breakup and general weathering have started, the fire potential can increase. Field situations are presented in photographs 34, 35, and 36.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	34.6
Dead fuel load, ¼-inch, tons/acre	4.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.3

Photo 34. Ponderosa pine clearcut east of Cascade mountain range in Oregon and Washington.

Photo 35. Cedar-hemlock partial cut in northern Idaho, Region 1, USFS.

Photo 36. Lodgepole pine thinning slash on Lewis and Clark National Forest. Red slash condition increases classification from light to medium.

Fire Behavior Fuel Model 13

Fire is generally carried across the area by a continuous layer of slash. Large quantities of material larger than 3 inches (7.6 cm) are present. Fires spread quickly through the fine fuels and intensity builds up more slowly as the large fuels start burning. Active flaming is sustained for long periods and a wide variety of firebrands can 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 (7.6-cm) diameter material. The total load may exceed 200 tons per acre (89.2 t/ha) but fuel less than 3 inches (7.6-cm) 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 1978 NFDRS fuel model I is represented and is illustrated in photographs 37 and 38 Areas most commonly fitting this model are old-growth stands west of the Cascade and Sierra Nevada Mountains. More efficient utilization standards are decreasing the amount of large material left in the field.

Fuel model values for estimating fire behavior

Total fuel load, < 3-inch dead and live, tons/acre	58.1
Dead fuel load, ¼-inch, tons/acre	7.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	3.0

For other slash situations:

Hardwood slash .... Model 6
Heavy "red" slash .... Model 4
Overgrown slash .... Model 10
Southern pine clearcut slash .... Model 12

The comparative rates of spread and flame lengths for the slash models at 8 percent dead fuel moisture content and a 5 mi/h (8 km/h) midflame wind are:

Model	**Rate of spread** *Chains/hour*	**Flame length** *Feet*
11	6.0	3.5
12	13.0	8.0
13	13.5	10.5

Photo 37. West coast Douglas-fir clearcut, quality of cull high.

Photo 38. High productivity of cedar-fir stand can result in large quantities of slash with high fire potential.

CORRELATION OF FIRE BEHAVIOR FUEL MODELS AND NFDRS FUEL MODELS

The following section, which correlates fuel models used for fire behavior with those used for fire danger rating, should help fire behavior officers (FBO's), researchers, or other concerned personnel understand the relationship of the two sets of fuel models. For initial fire behavior estimates, the fuel model used for fire danger rating can be cross referenced to a fire behavior fuel model suitable for the general area of interest. It also provides useful background about the character of each fuel model so specific selections can be made where vegetation varies considerably. Combining this information with the photographic representations of each of the 13 fuel models presents the concept that a single fuel model may represent several vegetative groups. **It is important that one maintain an open, flexible impression of fuel models so as to recognize those vegetative groups with common fire-carrying characteristics.**

The correlation with the 1978 NFDRS fuel models allows conversion from fire danger trend measurements to field-oriented prediction of fire behavior. The great variety of fuel, weather, and site conditions that exist in the field means the user of fuel models and fire behavior interpretation methods must make observations and adjust his predictions accordingly. Calibration of the fire behavior outputs for the selected fuel model can allow more precise estimation of actual conditions. This has been practiced in the field by instructors and trainees of the Fire Behavior Officer's (FBO) School, S-590, and has provided a greater degree of flexibility in application.

The fuel models shown in figure 3 were alined according to the fuel layer controlling the rate of fire spread. Some second and third choices are indicated for situations where fire spread may be governed by two or more fuel layers, depending on distribution and moisture content. From the four climates used in the 1978 NFDRS, climate 3 was used, with the live herbaceous fuels 99.7 percent cured and a wind of 20 mi/h (32 km/h) at the 20-foot (6.1-

PHYSICAL DESCRIPTION SIMILARITY CHART OF NFDRS AND FBO FUEL MODELS

NFDRS MODELS REALINED TO FUELS CONTROLLING SPREAD UNDER SEVERE BURNING CONDITIONS

NFDRS FUEL MODELS	FIRE BEHAVIOR FUEL MODELS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
A W. ANNUALS	X													GRASS
L W. PERENNIAL	X													GRASS
S TUNDRA	X					3rd			2nd					GRASS
C OPEN PINE W/GRASS		X							2nd					GRASS
T SAGEBRUSH W/GRASS		X			3rd	2nd								GRASS
N SAWGRASS			X											GRASS
B MATURE BRUSH (6FT)				X										SHRUB
O HIGH POCOSIN				X										SHRUB
F INTER. BRUSH					2nd	X								SHRUB
Q ALASKA BLACK SPRUCE						X	2nd							SHRUB
D SOUTHERN ROUGH						2nd	X							SHRUB
H SRT- NDL CLSD. NORMAL DEAD								X						TIMBER
R HRWD. LITTER (SUMMER)								X						TIMBER
U W. LONG- NDL PINE									X					TIMBER
P SOUTH, LONG- NDL PINE									X					TIMBER
E HRWD. LITTER (FALL)									X					TIMBER
G SRT- NDL CLSD. HEAVY DEAD										X				TIMBER
K LIGHT SLASH											X			SLASH
J MED. SLASH												X		SLASH
I HEAVY SLASH													X	SLASH
	GRASS			SHRUB				TIMBER			SLASH			

Figure 3. — Similarity chart to aline physical descriptions of fire danger rating fuel models with fire behavior fuel models.

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APPENDIX: EVOLUTION OF FUEL MODELS

Introduction

More than 64 years ago, foresters in the United States were concerned about fire danger and were attempting to develop methods to assess the hazard (Dubois 1914). The "inflammability" of a situation depended on four elements: (1) amount of ground fuels; (2) ease of ignition; (3) dryness of the cover; and (4) slope. Three fuel types were considered: grass, brush, and timber. In 1978, we are still concerned about fire danger and fire behavior. Through the use of mathematical fire behavior models (Rothermel 1972) and fire danger ratings (Deeming and others 1977), we can evaluate how fire danger changes with weather, fuels, and slope. In addition, the fire behavior officer on a fire can estimate the fire behavior for the next burning period if he can define the fuels (Albini 1976). Dubois grouped fuels as grass, brush, and timber, and these general groupings are still used with the addition of slash. Several fuel types or fuel models are recognized within each group. For fire danger rating, we have gone from two fuel models (USDA Forest Service 1964) to nine in 1972 (Deeming and others 1972) and 20 in 1978 (Deeming and others 1977). Research efforts to assist the fire behavior officer have utilized the 13 fuel models tabulated by Rothermel (1972) and Albini (1976).

Fuels Defined

Fuels are made up of the various components of vegetation, live and dead, that occur on a site. The type and quantity will depend upon the soil, climate, geographic features, and the fire history of the site. To a large extent, potential evapotranspiration and annual precipitation combinations with altitude and latitude changes can describe the expected vegetation and have been used for vegetation maps (Küchler 1967) An adequate description of the fuels on a site requires identifying the fuel components that may exist. These components include the litter and duff layers, the dead-down woody material, grasses and forbs, shrubs, regeneration and timber. Various combinations of these components define the major fuel groups of grass, shrub, timber and slash. Certain features of each fuel component or the lack of it contributes to the description of the fuels in terms suitable to define a fuel model. For each fuel component certain characteristics must be quantified and evaluated to select a fuel model for estimating fire behavior. The most important characteristics for each component are:

1. Fuel loading by size classes
2. Mean size and shape of each size class
3. Compactness or bulk density
4. Horizontal continuity
5. Vertical arrangement
6. Moisture content
7. Chemical content, ash, and volatiles.

Each of the above characteristics contributes to one or more fire behavior properties. Fuel loading, size class distribution of the load, and its arrangement (compactness or bulk density) govern whether an ignition will result in a sustaining fire. Horizontal continuity influences whether a fire will spread or not and how steady rate of spread will be. Loading and its vertical arrangement will influence flame size and the ability of a fire to "torch out" the overstory. With the proper horizontal continuity in the overstory, the fire may develop into a crown fire. Low fuel moisture content has a significant impact upon fire behavior affecting ignition, spread, and intensity; with high winds it can lead to extreme fire behavior. Certain elements of the fuel's chemical content, such as volatile oils and waxes, aid fire spread, even when moisture contents are high. Others, like mineral content, may reduce intensity when moisture contents are low. High fuel loads in the fine fuel size classes with low fuel moisture contents and high volatile oil contents will contribute to rapid rates of spread and high fire line intensities, making initial attack and suppression difficult.

How Fuels Have Been Described

In the expression of fire danger presented by Dubois (1914), the fuel types of grass, brush, and timber were defined, utilizing three causes—amount of fuel on the ground, lack of moisture in the cover, and slope—and two effects—ease of ignition and rate of fire growth or spread. As Dubois pointed out, however, not enough study had been made of rate of spread to effectively describe differences among the fuel types. Sparhawk (1925) conducted an extensive study of fire size as a function of elapsed time from discovery to initial attack by broad forest cover types Twenty-one fire regions for the western United States and the Lake States were defined and up to seven forest types selected for each region. These forest types basically were grass, brush, timber, and slash descriptions. The ranking of area growth rates by type showed the highest growth rates occurred in grasses and brush types, followed by slash and open timber situations and concluding with low growth rates in closed timber types. Sparhawk made the following comment regarding his data:

> Rating obtained, therefore, will represent averages of fairly broad application, but may now show what can be expected on individual units. These factors can be allowed for only when the fire records and the inventory of our forest resources include information concerning them.

Show and Kotok (1929) reported on a preliminary study of forest cover as related to fire control. Study of the nine major cover types in northern California showed definite differences between them regarding fire danger, ignition risk, rate of spread, and type of fire and several other fire control subjects. They did not attempt to complete analysis proposed by Sparhawk because the variability of individual fires was so great and the classification of type and hazard classes was so incomplete. However, their nine cover types fit a broader classification of:

1. Woodlands and grasslands
2. Chaparral and brush fields
3. Timber cover types:
   a. western yellow pine and mixed conifer
   b. Douglas-fir
   c. sugar pine-fir and fir.

These cover types and their classification express the broad groupings of grass-dominated, brush-dominated, and timber-residue-dominated fuel groups. Timber residues can be either naturally occurring dead woody or activity-caused slash. In terms of fire behavior, these cover types could be characterized as follows:

Crown fires (occur in secondary or primary overstory)—chaparral and brush types.

Surface fires (occurs in surface litter, dead down woody, and herbaceous material)—woodlands and grasslands; western yellow pine and mixed conifer; Douglas-fir.

Ground fires (occur in litter, duff, and subsurface organic material) sugar pine-fir; fir type.

This work showed the complexity of establishing hour control needs and contributes to continued efforts to describe types in terms of fire growth and control difficulty.

Hornby (1935) developed a fuel classification system that formalized the description of rate of spread and resistance to control into classes of low, medium, high, and extreme. For the Northern Rocky Mountains, the standard timber types relative ranking was similar to that of Show and Kotok as well as work in Colorado by Bates (1923) and described by Hornby (1935):

1. Brush—grass
2. Ponderosa pine
3. Larch—fir
4. Douglas-fir and lodgepole pine
5. White pine and Iodgepole pine
6. Subalpine fir
7. White fir and spruce.

Classification of these fuels was accomplished by utilizing 90 men experienced in fire hazard. A total of 42 ratings were assigned to typical fuels in Region 1. Hornby noted that a weakness of the system was the use of estimates rather than extensive accurate measurements, but until enough years of data had been collected on contributing influences, some procedures for rating fuels were needed. Adaptations of Hornby's approach have been utilized in the eastern United States (Jemison and Keetch 1942) and modified later in the West (Barrows 1951). Most Forest Service regions utilized some version of the Hornby rating method but generally assigned rate of spread values unique to their area, thereby reducing comparability. This is illustrated by a sampling of the number of ratings used by various regions and some of the variation that existed for rate of spread (ROS) classes.

Region	**Year**	**No. of ratings**	**ROS (chains/hour)**
Region 1	1969	234	High (51)
Region 1	1974	4	High (25)
Region 2	1972	59	High (25)
Region 3	1970	11	
Region 4	1972	48	High (30)
Eastern	1966	15	
Region 5	1973	17	
Region 6	1972	16 examples	High (25)
Region 8	1975		High (>10)
Region 9	1970	10	

The variation of ROS rating is due not so much to fuels alone as to the combination of fuels, climate, season, and local weather. These additional factors influence the quantity of live fuel and the moisture content of the dead fuels. Other agencies such as the BLM have utilized the approach for each management area and have a set of ratings for six areas.

Fuels became a consideration in fire danger ratings in the 1950's; in 1958 an effort was made to unify the eight fire danger rating systems into one national system (Deeming and others 1972). Two fuel conditions were considered—fuels sheltered under a timber cover and fuels in an open, exposed site. A relative spread index was developed and brought into general use by 1965. Review of the approach and the expressed need for the ignition, risk, and energy indexes resulted in a research effort that yielded the 1972 National Fire Danger Rating System (NFDRS). Fuels could be considered in greater detail because a mathematical fire spread model had been developed by Rothermel (1972). Nine specific descriptions of fuel properties, called fuel models, were developed for the NFDRS (Deeming and Brown 1975). Fahnestock (1970), in his guide "Two keys for appraising forest fire fuels," was among the first to use the Rothermel fire spread model. The keys provide tools for recognizing the differences in fuel types and identifying the relative fire hazard potential in terms of rate of spread or crowning. To use the keys, one must describe physical fuel properties in Fahnestock's terms: fine, small, medium for size classes and sparse, open, dense, fluffy, or thatched for compactness or combination of loading and depth. By keying on the fuel properties of the site, one of the 36 rate-of-spread ratings or one of the 24 crowning-potential ratings can be selected.

Fahnestock interpreted the size class descriptions for each fuel stratum according to the physical dimensions and timelags associated with the 1964 NFDRS. Timelag is the time necessary for a fuel size class to change 63 percent of the total expected change. These same descriptions were used when fuel models were developed to represent broad vegetative types of grasslands, brushfields, timbered land, and slash. Within each fuel model, the load was distributed by size or timelag classes, correlated with groupings of foliage and twigs, branchwood, and tree or shrub material as follows:

Size, diameter	**Timelag**
Inch	***Hours***
< ¼	1
¼ to 1	10
1 to 3	100
> 3	1,0001[1]

[1]Large fuels or layers slow to respond are recognized in the fuel models available in the 1978 NFDRS.

The initial fuel models were documented by Rothermel (1972) and these 13 models were reduced to 9 models for the 1972 NFDRS (Deeming and others 1972). The original 9 fuel models, except for one, have been retained in the 1978 NFDRS and supplemented by 11 others to accommodate differences across the country. For fire behavior officer training, the 13 fuel models initially presented by Rothermel (1972) and Albini (1976) are currently being used. The 13 models encompass those of the 1972 NFDRS and can be correlated to the 1978 NFDRS models. At the present time, the fuel models have the broadest application, while other research is providing fuel models for specific applications (Kessell 1976, 1977; Bevins 1976; Kessell, Cattelino, and Potter 1977; Philpot 1977; Hough and Albini 1978; Rothermel and Philpot 1973).

Anderson, Hal E.
1982. Aids to determining fuel models for estimating fire behavior. USDA For. Serv. Gen. Tech. Rep. INT-122, 22p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Presents photographs of wildland vegetation appropriate for the 13 fuel models used in mathematical models of fire behavior. Fuel model descriptions include fire behavior associated with each fuel and its physical characteristics. A similarity chart cross-references the 13 fire behavior fuel models to the 20 fuel models used in the National Fire Danger Rating System.

Keywords: forest fuels, modeling, fire behavior

The Intermountain Station, headquartered in Ogden Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 273 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

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Provo, Utah (in cooperation with Brigham Young University)

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