Fire Behavior Field Reference Guide

June 15, 2007

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In addition to inclusion of the 1992 content, additional information was added, including information on the 40 fire behavior fuel models and the new nomograph format.

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I. Fuels

Original 13 fuel models

Selecting a Fire Behavior Fuel Model

The fuel models available for calculating fire behavior are identical to the fuel models utilized by Albini (1976) to develop the nomograms published in his paper "Estimating Wildfire Behavior and Effects". They are tuned to the fine fuels that carry the fire and thus describe the conditions at the head of the fire or the fire front. Most fires spread by a series of runs when conditions are favorable for burning and that is what these fuel models are designed to simulate.

Assessment of fie behavior will be simpler if a single fuel model can be found to describe the fuels in the area. In fact, as experience is gained by observation of fires and estimating their behavior, it is possible to pick the fuel model not only by its description of the physical vegetation, but also by its known fire behavior characteristics.

Considerations in Selecting a Fuel Model

1. Determine the general vegetation type; grass, brush, timber, litter, or slash.
2. What stratum of the surface fuels is most likely to carry spreading fire? For instance, the fire may be in a timbered area but the timber is relatively open and dead grass is the stratum carrying the fire rather than needle litter. In this case, fuel model 2, which is not listed as a timber model, should be considered.
3. What is the general depth and compactness of the fuel? This is very important.
4. Which fuel classes are present and what is their influence on fire behavior expected to be? 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.

Fire Behavior Fuel Model Key

From: How to Predict the Spread and Intensity of Forest and Range Fires, Richard Rothermel (1983)

I. **PRIMARY CARRIER OF THE FIRE IS GRASS.** Expected rate of spread is moderate to high, with low to moderate 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 the 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. Vegetation 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 lt. in height. Brush requires moderate winds to carry fire. SEE THE DESCRIPTION ON MODEL 6

C. Live Fuel moisture can have a significant effect on the 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 a heavy loading of dead (woody) fuel. Very intense fire with high spread rates expected. SEE THE DESCRIPTION OF MODEL 4

3. Vegetation 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 litter; i.e., 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 significant amount of larger fuel. Larger fuel has attached branches and twigs, or has rotted enough that 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

IV. **PRIMARY CARRIER OF THE FIRE IS 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 the 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 feet. 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, EXCEFT all the needles are attached and are red. SEE THE DESCRIPTION OF MODEL 4

Fire Behavior Fuel Model Descriptions

These descriptions are taken from Hal Anderson's "Aids to Determining Fuel Models for Estimating Fire Behavior" (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 1 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 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 all 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. Pinyon-juniper 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-gallbeny 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 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 some twigs since little undergrowth is present in the stand. Representative conifer types are white pines, lodgepole pine, spruce, fire and larch.

Fire behavior fuel model 9 -- Fire runs 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 cause 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 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 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 light 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 harvest 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, most 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 fine 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 fuel 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.

Fuel model parameters

Primary Carrier of Fire	Fuel Model	SA/VOL Ratio (FT^2/FT^3) 1 HR	10 HR	100 HR	Live	Fuel Loading (Tons/Acre) 1 HR	10 HR	100 HR	Live	Depth	Marl	Heat	SCM	PR/OPR	PR	Char SA/VOL
	1	3500	—	—	—	0.74	0	0	0	1.0	12	8000	379	0.25	,00106	3500
Grass	2	3000	109	30	1500	2.00	1.0	0.50	0.5	1.0	15	8000	126	1.13	.00575	2704
	3	1500	—	—	—	3.01	0	0	0	2.5	25	8000	281	0.21	.00173	1500
	4	2000	109	30	1500	5.01	4.01	2.00	5.01	6.0	20	8000	214	0.52	,00383	1739
Shrub	5	2000	109	—	1500	1.00	0.50	0	2.00	2.0	20	8000	35	0.33	.00252	1683
	6	1750	109	30	—	1.50	2.50	2.00	0	2.5	25	8000	84	0.43	.00345	1564
	7	1750	109	30	1550	1.13'	1.87	1.50	0.37	2.5	40	8000	74	0.35	.00280	1562
	8	2000	109	30	—	1.50	1.00	2.50	0	0.2	30	8000	5	5.17	.03590	1889
Timber Litter	9	2500	109	30	—	2.92	0.41	0.15	0	0.2	25	BOOO	27	4.54	.02500	2484
	10	2000	109	30	1500	3.01	2.00	5.012	2.00	1.0	25	8000	23	2.33	.01725	1764
	11	1500	109	30	—	1.50	5	5.51	0	1.0	15	8000	14	1.62	.01653	1112
Slash	12	1500	109	30	—	4.01	14.03	16.53	0	2.3	20	8000	29	2.06	,02156	1145
	13	1500	109	30	—	7.01	23.04	28.05	0	3.0	25	8000	34	2.68	.02779	1159

40 fuel models

The original 13 fire behavior fuel models are "for the severe period of the fire season when wildfires pose greater control problems..." (Anderson 1982). Those fuel models have worked well for predicting spread rate and intensity of active fires at peak of fire season in part because the associated dry conditions lead to a more uniform fuel complex, an important assumption of the underlying fire spread model (Rothermel 1972). However, they have deficiencies for other purposes, including prescribed fire, wildland fire use, simulating the effects of fuel treatments on potential fire behavior, and simulating transition to crown fire using crown fire initiation models. Widespread use of the Rothermel (1972) fire spread model and desire for more options in selecting a fuel model indicate the need for a new set of models to

- Improve the accuracy of fire behavior predictions outside of the severe period of the fire season, such as prescribed fire and fire use applications. For example, the original grass models 1 (short grass) and 3 (tall grass) are fully cured to represent the most severe part of the fire season. Applying those fuel models to situations in which the grass fuelbed is not fully cured (that is, outside the severe part of the fire season) leads to over-prediction.

- Increase the number of fuel models applicable in high-humidity areas. With the Rothermel spread model, the only way to accommodate fuel complexes that burn well at high humidity is through the moisture of extinction parameter. Only a few of the original 13 fuel models are appropriate for fuelbeds that burn well at relatively high dead fuel moistures.

- Increase the number of fuel models for forest litter and litter with grass or shrub understory. Predicted surface fire behavior drives crown fire models (Van Wagner 1977, Alexander 1988), so increased precision in surface fire intensity prediction will lead to increased precision in crown fire behavior prediction and hazard assessment.

- Increase the ability to simulate changes in fire behavior as a result of fuel treatment by offering more fuel model choices, especially in timber-dominated fuelbeds. This fuel model set does not attempt to directly simulate the effects of the wide variety of available fuel treatment options.

Characteristics

This new set of standard fire behavior fuel models is designed to stand alone; none of the original 13 fire behavior fuel models is repeated in the new set; the fuel model selection guide points to the new fuel models only. However, the original 13 fire behavior fuel models will still be available; they are still called fire behavior fuel models 1-13. There is no immediate need to re-analyze existing fuel model maps or lookup tables that are sufficient for their purpose. However, we anticipate that new fuel model mapping projects will use this new set rather than the original 13.

Documentation and naming of the new fuel models refer to fuel or fuel types, not vegetation or vegetation types. For example, what was formerly termed a "Chaparral" fuel model might now be called a "heavy load, tall brush" model, because one fuel model can be applied in many vegetation types. Likewise, the fuel model selection guide does not refer to specific vegetation types except as necessary to illustrate an example.

In this new set, all fuel models with an herbaceous component are dynamic. In a dynamic fuel model, live herbaceous load is transferred to dead as a function of the live herbaceous moisture content. Although the new fuel model parameters can be input to a non-dynamic fire behavior processor, that approach does not produce the intended result. Using the dynamic fuel models in a non-dynamic fire behavior model would leave the live herbaceous load in the live category, regardless of moisture content. The grass models will therefore predict no (or very little) spread and intensity under any wind or moisture condition. The change to dynamic fuel models is really a change in both the fire behavior processors and concurrently how fuel models for grass- or herbaceous-dominated fuelbeds are conceived. In this case, our desire for grass and herbaceous fuel models that could be used at various levels of curing precipitated the change in fire behavior processors.

Fire behavior modeling systems must be modified to correctly use the new dynamic fuel models. Check the documentation of each fire behavior processor to be sure it implements the dynamic fuel models as intended.

Naming Convention

Fuel models in the new set are grouped by fire-carrying fuel type. The number of fuel models within each fuel type varies. Each fuel type has been assigned a mnemonic two-letter code. Non-burnable fuel models, even though not really a "fuel", were included in the set to facilitate consistent mapping of these areas on a fuel model map. Fuel types were ordered in a way similar to the original 13, with hybrid fuel types (such as Timber-understory) generally between the two types that comprise the hybrid. Fuel types are as follows:

- (NB) Non-burnable
- (GR) Grass
- (GS) Grass-shrub
- (SH) Shrub
- (TU) Timber-understory
- (TL) Timber litter
- (SB) Slash-blowdown

Within a fuel type, fuel models are ordered by increasing heat per unit area (at 8 percent dead, 75 percent live fuel moisture content). Wind speed and slope steepness do not affect heat per unit area. Fuel model numbers were kept below 256 so that an 8-bit number could be used for storing fuel model information in mapping or database applications.

The dead fuel extinction moisture assigned to the fuel model defines the weighted-average dead fuel moisture content at which the fire will no longer spread in the Rothermel model. This modeling parameter is generally associated with climate (humid vs. dry), though fire science research has yet to explain the mechanism for the association. Fuel models for dry climates tend to have lower dead fuel moistures of extinction, while fuel models for humid-climate areas tend to have higher moistures of extinction. Fuel model names (and the fuel model selection guide) include reference to the general climate where the fuel model is found.

Dynamic fuel models

In this new set, all fuel models that have a live herbaceous component are "dynamic", meaning that their herbaceous load shifts between live and dead depending on the specified live herbaceous moisture content. See the model parameters list ("fuel model type" column) to see which models contain live herbaceous load and are therefore dynamic.

- The dynamic fuel model process is described by Burgan (1979); the method is outlined and illustrated below.
- If live herbaceous moisture content is 120 percent or higher, the herbaceous fuels are green and all herbaceous load stays in the live category at the given moisture content.
- If live herbaceous moisture content is 30 percent or lower the herbaceous fuels considered fully cured and all herbaceous load is transferred to dead herbaceous.
- If live herbaceous moisture content is between 30 and 120 percent, then part of the herb load is transferred to dead. For example, if live herb moisture content is 75 percent (halfway between 30 and 120 percent), then half of the herbaceous load is transferred to dead herbaceous, the remainder stays in the live herbaceous class.

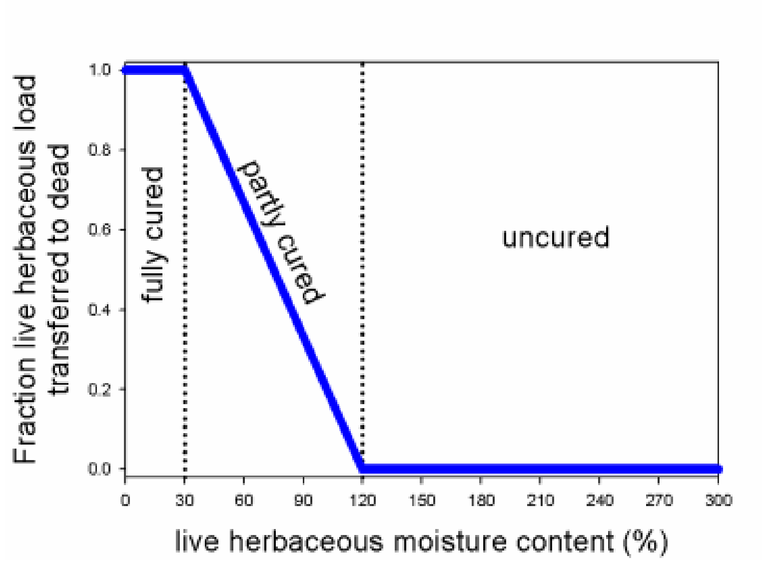


Figure 1 -- Graphical representation of the dynamic fuel model process.

Load transferred to dead is not simply placed in the dead 1-hr timelag class. Instead a new dead herbaceous class is created so that the surface-area-to-volume ratio of the live herbaceous component is preserved. However, for simplicity the moisture content of the new dead herbaceous category is set to the same as that for the dead 1-hr timelag class.

When evaluating dynamic models, be aware that live herbaceous moisture content significantly affects fire behavior because herbaceous load shifts between live and dead, and dead fuel usually has a much lower moisture content than live. It will often be preferable to estimate live herbaceous moisture content by working backward from observed or estimated degree of herbaceous curing (table 2). For example, if the fuelbed is observed to be 50 percent cured, use a value of 75 percent for live herbaceous moisture content.

Table 2 -- level of curing vs. live herbaceous moisture content

level of curing		live herbaceous moisture content
uncured	0 percent	120 percent or more
one-quarter	25	98
one-third	33	90
one-half	50	75
two-thirds	66	60
three-quarters	75	53
fully cured	100	30 or less

None of the original 13 fire behavior fuel models is dynamic. Therefore, direct comparisons between the new and original fuel models can only be made if the live herbaceous moisture content is 30 percent (fully cured) or lower. For example, models GR6 and GR8 are similar to original fuel model 3, but their behavior over a range of live herbaceous moisture content is very different (fig. 2). Fuel model 3 does not have a live herbaceous component, so its behavior does not change as that input is varied. Fuel models GR6 and GR8 are both dynamic, so fire behavior decreases rapidly with higher levels of live fuel moisture (less curing).

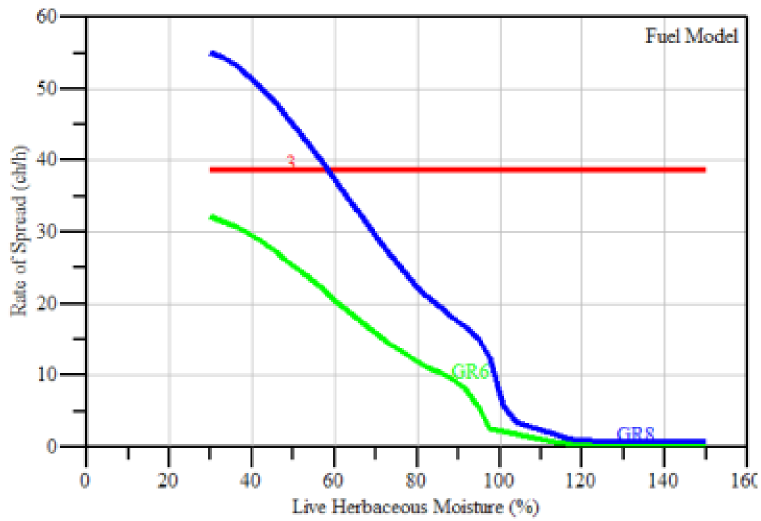


Figure 2 --Comparison of dynamic fuel models GR6 and GR8 with static fuel model 3.

To preserve the static nature of original fuel model 2 (which contains live herbaceous load as well as dead grass) and to preserve the ability to create custom fuel models in which dynamic load transfer does not take place, the fuel model description includes a fuel model type. A static fuel model with live herbaceous load should keep that load in the live category regardless of moisture content, whereas the same fuel model would undergo the load transfer if its type is dynamic. Custom fuel models can be either static or dynamic. If a fuel model does not have load in the live herbaceous category, then the fuel model type is irrelevant.

Selecting a fire behavior fuel model

Considerations for selecting a fuel model

1. Determine the general fire-carrying fuel type (grass, grass-shrub, shrub, timber litter, timber with (grass or shrub) understory, or slash or blowdown fuels. Estimate which stratum of surface fuels is most likely to carry the fire. For example, the fire

may be in a forested area, but if the forest canopy is open, grass, not needle litter, might carry the fire. In this case a grass model should be considered.

2. The dead fuel extinction moisture assigned to the fuel model defines the moisture content of dead fuels at which the fire will no longer spread. This fuel parameter, unique to the Rothermel surface fire spread model, is generally associated with climate (humid vs. dry). That is, fuel models for dry areas tend to have lower dead fuel moistures of extinction, while fuel models for wet humid areas tend to have higher moistures of extinction.

3. Note the general depth, compactness, and size of the fuel, and the relative amount of live vegetation.

4. Do not restrict your selection by fuel model name or fuel type. After selecting a fuel model, view its predicted fire behavior to be sure the predicted behavior agrees with your expectation or observation.

In this guide we refer to spread rates and flame lengths as being very low, low, moderate, high, very high and extreme, assuming two-thirds cured herbaceous, dry dead fuels (moisture scenario D2L2), a midflame wind speed of 5 mi/h, and zero slope. The classes are defined as follows:

Table 5 -- Adjective class definitions for predicted fire behavior.

Adjective Class	ROS (ch/h)	FL (ft)
Very Low	0-2	0-1
Low	2-5	1-4
Moderate	5-20	4-8
High	20-50	8-12
Very High	50-150	12-25
Extreme	>150	>25

Guide to selecting one of the 40 fuel models

The major fire-carrying fuel type is:

1. Nearly pure grass and/or forb type (Grass)
    a. Arid to semi-arid climate (rainfall deficient in summer). Extinction moisture content is 15 percent.
        i. **GR1** Grass is short, patchy, and possibly heavily grazed. Spread rate moderate; flame length low.
        ii. **GR2** Moderately coarse continuous grass, average depth about 1 foot. Spread rate high; flame length moderate.
        iii. **GR4** Moderately coarse continuous grass, average depth about 2 feet. Spread rate very high; flame length high.
        iv. **GR7** Moderately coarse continuous grass, average depth about 3 feet. Spread rate very high; flame length very high.

b. Sub-humid to humid climate (rainfall adequate in all seasons). Extinction moisture content is 30 to 40 percent.
    i. **GR1** Grass is short, patchy, and possibly heavily grazed. Spread rate moderate; flame length low.
    ii. **GR3** Very coarse grass, average depth about 2 feet. Spread rate high; flame length moderate.
    iii. **GR5** Dense, coarse grass, average depth about 1-2 feet. Spread rate very high; flame length high.
    iv. **GR6** Dryland grass about 1-2 feet tall. Spread rate very high; flame length very high.
    v. **GR8** Heavy, coarse, continuous grass 3-5 feet tall. Spread rate very high; flame length very high.
    vi. **GR9** Very heavy, coarse, continuous grass 5-8 feet tall. Spread rate extreme; flame length extreme.

2. Mixture of grass and shrub, up to about 50 percent shrub coverage (Grass-shrub)
    a. Arid to semi-arid climate (rainfall deficient in summer). Extinction moisture content is 15 percent.
        i. **GS1** Shrubs are about 1 foot high, low grass load. Spread rate moderate; flame length low.
        ii. **GS2** Shrubs are 1-3 feet high, moderate grass load. Spread rate high; flame length moderate.
    b. Sub-humid to humid climate (rainfall adequate in all seasons). Extinction moisture content is 30 to 40 percent.
        i. **GS3** Moderate grass/shrub load, average grass/shrub depth less than 2 feet. Spread rate high; flame length moderate.
        ii. **GS4** Heavy grass/shrub load, depth greater than 2 feet. Spread rate high; flame length very high.
3. Shrubs cover at least 50 percent of the site. Grass sparse to non-existent. (Shrub)
    a. Arid to semi-arid climate (rainfall deficient in summer). Extinction moisture content is 15 percent.
        i. **SH1** Low shrub fuel load, fuelbed depth about 1 foot; some grass may be present. Spread rate very low; flame length very low.
        ii. **SH2** Moderate fuel load (higher than SH1), depth about 1 foot, no grass fuel present. Spread rate low; flame length low.
        iii. **SH5** Heavy shrub load, depth 4-6 feet. Spread rate very high; flame length very high.
        iv. **SH7** Very heavy shrub load, depth 4-6 feet. Spread rate lower than SH5, but flame length similar. Spread rate high; flame length very high.
    b. Sub-humid to humid climate (rainfall adequate in all seasons). Extinction moisture content is 30 to 40 percent.
        i. **SH3** Moderate shrub load, possibly with pine overstory or herbaceous fuel, fuel bed depth 2-3 feet. Spread rate low; flame length low.
        ii. **SH4** Low to moderate shrub and litter load, possibly with pine overstory, fuel bed depth about 3 feet. Spread rate high; flame length moderate.

    iii. **SH6** Dense shrubs, little or no herb fuel, depth about 2 feet. Spread rate high; flame length high.
    iv. **SH8** Dense shrubs, little or no herb fuel, depth about 3 feet. Spread rates high; flame length high.
    v. **SH9** Dense, finely branched shrubs with significant fine dead fuel, about 4-6 feet tall; some herbaceous fuel may be present. Spread rate high, flame length very high.

4. Grass or shrubs mixed with litter from forest canopy. (Timber-understory)
    a. Semi-arid to sub-humid climate. Extinction moisture content is 20 percent.
        i. **TU1** Fuelbed is low load of grass and/or shrub with litter. Spread rate low; flame length low.
        ii. **TU4** Fuelbed is short conifer trees with grass or moss understory. Spread rate moderate; flame length moderate.
        iii. **TU5** Fuelbed is high load conifer litter with shrub understory. Spread rate moderate; flame length moderate.
    b. Humid climate. Extinction moisture content is 30 percent.
        i. **TU2** Fuelbed is moderate litter load with shrub component. Spread rate moderate; flame length low.
        ii. **TU3** Fuelbed is moderate litter load with grass and shrub components. Spread rate high; flame length moderate.
5. Dead and down woody fuel (litter) beneath a forest canopy. (Timber Litter)
    a. Fuelbed is recently burned but able to carry wildland fire.
        i. **TL1** Light to moderate load, fuels 1-2 inches deep. Spread rate very low; flame length very low.
    b. Fuelbed not recently burned
        i. Fuelbed composed of broadleaf (hardwood) litter
            1. **TL2** Low load, compact. Spread rate very low; flame length very low.
            2. **TL6** Moderate load, less compact. Spread rate moderate; flame length low.
            3. **TL9** Very high load, fluffy. Spread rate moderate; flame length moderate.
        ii. Fuelbed composed of long-needle pine litter
            1. **TL8** moderate load and compactness may include small amount of herbaceous load. Spread rate moderate; flame length low.
        iii. Fuelbed **not** composed broadleaf or long-needle pine litter
            1. Fuelbed includes both fine and coarse fuels
                a. **TL4** Moderate load, includes small diameter downed logs. Spread rate low; flame length low.
                b. **TL7** Heavy load, includes larger diameter downed logs. Spread rate low; flame length low.
            2. Fuelbed does not include coarse fuels
                a. **TL3** Moderate load conifer litter. Spread rate very low; flame length low.
                b. **TL5** High load conifer litter; light slash or mortality fuel. Spread rate low; flame length low.

        c. **TL9** Very high load broadleaf litter; heavy needle-drape in otherwise sparse shrub layer. Spread rate moderate; flame length moderate.

6. Activity fuel (slash) or debris from wind damage (blowdown). (Slash-blowdown)
    a. Fuelbed is activity fuel
        i. **SB1** Fine fuel load is 10 to 20 tons/ac, weighted toward fuels 1-3 in diameter class, depth is less than 1 foot. Spread rate moderate; flame length low.
        ii. **SB2** Fine fuel load is 7 to 12 tons/ac, evenly distributed across 0-0.25, 0.25-1, and 1-3 inch diameter classes, depth is about 1 foot. Spread rate moderate; flame length moderate.
        iii. **SB3** Fine fuel load is 7 to 12 tons/ac, weighted toward 0-0.25 inch diameter class, depth is more than 1 foot. Spread rate high; flame length high.
    b. Fuelbed is blowdown
        i. **SB2** Blowdown is scattered, with many trees still standing. Spread rate moderate; flame length moderate.
        ii. **SB3** Blowdown is moderate, trees compacted to near the ground. Spread rate high; flame length high.
        iii. **SB4** Blowdown is total, fuelbed not compacted, foliage still attached. Spread rate very high; flame length very high.
7. Insufficient wildland fuel to carry wildland fire under any condition. (Non-burnable)
    a. **NB1** Urban or suburban development; insufficient wildland fuel to carry wildland fire
    b. **NB2** Snow/ice
    c. **NB3** Agricultural field, maintained in non-burnable condition
    d. **NB8** Open water
    e. **NB9** Bare ground

Fuel model descriptions

Non-burnable group

These non-burnable "fuel models" are included to provide consistency in how the non-burnable portions of the landscape are displayed on a fuel model map. In all NB fuel models there is no fuel load -- wildland fire will not spread.

NB1 -- Fuel model NB1 consists of land covered by urban and suburban development. To be called NB1, the area under consideration must not support wildland fire spread. In some cases, areas mapped as NB1 may experience structural fire losses during a wildland fire incident; however, structure ignition in those cases is either house-to-house or by firebrands, neither of which is directly modeled using fire behavior fuel models. If sufficient inflammable vegetation surrounds structures such that wildland fire spread is possible, then choose a fuel model appropriate for the wildland vegetation rather than NB1.

NB2 -- Land covered by permanent snow or ice is included in NB2. Areas covered by seasonal snow can be mapped to two different fuel models: NB2 for use when snow-covered and another for use in the fire season.

NB3 -- Fuel model NB3 is agricultural land maintained in a non-burnable condition; examples include irrigated annual crops, mowed or tilled orchards, and so forth. However, there are many agricultural areas that are not kept in a non-burnable condition. For example, grass is often allowed to grow beneath vines or orchard trees, and wheat or similar crops are allowed to cure before harvest; in those cases use a fuel model other than NB3.

NB8 -- Land covered by open bodies of water such as lakes, rivers and oceans comprise NB9.

NB9 -- Land devoid of enough fuel to support wildland fire spread is covered by fuel model NB9. Such areas may include gravel pits, arid deserts with little vegetation, sand dunes, rock outcroppings, beaches, and so forth.

Grass group

The primary carrier of fire in the GR fuel models is grass. Grass fuels can vary from heavily grazed grass stubble or sparse natural grass to dense grass more than 6 feet tall. Fire behavior varies from moderate spread rate and low flame length in the sparse grass to extreme spread rate and flame length in the tall grass models.

All GR fuel models are dynamic, meaning that their live herbaceous fuel load shifts from live to dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is very strong.

GR1 -- The primary carrier of fire in GR1 is sparse grass, though small amounts of fine dead fuel may be present. The grass in GR1 is generally short, either naturally or by heavy grazing, and may be sparse or discontinuous. The moisture of extinction of GR1 is indicative of a dry climate fuelbed, but GR1 may also be applied in high-extinction moisture fuelbeds, because in both cases predicted spread rate and flame length are low compared to other GR models.

GR2 -- The primary carrier of fire in GR2 is grass, though small amounts of fine dead fuel may be present. Load is greater than GR1, and fuelbed may be more continuous. Shrubs, if present, do not affect fire behavior.

GR3 -- The primary carrier of fire in GR3 is continuous, coarse, humid-climate grass. Grass and herb fuel load is relatively light; fuelbed depth is about 2 feet. Shrubs are not present in significant quantity to affect fire behavior.

GR4 -- The primary carrier of fire in GR4 is continuous, dry-climate grass. Load and depth are greater than GR2; fuelbed depth is about 2 feet.

GR5 -- The primary carrier of fire in GR5 is humid-climate grass. Load is greater than GR3 but depth is lower, about 1-2 feet.

GR6 -- The primary carrier of fire in GR6 is continuous humid-climate grass. Load is greater than GR5 but depth is about the same. Grass is less coarse than GR5.

GR7 -- The primary carrier of fire in GR7 is continuous dry-climate grass. Load and depth are greater than GR4. Grass is about 3 feet tall.

GR8 -- The primary carrier of fire in GR8 is continuous, very coarse, humid-climate grass. Load and depth are greater than GR6. Spread rate and flame length can be extreme if grass is fully cured.

GR9 -- The primary carrier of fire in GR9 is dense, tall, humid-climate grass. Load and depth are greater than GR8, about 6 feet tall. Spread rate and flame length can be extreme if grass is fully or mostly cured.

Grass-shrub group

The primary carrier of fire in the GS fuel models is grass and shrubs combined; both components are important in determining fire behavior.

All GS fuel models are dynamic, meaning that their live herbaceous fuel load shifts from live to dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is strong, and depends on the relative amount of grass and shrub load in the fuel model.

GS1 -- The primary carrier of fire in GS1 is grass and shrubs combined. Shrubs are about 1 foot high, grass load is low. Spread rate is moderate; flame length low. Moisture of extinction is low.

GS2 -- The primary carrier of fire in GS2 is grass and shrubs combined. Shrubs are 1-3 feet high, grass load is moderate. Spread rate is high; flame length moderate. Moisture of extinction is low.

GS3 -- The primary carrier of fire in GS3 is grass and shrubs combined. Moderate grass/shrub load, average grass/shrub depth less than 2 feet. Spread rate is high; flame length moderate. Moisture of extinction is high.

GS4 -- The primary carrier of fire in GS4 is grass and shrubs combined. Heavy grass/shrub load, depth greater than 2 feet. Spread rate high; flame length very high. Moisture of extinction is high.

Shrub group

The primary carrier of fire in the SH fuel models is live and dead shrub twigs and foliage in combination with dead and down shrub litter. A small amount of herbaceous fuel may be present, especially in SH1 and SH9, which are dynamic models (their live herbaceous fuel load shifts from live to dead as a function of live herbaceous moisture content). The effect of live herbaceous moisture content on spread rate and flame length can be strong in those dynamic SH models.

SH1 -- The primary carrier of fire in SH1 is woody shrubs and shrub litter. Low shrub fuel load, fuelbed depth about 1 foot; some grass may be present. Spread rate is very low; flame length very low.

SH2 -- The primary carrier of fire in SH2 is woody shrubs and shrub litter. Moderate fuel load (higher than SH1), depth about 1 foot, no grass fuel present. Spread rate is low; flame length low.

SH3 -- The primary carrier of fire in SH3 is woody shrubs and shrub litter. Moderate shrub load, possibly with pine overstory or herbaceous fuel, fuel bed depth 2-3 feet. Spread rate is low; flame length low.

SH4 -- The primary carrier of fire in SH4 is woody shrubs and shrub litter. Low to moderate shrub and litter load, possibly with pine overstory, fuel bed depth about 3 feet. Spread rate is high; flame length moderate.

SH5 -- The primary carrier of fire in GS4 is grass and shrubs combined. Heavy grass/shrub load, depth greater than 2 feet. Spread rate very high; flame length very high. Moisture of extinction is high.

SH6 -- The primary carrier of fire in SH6 is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 2 feet. Spread rate is high; flame length high.

SH7 -- The primary carrier of fire in SH7 is woody shrubs and shrub litter. Very heavy shrub load, depth 4-6 feet. Spread rate lower than SH7, but flame length similar. Spread rate is high; flame length very high.

SH8 -- The primary carrier of fire in SH8 is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 3 feet. Spread rate is high; flame length high.

SH9 -- The primary carrier of fire in SH9 is woody shrubs and shrub litter. Dense, finely branched shrubs with significant fine dead fuel, about 4-6 feet tall; some herbaceous fuel may be present. Spread rate is high, flame length very high.

Timber-understory group

The primary carrier of fire in the TU fuel models is forest litter in combination with herbaceous or shrub fuels. TU1 and TU3 contain live herbaceous load and are dynamic, meaning that their live herbaceous fuel load is allocated between live and dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is strong, and depends on the relative amount of grass and shrub load in the fuel model.

TU1 -- The primary carrier of fire in TU1 is low load of grass and/or shrub with litter. Spread rate is low; flame length low.

TU2 -- The primary carrier of fire in TU2 is moderate litter load with shrub component. High extinction moisture. Spread rate is moderate; flame length low.

TU3 -- The primary carrier of fire in TU3 is moderate forest litter with grass and shrub components. Extinction moisture is high. Spread rate is high; flame length moderate.

TU4 -- The primary carrier of fire in TU4 is grass, lichen or moss understory plants. If live woody moisture content is set to 100 percent, this fuel model mimics the behavior of Norum's (1982) empirical calibration for Alaska Black Spruce. Spread rate is moderate; flame length moderate.

TU5 -- The primary carrier of fire in TU5 is heavy forest litter with a shrub or small tree understory. Spread rate is moderate; flame length moderate.

Timber litter group

The primary carrier of fire in the TL fuel models is dead and down woody fuel. Live fuel, if present, has little effect on fire behavior.

TL1 -- The primary carrier of fire in TL1 is compact forest litter. Light to moderate load, fuels 1-2 inches deep. May be used to represent a recently burned forest. Spread rate is very low; flame length very low.

TL2 -- The primary carrier of fire in TL2 is broadleaf (hardwood) litter. Low load, compact broadleaf litter. Spread rate is very low; flame length very low.

TL3 -- The primary carrier of fire in TL3 is moderate load conifer litter, light load of coarse fuels. Spread rate is very low; flame length low.

TL4 -- The primary carrier of fire in TL4 is moderate load of fine litter and coarse fuels. Includes small diameter downed logs. Spread rate is low; flame length low.

TL5 -- The primary carrier of fire in TL5 is High load conifer litter; light slash or mortality fuel. Spread rate is low; flame length low.

TL6 -- The primary carrier of fire in TL6 is moderate load broadleaf litter, less compact than TL2. Spread rate is moderate; flame length low.

TL7 -- The primary carrier of fire in TL7 is heavy load forest litter, includes larger diameter downed logs. Spread rate low; flame length low.

TL8 -- The primary carrier of fire in TL8 is moderate load long-needle pine litter, may include small amount of herbaceous load. Spread rate is moderate; flame length low.

TL9 -- The primary carrier of fire in TL9 is very high load, fluffy broadleaf litter. TL9 can also be used to represent heavy needle-drape. Spread rate is moderate; flame length moderate.

Slash/blowdown group

The primary carrier of fire in the SB fuel models is activity fuel or blowdown. Forested areas with heavy mortality may be modeled with SB fuel models.

SB1 -- The primary carrier of fire in SB1 is light dead and down activity fuel. Fine fuel load is 10 to 20 t/ac, weighted toward fuels 1-3 in diameter class, depth is less than 1 foot. Spread rate is moderate; flame length low.

SB2 -- The primary carrier of fire in SB2 is moderate dead and down activity fuel or light blowdown. Fine fuel load is 7 to 12 t/ac, evenly distributed across 0-0.25, 0.25-1, and 1-3 inch diameter classes, depth is about 1 foot. Blowdown is scattered, with many trees still standing. Spread rate is moderate; flame length moderate.

SB3 -- The primary carrier of fire in SB3 is heavy dead and down activity fuel or moderate blowdown. Fine fuel load is 7 to 12 t/ac, weighted toward 0-0.25 inch diameter class, depth is more than 1 foot. Blowdown is moderate, trees compacted to near the ground. Spread rate is high; flame length high.

SB4 -- The primary carrier of fire in SB4 is heavy blowdown fuel. Blowdown is total, fuelbed not compacted, most foliage and fine fuel still attached to blowdown. Spread rate very high; flame length very high.

Fuel model parameters

Fuel model code	Fuel load (t/ac)					Fuel model type[a]	SAV ratio (1/ft)[b]			Fuel bed depth (ft)	Dead fuel extinction moisture (percent)	Heat content BTU/lb)[c]
	1-hr	10-hr	100-hr	Live herb	Live woody		Dead 1-hr	Live herb	Live woody			
GR1	0.10	0.00	0.00	0.30	0.00	dynamic	2200	2000	9999	0.4	15	8000
GR2	0.10	0.00	0.00	1.00	0.00	dynamic	2000	1800	9999	1.0	15	8000
GR3	0.10	0.40	0.00	1.50	0.00	dynamic	1500	1300	9999	2.0	30	8000
GR4	0.25	0.00	0.00	1.90	0.00	dynamic	2000	1800	9999	2.0	15	8000
GR5	0.40	0.00	0.00	2.50	0.00	dynamic	1800	1600	9999	1.5	40	8000
GR6	0.10	0.00	0.00	3.40	0.00	dynamic	2200	2000	9999	1.5	40	9000
GR7	1.00	0.00	0.00	5.40	0.00	dynamic	2000	1800	9999	3.0	15	8000
GR8	0.50	1.00	0.00	7.30	0.00	dynamic	1500	1300	9999	4.0	30	8000
GR9	1.00	1.00	0.00	9.00	0.00	dynamic	1800	1600	9999	5.0	40	8000
GS1	0.20	0.00	0.00	0.50	0.65	dynamic	2000	1800	1800	0.9	15	8000
GS2	0.50	0.50	0.00	0.60	1.00	dynamic	2000	1800	1800	1.5	15	8000
GS3	0.30	0.25	0.00	1.45	1.25	dynamic	1800	1600	1600	1.8	40	8000
GS4	1.90	0.30	0.10	3.40	7.10	dynamic	1800	1600	1600	2.1	40	8000
SH1	0.25	0.25	0.00	0.15	1.30	dynamic	2000	1800	1600	1.0	15	8000
SH2	1.35	2.40	0.75	0.00	3.85	N/A	2000	9999	1600	1.0	15	8000
SH3	0.45	3.00	0.00	0.00	6.20	N/A	1600	9999	1400	2.4	40	8000
SH4	0.85	1.15	0.20	0.00	2.55	N/A	2000	1800	1600	3.0	30	8000
SH5	3.60	2.10	0.00	0.00	2.90	N/A	750	9999	1600	6.0	15	8000
SH6	2.90	1.45	0.00	0.00	1.40	N/A	750	9999	1600	2.0	30	8000
SH7	3.50	5.30	2.20	0.00	3.40	N/A	750	9999	1600	6.0	15	8000
SH8	2.05	3.40	0.85	0.00	4.35	N/A	750	9999	1600	3.0	40	8000
SH9	4.50	2.45	0.00	1.55	7.00	dynamic	750	1800	1500	4.4	40	8000
TU1	0.20	0.90	1.50	0.20	0.90	dynamic	2000	1800	1600	0.6	20	8000
TU2	0.95	1.80	1.25	0.00	0.20	N/A	2000	9999	1600	1.0	30	8000
TU3	1.10	0.15	0.25	0.65	1.10	dynamic	1800	1600	1400	1.3	30	8000
TU4	4.50	0.00	0.00	0.00	2.00	N/A	2300	9999	2000	0.5	12	8000
TU5	4.00	4.00	3.00	0.00	3.00	N/A	1500	9999	750	1.0	25	8000
TL1	1.00	2.20	3.60	0.00	0.00	N/A	2000	9999	9999	0.2	30	8000
TL2	1.40	2.30	2.20	0.00	0.00	N/A	2000	9999	9999	0.2	25	8000
TL3	0.50	2.20	2.80	0.00	0.00	N/A	2000	9999	9999	0.3	20	8000
TL4	0.50	1.50	4.20	0.00	0.00	N/A	2000	9999	9999	0.4	25	8000
TL5	1.15	2.50	4.40	0.00	0.00	N/A	2000	9999	1600	0.6	25	8000
TL6	2.40	1.20	1.20	0.00	0.00	N/A	2000	9999	9999	0.3	25	8000
TL7	0.30	1.40	8.10	0.00	0.00	N/A	2000	9999	9999	0.4	25	8000
TL8	5.80	1.40	1.10	0.00	0.00	N/A	1800	9999	9999	0.3	35	8000
TL9	6.65	3.30	4.15	0.00	0.00	N/A	1800	9999	1600	0.6	35	8000
SB1	1.50	3.00	11.00	0.00	0.00	N/A	2000	9999	9999	1.0	25	8000
SB2	4.50	4.25	4.00	0.00	0.00	N/A	2000	9999	9999	1.0	25	8000
SB3	5.50	2.75	3.00	0.00	0.00	N/A	2000	9999	9999	1.2	25	8000
SB4	5.25	3.50	5.25	0.00	0.00	N/A	2000	9999	9999	2.7	25	8000

[a] Fuel model type does not apply to fuel models without live herbaceous load.
[b] The value 9999 was assigned in cases where there is no load in a particular fuel class or category
[c] The same heat content value was applied to both live and dead fuel categories.

Two-fuel Model Concept

If nonuniformity of the fuel makes it impossible to select a fuel model, 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 litter 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 vice 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 the TWO module worksheet. Record the estimated proportional coverage of the primary model .This completes the information needed as inputs to the two-fuel-model concept.

Guidelines for TWO Module Worksheet

[This content not transcribed because it is out-dated in BehavePlus]

Worksheet for fuel Module input

[This content not transcribed because it is out-dated in BehavePlus]

Interior Alaska – fuel types, fire behavior, and fuel models

INTRODUCTION

Material for this guide was extracted from various sources. Fuel models and fire behavior outputs have been field tested by fire behavior specialists of Alaska. Your use of them, as suggested, will save many hours of trial and error. This guide is by no means the last and all-inclusive work for dealing with fire problems in the Alaska fuel types. High summer temperatures with little night cooling, long periods with minimal precipitation, fuel types that respond rapidly to climatic changes, and frequent lightning storms contribute to the high frequency of fires in Alaska.

Environmental Characteristics (Fire Prone-Area)

- Elevation - near sea level to 3,500 feet. Slopes generally under40%, all aspects.
- Precipitation - Annual precipitation is generally 12 inches or less in the Interior of Alaska. Summer accumulations, June, July, and August, average from three to six inches. Frequent lightning storms produce as high as 4,000 strikes in a 24-hour period. Winter snow pack usually melts by mid to late April.
- Humidity -Averages fall in the 40% and 60% range during summer days, with little nighttime variation. During warm, dry periods, humidity in the teens and low 20% range are to be expected.
- Temperatures - It is not uncommon to have extended periods of daytime highs in the upper 80's during late June and July. The time of maximum temperatures and relative humidity is also influenced by the long days. Maximum temperatures and minimum relative humidity occur between 1500 and 1600 (Alaska daylight time) during the summer months.
- Daylight Hours - Range from 20 to 24 hours. The so-called "midnight sun" of June and July decreases the nocturnal temperature differential. The long summer days in Alaska influence temperatures during the brief night period. The temperature does not cool down significantly and humidity can remain low, with complete recovery in the morning hours. Fires can burn very actively during the usual nighttime hours.
- Winds - Surface winds vary greatly, dependent upon local terrain. Afternoon and evening thunderstorms produce significant winds which affect fire behavior, and are the largest cause of fire escaping suppression actions.
- In May, dead grasses are drying out and deciduous shrubs have not greened up. This period of pre-greening is a period of high human-caused fire occurrence.

- The first lightning storms begin around the last week of May to the first week of June, which may also be during the pre-greenup period. It is common to have an early fire bust during this period, with the lightning storms continuing to start fires into the second week of June. The primary fire season, lightning-caused fires, is from June 21 to July 24. A dramatic decrease in occurrence begins on about August 7.

General Vegetation Patterns (Fire -Prone Areas)

- Areas above 3,500 foot elevation are predominantly alpine tundra, or rock.
- Broad valleys are generally a continuous black spruce/feather moss-lichen cover type, or sometimes fairly continuous tussock tundra, usually underlain by - permafrost, permanently frozen soil.
- South facing slopes are better-drained, with less permafrost and more hardwood stands of birch and aspen.
- Drainage bottoms are characteristically meandering, with stringers of white spruce or willow and alder.

Fire Weather

- Weather in Alaska is difficult to predict, because little weather data is available from stations in Alaska or from areas where major systems originate. Many weather systems move rapidly across Alaska in the summertime, and heavy thunderstorm activity is to be expected. The gusty down draft winds from these thunderstorm cells are common; these strong winds can cause extreme fire behavior situations and create safety problems for line personnel and threaten fire camps.
- Areas in the proximity of the major mountains ranges also experience strong, gusty, downslope winds that can bring smoldering fires back to life and cause spotting and high forward rates of spread. The best policy is to request a local fire behavior expert or an Alaska-qualified FBA to assist outside overhead teams.

Fire WX Forecasting

- Fire weather forecasting in Alaska is done by employees of the National Weather Service (NWS) located in Anchorage and Fairbanks. Daily weather briefings are given at AFS headquarters in Fairbanks by a forecaster specializing in fire weather. Daily spot weather predictions are made for 30 weather reporting stations across the State, including all main fire-prone areas, and are issued from the Fairbanks NWS office.

- Spot weather forecasts for project fires can be obtained through the Fairbanks logistics office on a twice-daily basis, corresponding to morning and evening shift plan schedules. Remote weather units are not available in Alaska, and contact with the fire weather forecaster depends upon radio or telephone communications between the fire and a BLM field station.

FUEL TYPES, FIRE BEHAVIOR, AND FUEL MODELS

The boreal fuel types most commonly encountered in Interior Alaska are:

Forest Fuel Types	**Tundra Fuel Types**
Black Spruce-Feather Moss-Lichen	Tussock
White Spruce	Shrub
Hardwoods	Alpine
Conifer/hardwood mix	

Some of these fuel types present suppression and management situations very different from those found anywhere in the Lower 48 states. You should be familiar with these differences, fire behavior patterns, and logistical problems to accurately assess the situation.

Forest Fuel Types

Black Spruce-Feather Moss/Lichen

Description - Black spruce stands are widespread in Interior Alaska. Generally, they are in relatively flat valley bottoms, or flat to gentle rolling land, and on cold slopes having a north exposure. They can form a continuous solid stand uninterrupted for miles. These trees are small, usually 8 to 15 feet. Maximum heights in mature stands seldom exceed 30 feet, but can grow to 50-60 feet in height. They are slow growing and seldom exceed eight inches in diameter and usually have DBH of 2 to 3 inches. Black spruce forest with canopy closures of less than 25% typically occurs on poorly drained permafrost sites. Stands with canopy cover greater than 25% occur on slightly drier sites. The understory vegetation is usually a continuous layer of feather mosses, lichens, and, frequently, sphagnum moss. Ericaceous shrubs, blueberry, cranberry, and Labrador tea are also components of this type. There is little down, dead woody fuels in these stands. The fire is carried by the feather mosses and lichen. These fuels should not be referred to as "tundra". "Tundra" is a treeless boreal area. Approximately 75% of Alaska's problem wildfires occur in the black spruce-feather moss/lichen fuel type. It is in this fuel type that fire conditions and suppression situations are very different from those of the Lower 48 states.

Fire Behavior - Fires in Alaska black spruce are usually intense, killing all trees and consuming all branches. Although tree crowns are usually involved, fires are rarely running crown fires. That is, the fire is carried by surface fuels, with a crown fire often following some distance behind the fire front, giving the impression of a full-blown running crown fire. The tendency of fires to crown is related to the distribution of the fuels within the stand, the flashy carrier fuels, feather moss, lichen, and the dry black spruce needles. In most black spruce stands, the carrier fuels can carry flames three feet above the surface. The characteristic layering of the lower black spruce branches (often covered with dead lichen), provides nearly continuous fuel from the forest floor to the tree crowns (ladder effect). The lichens are an excellent indicator of fuel moisture, as they crumble when dry, and are resilient when the R.H. and fuel moisture is increased. A significant change can be observed in a 20-minute period of drying. The carrier fuels, feather moss and lichen, have a tremendous surface-area-to-volume ratio and exhibit immediate responses to changes in relative humidity. Though live fuels, they respond like a dead fuel to changes in weather conditions. When free of surface moisture, the response to change in R.H. would class feather moss as a twenty minute timelag fuel. With R.H. of 55% of less, it will burn even if temperatures are cool. Studies have concluded that black spruce is always ready to burn at any time. Even in a wet summer, the spruce needles remain dry (with 80% to 85% moisture content common in June). This explains the problem faced by Alaska fire managers of having a crowning spruce fire at any time, including the day after a good, soaking rain.

The black spruce fire is carried by surface fuels with a crown fire following a few feet behind the fire front if the flame length is two feet or greater. Rate of spread is low and predictable, while intensity is high. It is common to have spotting by aerial firebrands in a crowning spruce fire. Wind is the crucial factor. Spotting may occur ½-mile ahead of the fire and even up to two miles. Spot fires are often difficult to detect until they take off and start running. Fire breaks then are a matter of condition. If conditions are right for long-range spotting, your fire break must be burned out with enough separation to hold. Spotting distance determines the usability of firebreaks.

In this fuel type, it is not uncommon to have an extended rainy period followed by a clear sky, a little wind, R.H. to 25%, with spruce trees crowning out by mid-afternoon. - A fire that is lying down and appears to be no problem, can be off and running within a few hours. This scenario has ruined the day for many overhead teams in Alaska.

Fuel Models - Use Fuel Model 9, multiplied by a factor of 1.21, for the forward rate of spread in the black spruce fuel type. This fuel model exhibits one of the slowest rates of spread. Fuel Model 5 is used to predict flame length and fireline intensity. This fuel model exhibits one of the highest fireline intensities. The homogeneous fuel which is extensive and continuous presents an opportunity for the FBAN to make reliable calculations with a high degree of accuracy. NFDRS Fuel Model E, Hardwood litter and Mixed Hardwood/Conifers and be used where hardwoods dominate. Model O does not accurately predict fire conditions for this fuel type in Alaska.

White Spruce

Description - White spruce forests with canopy closure greater that 25% form large, productive stands on warm, well drained sites, especially along major rivers. White spruce also commonly forms "stringers" along smaller streams and around lakes. Paper birch and balsam poplar often comprise a significant part of the tree canopy in these stands. In open stands, a wide variety of shrubs and herbs dominate the understory, along with feather moss. Alder, tall willow, prickly rose, buffaloberry, bunchberry, twinflower, and ericaceous shrubs are common.

Fire Behavior - Fire occurs much less frequently in these forests than in the black spruce types. When they occur they tend to have lower intensities. Crowning is less frequent than in the black spruce fuel type because fuel ladders are less likely to occur. However, an intense ground fire may exist where feather moss-lichen understories are well developed.

Fuel Model - Use Fuel Model 8. This fuel model corresponds to NFDRS Model H, Short-Needled Conifers; fires are typically slow-spreading and will present a suppression problem where downed woody material is concentrated.

Hardwoods

Description - Pure stands of birch, aspen, or mixtures of the two species are common on upland sites in the Interior. Aspen are most common on warm, well drained sites, and grade into birch on colder, wetter sites. Aspen is an intermediate stage leading to white spruce, while paper birch sites may later be dominated by white or black spruce. A well developed understory of alder, willow, highbush cranberry, and low shrubs is usually present, as well as herbaceous vegetation, mosses and lichens. White or black spruce may form some component of either the understory or overstory.

Fire Behavior - Although this is a major fuel type, it is primarily useful for the fire manager as a target of opportunity and not a problem fuel. Hardwoods normally serve as a natural barrier and offer a firebreak in all but rare periods of extended drought. A crowning spruce fire will drop to the forest floor when encountering a stand of hardwoods.

Surface loading of dead fuels is low. Humidity is usually higher and temperature lower than in adjacent exposed areas. Fire in hardwoods will usually creep along the surface, doing little damage and offering little danger to the fire fighter. Difficulty may **be** encountered, however, when grubbing the fire out from among the maze of roots.

As more spruce appear in these stands, the behavior of a fire may become more erratic. The surface layer of moss in some hardwood areas can be quite deep burning. This presents a difficult mop-up situation. Frequently, with deep burning in moss and hardwood roots, a hotspot can smolder undetected for days.

Fuel Model - To estimate fire behavior in most hardwood stands, use Fuel Model 9.

Conifer/Hardwood mix

Description - The Spruce/Hardwood mix extends up the slopes to tree lines that are 2,000 to **3.500** feet in elevation along the Alaska-Yukon border, and to **1,000** feet or lower along the lower Yukon Valley. The forests are extensive along the lower slope of the Alaska Range, the south slopes of the Brooks Range, and especially along the uplands of the Tanana, Yukon, Susitna. Koyukuk, and upper Kuskokwim rivers (dry upland sites, primarily south-facing slopes).

Fire Behavior - The fire behavior in the Spruce/Hardwood mix would be less intense than White Spruce, but more intense than a Birch/Aspen stand. Fires will creep in the surface fuels with crowning of trees occurring less frequently than in pure White Spruce stands. Fires backing downhill against the wind or moving across slopes have - an average rate-of-spread of 1/2 chain/hour.

Fuel Model - Use Fuel Model 8 or 9; when heavy loading of down and dried woody material is present, use Model 10.

Tundra Fuel Types

Description - Tundra is a treeless region of lichens, mosses, grasses, sedges, and some low shrubs, including dwarf willow, birches, alder, blueberry, and Labrador tea.

Tussock Tundra

Description - This fuel type can best be described as a bunchgrass prairie in which all of the space between bunches has been filled in with a thick cushion of other plants. Ericaceous shrubs, shrub birch, and willow are common. Tussock tundra is found on extensive areas of land in western Alaska, and on shallow slopes of many mountain valleys and above tree line in the Interior. Permafrost, permanently frozen ground, occurs beneath, and a thick organic layer is present unless the tundra has been severely burned fairly recently.

Fire Behavior –Tussock tundra can be a dangerous fuel type because of its flashy nature. A large component of dead vegetation is almost always intermixed with the live tussock plants. Fifty-five percent is the relative humidity at which "moisture of extinction" occurs. A 30% relative humidity, with a moderate wind, can develop a three-foot flame length. This is, of course, approaching the limit of successful hand tool work, without the aid of water or retardant. A 14% one-hour dead fuel moisture and wind speeds of 15 mph can result in a flame length of 20 feet. Obviously, this condition is too hot to handle with conventional hand tools.

Fuel Model - The carrier fuels in tussock tundra are similar to those in grasslands. If tussocks are less than one foot high, use Fuel Model 1 (short grass). If tussocks are more than one foot high, use Fuel Model 3 (tall grass). The gentle terrain, where tussock tundra is located is a major advantage in suppression considerations. Fuel Model 1, short grass, corresponds to NFDRS Models A, L, and S.

The depth of tundra burning is dependent upon the dryness of the organic layer. Great variation in depth of bum is to be expected, depending on the duration of the burn, time of year, drought condition, and relative humidity/wind conditions at the time of bum. Normally, once active flame is removed in tussock tundra, it does not present a mopup problem.

Shrub Tundra

Description - This fuel type is a treeless area of low or dwarf shrubs, common throughout the interior and the Seward Peninsula. The most common types of shrub tundra are dominated by ericaceous shrubs such as blueberry and Labrador tea, sometimes with shrub birch and willow. Sedges, grasses, mosses, and lichens may be present.

Fire Behavior -

Fuel Model - In an area with a high percentage of shrubs, generally fires are not common, because of moist conditions and sparse fuel. This is characterized by Fuel Model 5 and may give you a fireline intensity that is too high. In these cases, use Fuel Model 6. If there is a large component of dead grasses and sedges mixed with the shrubs, a grass model might be a better description of fire behavior.

Alpine Tundra

Description - This fuel type is generally located above treeline, where harsh environmental conditions limit the development of vegetative cover. Low-growing mats of vegetation, containing various mixtures of *dryas* species, and prostrate willow, along with low-growing ericaceous shrubs, forbs, sedges, and sometimes lichens. The vegetation mat is shallow.

Fire Behavior- Fires will be infrequent and of low intensity because of low fuel loading and summer green or wet conditions.

Fuel Model - The characteristics of this fuel type are such that the fuel models do not describe the fire behavior. Fuel Model 1 could be used if sedges make up a large portion of the vegetative composition.

Wind adjustment factors for calculating the midflame windspeed were experimentally determined for three common Alaska fuel types. Black spruce/feathermoss (*Picea mariana* (Mill.)/*Hylocomium splendens-Pleurozium schreberi*), tussock tundra

(*Eriophorum vaginatum* (*L. vaginatum*) and deciduous tree (hardwood) stands of either paper birch (*Betula papyrifera*, Marsh.) or aspen (*Populus tremuloides* Michx.) were studied. Two wind adjustment factors are given for the black spruce fuels, one for tussock tundra, and two for the hardwood forests. The values are suitable for entry into the wildfire behavior prediction models developed by Rothermel and others (1976 and 1982).

1. Black spruce
    a. Dense, mature stands on flat or rolling terrain (WAF = 0.11)
    b. Open stands or dense stands on the upper 1/3 of unsheltered ridges (WAF = 0.21)
2. Tussock tundra
3. Hardwoods
    a. Birch or aspen stands with leaves on, located on flat or rolling terrain (WAF = 0.31)
    b. Birch or aspen stands on wide spacing or on the upper 1/3 of unsheltered ridges (WAF = 0.53)

These values should be used only for stands in the interior of Alaska.

SAFETY

Safety is a delegated responsibility from the top of the organizational structure down to the individual employee, no matter what type of job or under what conditions. Each individual is responsible for promoting a constant safe attitude.

Any fire that exhibits special safety problems (for example, complicated air operations) extreme fire behavior, or steep terrain indicates a safety problem. Immediate action must be taken to alleviate all safety problems.

SUPPRESSION

Strategy

This will be developed relative to many contributing factors and special situations for specific locations. Your delegation of authority will contain the land managers' concern for the specific resources involved. Fire Management Plans will also set policy and procedures, and should be reviewed along with the Alaska Fire Suppression Field Reference Handbook.

Checklist for Strategic Plans:

1. Priority of control as set by land manager/owner.

2. Cut off fire from most dangerous fuels, i.e., black spruce.

3. Alternate plans of action.

Attack Method

Direct Attack - For firelines of low intensity this is the most common method of attack. Work directly on the flame edge with "spruce bough" or wet gunny sack. Cold trailing is the most reasonable method of securing the line.

Indirect Attack - When fireline intensity or size of a fire dictates indirect attack methods, a number of options or combinations are available.

1. Natural barriers, i.e., small streams, rivers, lakes, or wet drainages
2. Wet line laid by PBY (lake scooping) aircraft, hose and pump, or Fedcos.
3. Fireline explosive (FLE) constructed lines.
4. Handline.

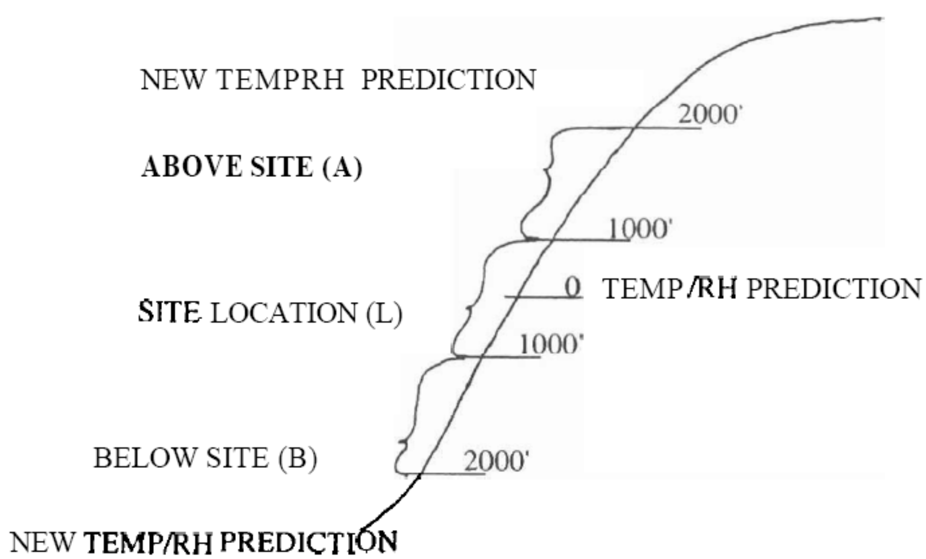
Once indirect lines are prepared, they must be burned out to be effective. Aerial ignition from helicopter or fixed-wing may save time over traditional hand ignition. Both the heli-torch and aerial fusee dispenser are available.

II. Fuel Moisture

Guidelines to determining fine dead fuel moisture

Dead fuel moisture content is an important input to fire behavior predictions. Fuel moisture measurements are difficult to make in the field due to equipment and timing. Estimates can be made, however, from measured or values of dry bulb temperature and relative humidity. Because of solar radiation differences that exist between aspect, time of year, and shading, and the adiabatic differences between positions on slope, it is necessary to modify a simple estimate of fuel moisture. This is because the NFDRS tables used here were originally developed for "worst case" conditions (summer, 1400 hrs, SW aspect, open conditions). These fuel moisture predictions are for fine, dead forest fuels. Consideration for coarser fuels can be estimated by other means as needed.

Temperature and humidity are predicted for a particular place. If your area of concern on a slope is within 1000 feet of elevation either way of the predicted position, use only site location (L) corrections to the reference fuel moisture. When your area of concern is greater than 1000 feet above the prediction place, use above-site (A) corrections. If more than 1000 feet below, use below-site (B) corrections. When you are concerned with a place more than 2000 feet away in elevation, seek a new forecast for that place.



Time corrections cannot be made. Temperature and relative humidity must be obtained for the time in question.

Low slope conditions in Table F are for inversion conditions, that is, cold air draining into a steep narrow canyon with no outlet - very still, "cold", damp air. Do not make fuel moisture prediction corrections from "bottoms" to higher elevations. When extreme inversions do not exist, use the night time reference fuel moisture without correction.

Fine fuel moisture tables

REFERENCE **FUEL** MOISTURE

DAY TIME
0800-1959

RELATIVE HUMIDITY (PERCENT)

Dry Bulb Temperature (°F)	0 ↓ 4	5 ↓ 9	10 ↓ 14	15 ↓ 19	20 ↓ 24	25 ↓ 29	30 ↓ 34	35 ↓ 39	40 ↓ 44	45 ↓ 49	50 ↓ 54	55 ↓ 59	60 ↓ 64	65 ↓ 69	70 ↓ 74	75 ↓ 79	80 ↓ 84	85 ↓ 89	90 ↓ 94	95 ↓ 99	100
10 - 29	1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	14
30 - 49	1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	13
50 - 69	1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	13
70 - 89	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
90-109	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
109+	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	12

GO TO TABLE B, C, or D FOR CORRECTIONS

TABLE □

DAYTIME
0800-1959

DEAD **FUEL** MOISTURE CONTENT CORRECTIONS

MAY JUNE JULY

EXPOSED – LESS THAN 50% SHADING OF SURFACE FUELS		0800 ➤			1000 ➤			1200 ➤			1400 ➤			1600 ➤			1800 ➤		
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30%	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	4
	31%+	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	4
E	0-30%	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	4
	31%+	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	6
S	0-30%	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	3
	31%+	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	3
W	0-30%	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	3
	31%+	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	2
SHADED – GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
E	0%+	4	4	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	6
S	0%+	4	4	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
W	0%+	4	5	6	3	4	5	3	3	4	3	3	4	3	4	5	4	4	5

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

DAYTIME
0800-1959

DEAD FUEL MOISTURE CONTENT CORRECTIONS

FEBRUARY MARCH APRIL/AUGUST SEPTEMBER OCTOBER

		0800 ➤			1000 ➤			1200 ➤			1400 ➤			1600 ➤			1800 ➤		
EXPOSED – LESS THAN 50% SHADING OF SURFACE FUELS																			
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30%	3	4	5	1	2	3	1	1	2	1	1	2	1	2	3	3	4	5
	31%+	3	4	5	3	3	4	2	3	4	2	3	4	3	3	4	3	4	5
E	0-30%	3	4	5	1	2	3	1	1	1	1	1	2	1	2	3	3	4	5
	31%+	3	3	4	1	1	1	1	1	1	1	2	2	3	4	5	4	5	6
S	0-30%	3	4	5	1	2	2	1	1	1	1	1	1	1	2	3	3	4	5
	31%+	3	4	5	1	2	2	0	1	1	0	1	1	1	2	2	3	4	5
W	0-30%	3	4	5	1	2	3	1	1	1	1	1	1	1	2	3	3	4	5
	31%+	4	5	6	3	4	5	1	2	3	1	1	1	1	1	1	3	3	4
SHADED – GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	6	4	5	5	3	4	5	3	4	5	4	5	5	4	5	6
E	0%+	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6	4	5	6
S	0%+	4	5	6	3	4	5	3	4	5	3	4	5	3	4	5	4	5	6
W	0%+	4	5	6	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

TABLE D

DAYTIME
0800-1959

DEAD FUEL MOISTURE CONTENT CORRECTIONS

NOVEMBER DECEMBER JANUARY

		0800 ➤			1000 ➤			1200 ➤			1400 ➤			1600 ➤			1800 ➤		
EXPOSED – LESS THAN 50% SHADING OF SURFACE FUELS																			
		B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N	0-30%	4	5	6	3	4	5	2	3	4	2	3	4	3	4	5	4	5	6
	31%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0-30%	4	5	6	3	4	4	2	3	3	2	3	3	3	4	5	4	5	6
	31%+	4	5	6	2	3	4	2	2	3	3	4	4	4	5	6	4	5	6
S	0-30%	4	5	6	3	4	5	2	3	3	2	2	3	3	4	4	4	5	6
	31%+	4	5	6	2	3	3	1	1	2	1	1	2	2	3	3	4	5	6
W	0-30%	4	5	6	3	4	5	2	3	3	2	3	3	3	4	4	4	5	6
	31%+	4	5	6	4	5	6	3	4	4	2	2	3	2	3	4	4	5	6
SHADED – GREATER THAN OR EQUAL TO 50% SHADING OF SURFACE FUELS																			
N	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
S	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
W	0%+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6

NOTE: A = 1000'-2000' above site
L = ±1000' of site location
B = 1000'-2000' below site

TABLE E

REFERENCE FUEL MOISTURE

NIGHT TIME
2000-0759

Dry Bulb Temperature (°F)	RELATIVE HUMIDITY (PERCENT) 0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100
10 - 29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
30 - 49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
50 - 69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
70 - 89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
90 - 109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

TABLE F

NIGHT TIME
2000-0759

DEAD FUEL MOISTURE CONTENT CORRECTIONS

	2000 ➤			2200 ➤			0000 ➤			0200 ➤			0400 ➤			0600 ➤		
	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N+E	9	1	1	13	1	2	16	2	2	17	1	1	18	1	1	16	2	1
S+W	9	0	1	14	0	1	16	0	2	17	0	1	18	0	0	9	0	1

NOTE: A = 1000'-2000" above size
L = ±1000' of site location
B = 1000'-2000' below site

Guidelines for fine dead fuel moisture calculations and worksheet

[This content not transcribed because it is out-dated in BehavePlus]

Live fuel moisture estimates

Guidelines for estimating live fuel (foliage) moisture content. Live fuel moisture is required for fuel models 2, 4, 5, 7, and 10. If data are unavailable for estimating live fuel moisture, the following rough estimates can be used.

Stage of vegetative development	Moisture content, percent
Fresh foliage, annuals developing, early in growing cycle	300
Maturing foliage, still developing with full turgor	200
Mature foliage, new growth complete and comparable to older perennial foliage	100
Entering dormancy, coloration starting, some leaves may have dropped from stem	50
Completely cured	Less than 30, treat as a dead fuel

Relative humidity tables

[This content not transcribed because it isn't in the contents of the FB Field Guide (but it's in the guide's table of contents]

Average latitude for each state

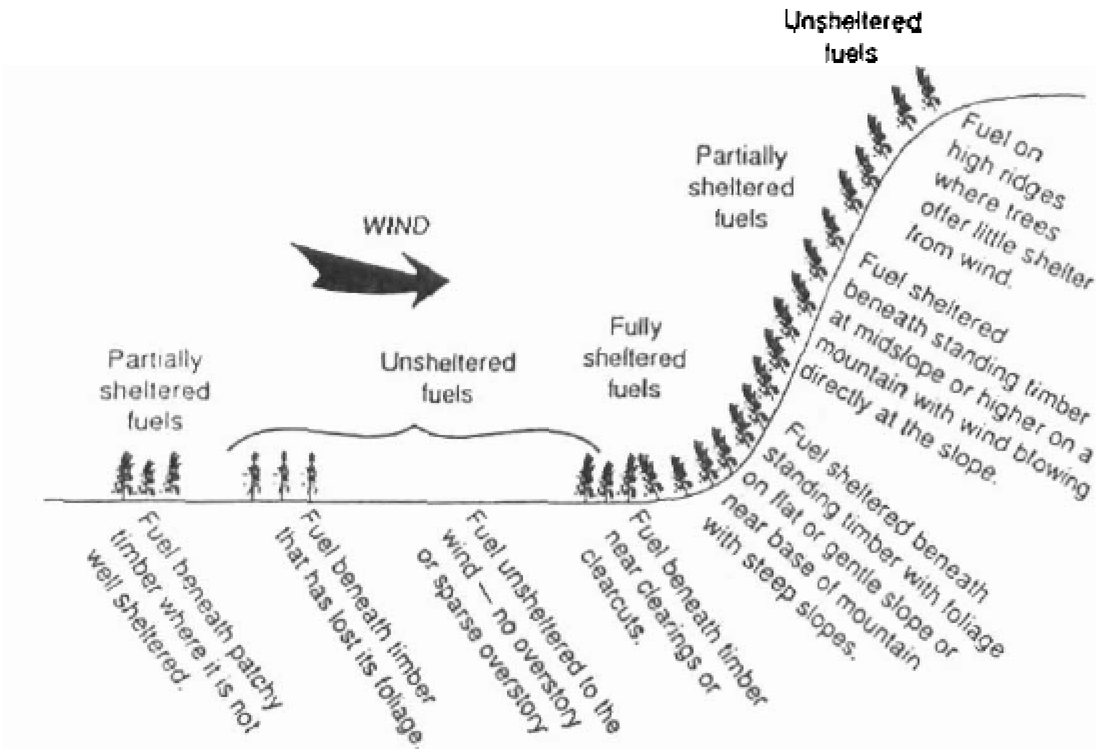
Alabama	33	Montana	47
Alaska	65	Nebraska	41
Arizona	35	Nevada	39
Arkansas	35	New Hampshire	44
California	38	New Jersey	40
Colorado	39	New Mexico	34
Connecticut	41	New York	43
Delaware	39	North Carolina	35
Florida	28	North Dakota	47
Georgia	33	Ohio	40
Hawaii	21	Oklahoma	35
Idaho	45	Oregon	44
Illinois	40	Pennsylvania	41
Indiana	40	Rhode Island	41
Iowa	42	South Carolina	34
Kansas	39	South Dakota	44
Kentucky	37	Tennessee	36
Louisiana	31	Texas	32
Maine	45	Utah	39
Maryland	39	Vermont	44
Massachusetts	42	Virginia	37
Michigan	43	Washington	47
Minnesota	46	West Virginia	38
Mississippi	32	Wisconsin	44
Missouri	39	Wyoming	43

MOISTURE module worksheet guidelines

[This content not transcribed because it is out-dated in BehavePlus]

III. Weather

Guidelines for sheltering and wind adjustment table



Fuel exposure	Original 13 Fuel models	40 fuel models	Adjustment factor
Unsheltered fuels Fuel exposed directly to the wind—no overstory or sparse overstory; fuel beneath timber that has lost its foliate; fuel beneath timber near clearings or clearcuts; fuel on high ridges where trees offer little shelter from wind.	4	SH5, SH7	0.6
	13	GR7, GR8, GR9 SH4, SH8, SH9 SB4	0.5
	1, 2[1], 3, 5, 6, 7[1], 8[2], 9[2], 10[2], 11, 12	GR2 through GR6 GS1 through GS4 SH1, SH2, SH3, SH6 TU2[1], TU3[1], TU5[2] SB1, SB2, SB3	0.4
		GR1 TU1, TU4 TL1 through TL9[2]	0.3
Partially sheltered fuels Fuel beneath patchy timber where it is not well sheltered; fuel beneath standing timber at midslope or higher on a mountain with wind blowing directly at the slope.	All fuel models		0.3
Fully sheltered fuels Fuel sheltered beneath standing timber on flat or gentle slope near the base of mountain with steep slopes.	All fuel models—open stands		0.2
	All fuel models—closed stands		0.1

[1]Fuels usually partially sheltered

[2]Fuels usually fully sheltered

Modified Beaufort Scale

Wind class	Range of wind speeds (mi/h)	Nomenclature
1	≤ 3	**Very Light** - Smoke rises nearly vertically. Leaves of quaking aspen in constant motion; small branches of bushes sway; slender branchlets and twigs of trees move gently; tall grasses and weeds sway and bend with wind; wind vane barely moves.
2	4-7	**Light** - Trees of pole size in the open sway gently; wind felt distinctly on face; loose scraps of paper move; wind flutters small flag.
3	8-12	**Gentle Breeze** - Trees of pole size in the open sway very noticeably; large branches of pole-size trees in the open toss; tops of trees in dense stands sway; wind extends small flag; a few crested waves form on lakes.
4	13-18	**Moderate Breeze** - Trees of pole size in the open sway violently; whole trees in dense stands sway noticeably; dust is raised in the road.
5	19-24	**Fresh** - Branchlets are broken from trees; inconvenience is felt in walking against wind.
6	25-31	**Strong** - Tree damage increases with occasional breaking of exposed tops and branches; progress impeded when walking against wind; light structural damage to buildings.
7	32-38	**Moderate Gale** - Severe damage to tree tops; very difficult to walk into wind; significant structural damage occurs.
8	≥ 39	**Fresh Gale** - Surfaced strong Santa Ana; intense stress on all exposed objects, vegetation, buildings; canopy offers virtually no protection; wind flow is systematic in disturbing everything in its path.

Air Transportable Mobile Unit (ATMU) Description and locations

GENERAL INSTRUCTIONS

Introduction

The Advanced Technology Meteorological Unit (ATMU) is composed of two large shipping boxes with a total weight of 207 pounds. The weight, cubic feet, and a brief description of each module are shown on page A2. The cubic feet are necessary for shipment by air. The same specifications shown are also listed in the user agencies NATIONAL MOBILIZATION GUIDE. This unit is intended for use anywhere in the United States by properly trained National Weather Service (NWS) forecasters. It provides the equipment and supplies for field meteorological operations. The success of the operation depends in part on the user agency providing shelter and logistical support. Prior to the use of this unit, all Incident Meteorologists (IMETS) are expected to have coordinated with their local user agencies to ensure proper field support. The meteorologist must ensure that a Micro-REMS has also been ordered for an incident.

Standardization

Since the ATMU is intended for use by a trained NWS forecaster anywhere in the United States, it is extremely important that the contents of the modules not be changed arbitrarily. The configuration as described in this manual is considered to be the basic unit. If states or regions want to add other equipment they should be placed in separate support modules, NOT IN THIS BASIC UNIT. After using the unit it is important to replace all components in their proper module. Any changes to the basic unit will be coordinated through the NWS National Fire Weather Program Leader (W/OM12) .

Dispatch

The ATMU will be dispatched by the user agency through their normal dispatch channels. If you are not traveling with the unit, find out how the unit is being shipped. This will give you some idea of when to expect it. Furthermore, the IMET must bring a separate computer module (not cached as part of the ATMU) to the incident. If a computer module is not located at your local Weather Forecast Office (WFO), you need to arrange shipment of the separate computer module with the Staff Meteorologist to NIFC (SMN). Once the computer unit arrives, it is your property and responsibility until it is returned to the home office.

Operation

Once at the incident you should work with the Fire Behavior Analyst (FBAN) or Planning Section Chief (PSC) to find a suitable site to set up the unit. Then set up the satellite dish, USB, laptop and printer. When time permits, and with the help of the FBAN, set up the

Micro-REMS. If PIBALs are going to be taken be sure to have the FBAN order helium as soon as possible.

Release and Return

Upon release, re-pack the modules. BE SURE TO PUT EVERYTHING BACK IN THE PROPER PLACE according to the figures located at the end of this section. The user agency will transport the ATMU back to its cache location or to the controlling fire weather office. The IMET is responsible for transporting the computer module back to the home office. If the computer module resides at a different location than the IMET, the IMET must make arrangements to Fedex the unit to the proper office, and charge any shipping costs to the fire. Before you leave the incident complete the checklist located in Appendix 1 for supplies needed and equipment to be repaired. Send a copy of the list to the fire weather office responsible for checking and restocking the unit.

Restocking

Normal expendable supplies can be ordered through GSA. The ATMU Equipment Checklist includes a list of the supplies with the GSA stock numbers when applicable. Pens, pencils, computer disks and markers are not listed since these are common to moat NWS offices.

CONTENTS OF MODULES

Module number	**description**	**Weight (lbs)**	**Size (inches)**	**Volume (ft^3)**
1	Field unit (theodolite and tripod)	122	42x27x21	13.8
2	Communication unit (satellite dish)	85	42x27x21	13.8
ATMU total		**207**		**27.6**
3	Computer carry case (separate from ATMU)	34	24x15x10	2.1
Total for all three modules		**241**		**29.7**

NWS ATMU LOCATIONS AND CONTACTS

(lower 48 states)

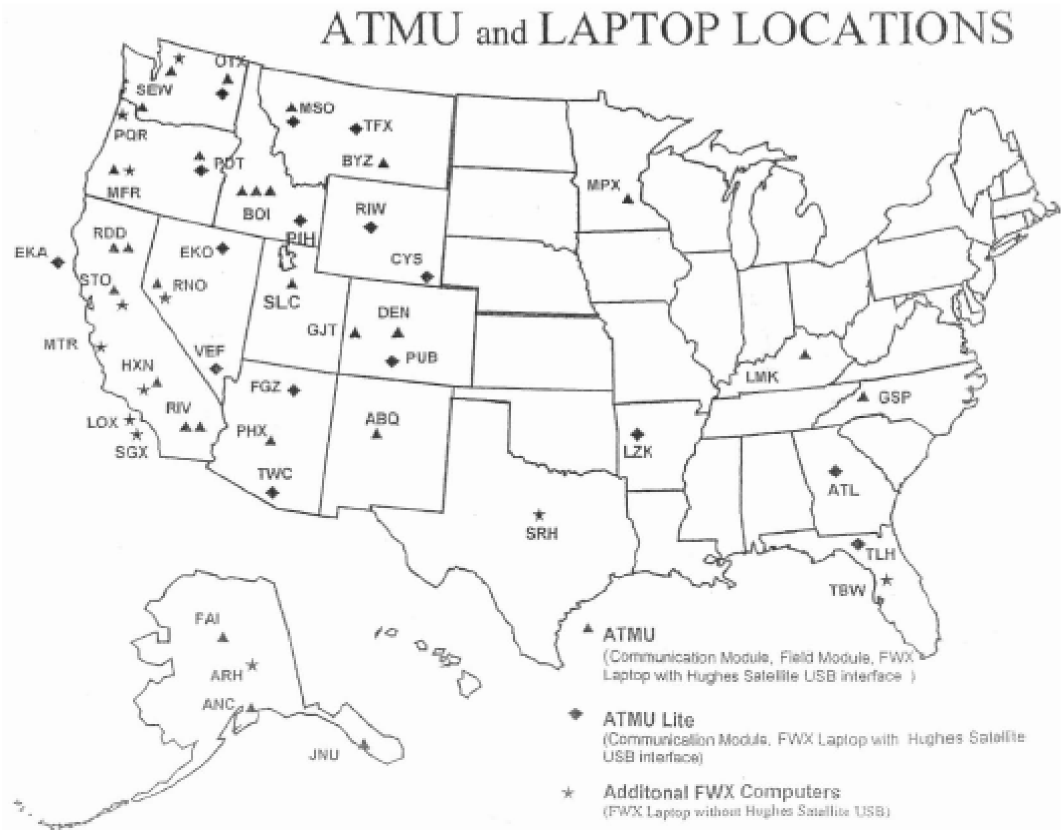
27 MAY 2000

STATION	ADDRESS/CONTACT	ID
Seattle	National Weather Service 7600 Sand Point Way NE - Seattle, WA 98115 Contact: John Werth or Jim Prange (206) 526-6088	WA01
Spokane	National Weather Service 2601 N Rambo Road Spokane, WA 99224-9164 Contact: Gary Bennett or Todd Carter (509) 244-5031	WA02
Portland	National Weather Service 5420 NE Marine. Drive Portland, OR 97218 Contact: Terry Marsha or John Saltenberger (503) 326-2420	OR01
Medford	National Weather Service 4003 Cirrus Drive Medford, OR 97504 Contact: Rick Holtz or Frederick Bunnag (541) 776-4303	OR02
Pendleton	National Weather Service 2001 NW 56- Drive Pendleton, OR 97801-4532 Contact: Bob Tobin or Joe Solomon (541) 276-4493	OR03
Redding	IFFWU 6101 Airport Road Redding, CA 96002-9423 Contact: Fred Svetz or Chris Fontana (530) 226-2730	CA01 CA03 CA07
Sacramento	National Weather Service 3310 El Camino Rm 228 Sacramento, CA 95821-6308 Contact: Mike Smith or Bazil Newmerzhycky (916) 979-3047	CA05
Hanford	National Weather Service 900 Foggy Bottom Road Hanford, CA 93230-5236 Contact: Jeff Nesmith or Cindy Bean (559) 584-9505	CA02
Riverside	IFFWU Operations and Coordination Center 2524 Mulberry St. Riverside, CA 92501 Contact: Tom Rolinski or Ron Hamilton (909) 276-6520	CA04 CA06
Reno	National Weather Service 2350 Raggio Parkway Reno, NV 89512-3900 Contact: Bob Nester or Steve Brown (702)-673-8100	NV01
Boise	National Weather Service NIFC 3833 S Development Ave. Bldg 3807 Boise, ID 83705-5354 Contact: Rick Ochoa or Chuck Redman(208) 334-9862	ID01 ID02 ID03
Missoula	National Weather Service 5765 Highway 10 West Missoula, MT 59808 Contact: Marty Whitmore or Steve Stoll (406) 329-4715	MT01
Billings	National Weather Service 2170 Overland Ave. Billings, MT 59102-6455 Contact: Bruce Thoricht (406) 652-2936 or cache manager James Chapman (406) 657-6889	MT02
Salt Lake City	National Weather Service 2242 W North Temple Salt Lake City, UT 84116 Contact: Chris Maier or Chris Gibson (801) 524-5106	UT01
Phoenix	National Weather Service Salt River Proj. Bldg PAB 500	AZ01

	1521 N Project Drive Tempe, AZ 85281-1206 Contact: Bob Berkovitz or Tony Haffer (602) 379-4607	
Denver	Rocky Mountain Fire Cache P.O. Box 25507 Lakewood, CO 80225 Contact: Dan Leszcynski or Mike Baker (303) 361-0661	CO01
Albuquerque	National Weather Service 2341 Clark Carr Blvd. SE Albuquerque, MN 87106 Contact: Chuck Maxwell (505) 244-9148	NM01
Minneapolis	NE Interagency Fire Cache 402 11th Street SE Grand Rapids, MN 55744 Contact: Byron Paulson (612) 361-6672	MN01
Louisville	London Fire Cache 188 Sublimity School Road London, KY 40743 Contact: Joe Amerman (502) 969-8842	KY01 KY02

ATMU Cache Sites

Appendix 2


ATMU and LAPTOP LOCATIONS
SEW
OTX
PQR
PDT
MFR
MSO
TFX
BYZ
BOI
PIH
RIW
CYS
MPX
RDD
EKA
EKO
STO
RNO
SLC
GJT
DEN
PUB
MTR
HXN
VEF
FGZ
LOX
RIV
SGX
PHX
ABQ
TWC
LZK
LMK
GSP
ATL
SRH
TLH
TBW
FAI
ARH
ANC
JNU
ATMU
(Communication Module, Field Module, FWX Laptop with Hughes Satellite USB interface)
ATMU Lite
(Communication Module, FWX Laptop with Hughes Satellite USB interface)
Additonal FWX Computers
(FWX Laptop without Hughes Satellite USB)

Stability and fire whirls

STABILITY

Definition - resistance to vertical action (i.e., buoyancy)

Dry-adiabatic lapse rate = 5.5 degrees F per 1000 ft.

STABLE	temp decrease with height **less than** 5.5 degrees F per 1000 ft.
NEUTRAL	temp decrease with height **equals** 5.5 degrees F per 1000 ft.
UNSTABLE	temp decrease with height **greater than** 5.5 degrees F per 1000 ft.

Visual Indicators

STABLE	UNSTABLE
• clouds in layers no vertical action • stratus clouds • smoke column drifts apart, limited rise • poor visibility due to smoke and haze • steady winds	• clouds grow vertically • cumulus clouds • taller smoke column • good visibility • gusty winds

INDICATORS FOR FIRE WHIRLS

Weather

- Clear skies or few clouds
- Low humidity
- Light winds (5 mph or less at 30 feet)
- Unstable at lower levels
- Cumulus clouds/towering cumulus/thunderstorm
- Rough, bumpy conditions reported by aircraft
- Airmass changes

Topography

- Aspect and slope on which sun is nearly perpendicular
- Winds across ridgetop with heating on leeward slope
- Up or down canyon winds when they:
    - flow around a spur ridge
    - flow around a sharp bend in the canyon
    - encounter flow from adjoining canyons

Fire

- Well developed convection column
- Bare exposed soil or burned-over area
- Strong convection column causing air to split around it and form fire whirls on the lee side of the column
- Intense heat output & turbulent winds extending vertically over the fire

DATA SOURCES FOR STABILITY & FIRE WHIRLS

- BEST - Fire weather meteorologist/forecast
- Observations - fire line, helicopter temp profiles, air operations
- Nearby RAWS, NFDRS stations, lookouts

The Haines Index and Idaho Wildfire Growth

[not transcribed]

IV. Slope

Process for Determining Slope

In many situations, even in the field, you will be working with topographic maps or maps with elevation contours. There are a great many methods, tables, and shortcuts for determining slope from a contour map. If you have a favorite one and it works well, use it. Only the direct calculation method will be discussed here.

The slope between two points is simply the change in elevation between two points divided the horizontal distance between them. This ratio, when multiplied by 100, gives the slope in percent.

The process can be summarized in five steps:

1. Determine the contour interval. This is the elevation change between adjacent contour lines.

   Example: 40 ft.

2. Determine the map scale and conversion factor. The map scale must be found in terms of the number of feet that each inch on the map represents (ft/in).

   a. Map scales are usually given as the number of inches per mile, such as 2 in/mi, or as a representative fraction such as 1 :31,680.

   b. Use the spacing of section lines to determine the map scale. Normally section line spacing is 1 mile; be careful of foreshortened sections; look around on the map and find square sections with equal spacing. Measure the distance with a ruler graduated in inches and tenths of inches. Divide 5,280 by the map distance between section lines.

   Example: Measured map distance between section lines = 2.64 in
   Map scale = 5,280/2.64 = 2,000 ft/in

3. Determine rise in elevation by counting contour intervals and convert to feet.

   Example: 11 contour intervals
   11 x 40 ft/contour interval = 440 ft.

4. Measure the horizontal distance with a ruler graduated in inches and tenths of inches, and convert to feet with the map scale from step 2.

   Example: Measured map distance of slope length = 1.2 in
   1.2 in x 2,640 ft/in = 3,168 ft.

5. Divide the rise in elevation from step 3 by the horizontal distance from step 4.

Example: 440/3,168 x 100 = 14 percent

Map Scale Conversion Chart

Scale	Representative fraction	Map (in/mi)	Map (in/ch)	Feet per map inch
1 : 253,440	253.44	0.25	0.0031	21120
1 : 126,720	126.72	0.50	0.0063	10560
1 : 63,360	63.36	1	0.0125	5280
1 : 62,500	62.5	1.01	0.0127	5188
1 : 31,680	31.68	2	0.025	2640
1 : 24,000	24	2.64	0.033	2000
1 : 21,120	21.12	3	0.0375	1760
1 : 15,840	15.84	4	0.05	1320
1 : 7,920	7.92	8	0.1	660

Metric Equivalent Chart

[Dan, rather than include the limited conversion table the old guide contains, I suggest publishing a more comprehensive set of tables based on a spreadsheet I put together years ago specifically for wildland fire units conversions. It's comprehensive and pretty easy to use. The table below is an example for units of mass; I have tables for 13 or 14 quantities used in fire management (ROS, FLI, HPA, *etc*. I no longer include reciprocals to avoid the potential for error when going back and forth between units.]

MASS		from these units, divide					
		g	**oz**	**lb**	**kg**	**ton**	**Mg**
from these units, multiply	**g**	1					
	oz	28.35	1				
	lb	453.6	16	1			
	kg	1000	35.27	2.205	1		
	ton	907,185	32,000	2,000	907.2	1	
	Mg	1,000,000	35,274	2,205	1000	1.102	1

Example: 4.5 lbs = 4.5/2.205 = 2.041 kg

Guidelines for SLOPE module Worksheet

[This content not transcribed because it is out-dated in BehavePlus]

V. Fire Behavior Worksheets

Worksheet Color Key

[This content not transcribed because it is out-dated in BehavePlus]

Worksheet Instructions

[This content not transcribed because it is out-dated in BehavePlus]

Worksheets

[This content not transcribed because it is out-dated in BehavePlus]

VI. Fire Behavior Predictions

Calculating Fire Behavior with Nomograms

A nomogram is a group of interconnecting graphs that can be used to solve a mathematical equation or series of equations. In this case the surface fire model equations developed by Rothemel (1972) can be solved by constructing a series of lines on one sheet of paper.

Original format

Nomograms for predicting fire behavior were originally developed by Albini (1976). The nomograms presented here have been modified somewhat from Albini's original version. The primary change has been the adoption of midflame windspeed rather than 20-foot windspeed as an input. Albini used 20-foot windspeed with a wind time, to predict fire behavior in all conditions. To correct the over prediction of fire spread in cases where the fuels were sheltered by an overstory of trees, the method of calculating windspeed in sheltered fuel presented by Albini and Baughman (1979) was adopted. There are two nomograms for each of the 13 fuel models; a low windspeed version and a high windspeed version. They will both give the same answers, but better resolution can be obtained from the low windspeed version; so it should be used whenever possible. Nomograms for all fuel models are given in this envelope. Solution of a fire spread problem on a nomogram will provide an estimate of rate-of-spread, fireline intensity, flame length, and heat per unit area. The fire behavior worksheet provides the input data and is used to record the outputs. It has been designed for use with either the nomograms or the HP-71B. Not all values are used with both systems; consequently, some lines on the HP-71B - DIRECT worksheet will not be used. Whenever the worksheet is needed, the line number on the left-hand margin will be referenced. For the nomograms, data on the following lines are necessary:

1. Fuel model number
2. Fine dead fuel moisture (l-hr)
3. Live woody fuel moisture (for some fuels)
4. Midflarne windspeed
5. Windward slope

Fuel models 2, 4, 5, 7, and 10 contain living fuel. The procedures for handling live fuel moisture are somewhat different than for the fuel models that have only dead fuel. Methods for calculating fire behavior with fuel models containing only dead fuels will be covered first.

It is assumed that a DIRECT worksheet has been prepared with the required information (see Figure 1).

Select the nomogram for the fuel model designated on the DIRECT worksheet, line 1; use the low windspeed nomogram when possible. Note that there are four parts to the nomogram. These are called quadrants and are referred to as upper and lower (meaning the top and bottom of the page) and by left and right.

Solving a fire spread problem on a nomogram requires initial preparation and then a trip through all four quadrants with a continuous line starting and finishing in the upper right quadrant. All of the answers are read in that quadrant. A diagrammatic depiction of the written instructions is given in Figure 2.

Before starting, a note on technique is worthwhile. Lay the nomogram on a flat surface. Have a narrow 10 or 12 inch straight edge available. Note that there is an underlying ¼-in grid; use this to keep your lines true with the nomogram; i.e., parallel with the edges and forming right angles at intersections.

Step 1 - Determine effective value of the midflame windspeed. (This step combines wind and slope.) Note the slope given on line 8 of the DIRECT worksheet. In the lower left quadrant find the percent slope (Figure 1, 35%) and draw a vertical line to the top of the quadrant. On the right hand side of the lower left quadrant, find the midflame windspeed given on line 7 of the DIRECT worksheet (Figure 1, 5 mi/h). Follow the curved windspeed line to the left until it intercepts the vertical line just drawn. At the intersection of the vertical line from the slope and the midflame windspeed, draw a horizontal line to the left hand margin. The effective windspeed is read from the margin (example shown on Figure 2, 6 mi/h). Record the effective (midflame) windspeed (EWS) on line 6 of the DIRECT worksheet (OUTPUT section).

The construction lines drawn in the lower left quadrant are not used again.

Step 2 - Prepare the lower right quadrant by locating a ray (line from the origin) that represents the effective windspeed. Such lines are already in the quadrant to guide you. Interpolate if necessary to establish a ray for the effective windspeed determined in Step 1 (see Figure 2). This line will be used later as a turning line when taking the trip around the nomogram.

Fuel Models With No Living Fuels

Step 3 - This step prepares the upper left quadrant. Find the dead fuel moisture value, given on line 2 of the DIRECT worksheet, on the upper edge of the quadrant. Interpolate if necessary, and construct a new ray for the fuel moisture value (see Figure 2).

All preparations have been made, and you can begin your trip around the nomogram.

Fuel Models With Living Fuels

Fuel models 2, 4, 5, 7, and 10 have living fuels requiring a different procedure in Step 3. Do not be discouraged; the genius of Albini's nomograms is that they can handle this extra variable without requiring two pages for the solution. (See Figures 3 and 4 for an example.)

Step 3 With Live Fuels - Find the dead fuel moisture on the right side of the upper-right quadrant and on the left side of the upper-left quadrant. Draw a line across both quadrants at the designated dead fuel moisture. See Figure 4. In the upper left quadrant find the intersection of the horizontal line just drawn with a slightly curved line representing the live fuel moisture given on line 6 of the DIRECT worksheet. Lay your straight edge between the intersection just found and the origin and draw a ray from the origin up through the intersection just found and edge of the quadrant (see Figure 4). This line will be the turning line in the upper left quadrant when you make your trip around the nomogram (Figure 4). Note that for some fuel models and some conditions the slightly curved lines are so straight that this step provides little correction.

Starting the trip on a nomogram with live fuel moisture - The trip is started in the upper right quadrant at the intersection of the horizontal dead fuel moisture line with the S-shaped curve that is closest to the live fuel moisture. You can interpolate between these lines if desired. The trip will end at the intersection of this vertical line. All other steps are the same as used for dead fuel.

Continue With All Fuel Models

Step 4 - Begin in the upper right quadrant. In the margin, locate the dead fuel moisture from line 2 of the DIRECT worksheet. Draw a horizontal line across the upper right quadrant until it intercepts the S-shaped curve. At the interception, draw a vertical line all the way from the top of the upper right quadrant through the intersection just found and into the lower right quadrant until it hits the ray designating the effective windspeed (Figure 2).

NOTE: The lower right quadrant contains a curved dashed line. There is a note in this quadrant that reads:

> "Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and fireline intensity may be overstated."

The correct procedure to follow if the vertical line from the upper right quadrant intersects the curved dashed line above the effective windspeed line is to stop at the intersection with the dashed line and construct the net line into the lower left, quadrant from that intersection. This will produce a lower rate-of-spread and fire intensity that would result if you continued and used the effective windspeed - line. See Figure 5.

Step 5 - Note the diagonal line in the lower left quadrant. This is the next turning line. From the intercept of the effective windspeed in the lower right quadrant, draw a horizontal line into the lower left quadrant where it intercepts the diagonal line. (Pay no attention to the previously constructed lines from Step 1 in the lower left quadrant.)

Step 6 - From the lower left quadrant, draw a vertical line into the upper left quadrant until it intercepts the appropriate ray for the fuel moisture marked from Step 3 (see Figure 2).

Step 7 - At the intercept in the upper left quadrant, draw a horizontal line into the upper right quadrant extending it until it intercepts the vertical line constructed at the beginning of your trip in Step 4. Draw a small circle at this intercept (see Figure 2).

You have completed the trip; line construction is complete, and you can read the answers.

Rate-of-spread is taken from the left-hand margin of the upper right quadrant where the horizontal line from Step 7 enters the quadrant. See Figure 2. Record rate-of-spread on line 1 of the DIRECT worksheet (OUTPUT section).

Fireline intensity is found at the small circle drawn in Step 7 in the upper right quadrant. The fireline intensity numbers are indicated on each curved line running through the quadrant. Interpolate between lines. See Figure 2. Record on line 3 of the DIRECT worksheet (OUTPUT section).

Flame length is found on the upper horizontal axis of the upper right quadrant. Start at the small circle drawn in Step 7, interpolating where necessary, and staying parallel, follow the curved lines upward to the upper horizontal axis. Record on line 4 of the DIRECT worksheet (OUTPUT section).

Heat per unit area. Read on the lower horizontal axis of the upper right quadrant where it is crossed by the vertical lime dawn in Step 4. Record on line 2 of the DIRECT worksheet. In Figure 2, the heat per unit area is 85 BTU/ft^2.

NOTE: When you have had some practice, you will find that it is not necessary to draw lines all around the nomogram when you make the trip; tic marks at each intersection are sufficient. The starting point in the upper right quadrant usually requires a line so you will not miss it at the completion of the trip.

Interpretation and use of the answers obtained from the nomograms are discussed in other lessons.

Revised (2007) format

[Instructions on use of the new nomograph format can go here. Contact Joe Scott to get those instructions in electronic format.]

There are three significant changes in format and operation with these new nomographs. First, the limitation to upslope wind direction has been eliminated with the development of a separate chart for combining the effects of wind speed, wind direction, and slope steepness. Second, the limitation to computing fire behavior in the heading direction only has been eliminated with the development of a separate chart for reducing head fire spread rate and flame length to appropriate values for non-heading spread directions. Finally, the nomographs have been reformatted to focus on primary model inputs (fuel moisture and effective midflame wind speed) and primary outputs (rate of spread and flame length). The original format allowed the user to compute intermediate model results (reaction intensity and propagating flux). The new format estimates outputs directly, without showing intermediate results. For sake of completeness, nomographs for the original 13 fuel models have been created in the new format.

Gathering Inputs

Gathering the required inputs is the first step in using the nomographs. (Procedures for selecting a fuel model and estimating other input values are covered in training courses and other reports.) Inputs are required in the following categories: fuel and moisture, wind and slope, and spread direction. All inputs and outputs can be recorded on the nomograph worksheet provided in this report.

Fuel and Moisture Inputs

The first fuel input to specify is the fuel model. Any of the original 13 or new 40 fire behavior fuel models may be selected.

Dead fuel moisture content is a required input for all fuel models. To be consistent with predictions made with computerized fire behavior prediction systems, the dead fuel moisture content input should be the surface-area-weighted average moisture content of the 1-, 10-, and 100-h timelag classes (Rothermel 1972). Weighting factors vary by fuel model, but in all cases are weighted heavily toward the 1-h timelag class (table 1). Therefore, the moisture content of the 1-h timelag class can be used for the dead fuel moisture input without significant error. For more precision, or to match the results from computerized applications, compute the weighted-average dead fuel moisture using the weighting factors listed in table 1.

Live herbaceous (LHMC) and live woody moisture content (LWMC) inputs are required only if the selected fuel model contains fuel in one of those components (see table 1). LHMC has a strong effect on predicted fire behavior in the new fuel model set (Jolly

2005) because dynamic load transfer is tied to LHMC (Scott and Burgan 2005). Dynamic load transfer is the simulation of curing in herbaceous fuels by shifting herbaceous fuel load from the live component to dead, where it takes on the moisture content of the 1-h timelag class. The transfer of live herbaceous load to dead is a function of LHMC (Burgan 1979), on the assumption that LHMC decreases as curing takes place. For LHMC ≥ 120 percent, no herbaceous load is transferred to dead; all herbaceous fuel is green and at the specified LHMC, and fire behavior is correspondingly benign. For LHMC ≤ 30 percent, all herbaceous load is transferred to dead; none remains in the live component, and fire behavior is at its maximum potential for the fuel model. For LHMC between 30 and 120 percent, a fraction of the load is transferred to dead (fig. 1). The degree of curing is therefore an important factor for determining a LHMC value (see table 2).

Wind and Slope Inputs

Slope steepness for the nomographs is measured in percent. Estimating slope to the nearest 10 percent is sufficient.

An estimate of midflame wind speed is required, and can be estimated by direct observation or by multiplying 20-ft wind speed by a wind adjustment factor (WAF). On flat terrain, WAF can be determined using tables based on Albini and Baughman's (1979) models of wind reduction. Those same models are used in BehavePlus, FARSITE, and FlamMap. If the surface fuelbed in question is sheltered by a forest canopy (canopy cover greater than 5 percent), use table 3, otherwise use table 1.

Wind direction for the nomographs is the direction the wind is pushing the fire, and is entered in degrees clockwise from upslope. For example, a cross-slope wind blowing from left to right (while facing upslope) is pushing the fire in the direction 90 degrees clockwise from upslope.

Spread Direction

Basic nomograph outputs are rate of spread and flame length in the direction of maximum spread—the heading direction. By assuming fire spreads as a simple ellipse, spread rate and flame length can also be estimated in other spread directions (see Appendix A). Flanking fire behavior occurs at the widest part of the ellipse, where the flame front is oriented perpendicular to the heading direction, while backing fire behavior occurs at the rear (directly opposite the heading direction). The chart also allows calculation of "hanking" fire behavior—fire behavior between the head and flank of a fire—where the flame front is oriented 45 degrees off the heading direction (fig. 2).

Estimating fire behavior with Nomographs

Once the inputs are gathered, estimating fire behavior with nomographs is a three-step process. The first step is to estimate effective midflame wind speed using the wind vectoring chart provided with each nomograph. The next step is to estimate rate of spread and flame length in the direction of maximum spread. For this step, nomograph format and use depends on whether the selected fuel model contains a live fuel component (either herbaceous or woody). In the new fuel model set, only the timber litter (TL) and slash/blowdown (SB) fuel models do not have a live fuel component; the grass (GR), grass-shrub (GS), shrub (SH), and timber-understory (TU) fuel models contain herbaceous and/or woody fuel. Original fuel models 2, 4, 5, 7, and 10 contain live fuel; 1, 3, 6, 8, 9, and 11 through 13 do not. The final step, if necessary, is to estimate rate of spread and flame length in a non-heading direction. This is accomplished with a single chart applicable to all fuel models. These three steps are described separately in the following sections.

Step 1: Effective midflame wind speed

The procedure for estimating effective midflame wind speed is the same for all fuel models, but there is a unique pair of wind vectoring charts for each fuel model, one for low wind speeds and another for high. If you are not certain whether the effective wind speed will be low or high, start with the chart for low wind speeds and switch to the higher one if necessary. For fuel models without a live fuel component, both vectoring charts are on the same page. For fuel models with a live herbaceous or live woody fuel component, the vectoring charts are on separate pages.

Estimation of midflame wind speed will be demonstrated with the following example: fuel model TL5, slope steepness 60 percent, midflame wind speed 7 mi/h, and wind direction 135 degrees clockwise from uphill. Inputs and results for this and following examples are shown in a nomograph worksheet (fig. 3).

1) **Select nomograph and wind vectoring chart**. Select the nomograph for TL5, and then locate the vectoring chart for low wind speeds (the upper "bulls-eye" chart on the nomograph page).
2) **Determine effective midflame wind speed**
    a) Draw a vertical line from the origin of the concentric circles to the point on the line corresponding to the slope steepness. Interpolate between tick marks as necessary (fig. 4, line a). This line represents the slope vector (direction and magnitude of the effect of slope on fire spread).
    b) Draw a line from the origin of the concentric circles in the direction the wind is pushing the fire. Stop the line at the circle representing the midflame wind speed (fig. 4, line b). Each circle represents 1 mi/h wind speed (2 mi/h for high wind speed nomographs). Interpolate between circles as necessary. Faint gray diagonal and horizontal lines aid in drawing lines along common wind directions: quarter up-slope, cross-slope, and quarter down-slope. Tick marks around the

perimeter of the chart indicate 15 degree increments of wind direction. The line you have just drawn represents the wind vector (direction and magnitude of the effect of wind on fire spread).

c) Draw a vertical line from the end of the wind vector (fig. 4, line c). Use the vertical gray lines on the chart to assist in drawing the line.

d) Draw a line parallel to the wind vector, beginning from the tip of the slope vector and continuing to (or beyond) the vertical line drawn in line c above (fig. 4, line d).

e) Draw a line from the origin to the intersection of lines c and d. This line is the effective wind vector (fig. 4, line e).

f) The direction of the effective wind vector indicates the direction of maximum fire spread. Trace this line to the outer circle, and then read the direction to within 5 degrees clockwise from upslope. For this example, the result is 110 degrees clockwise from upslope (fig. 4, point f).

g) The length of the effective wind vector indicates the effective midflame wind speed. Read that value by interpolating between circles. For this example, the result is 5.8 mi/h (see fig. 4).

Step 2: Head fire rate of spread and flame length

The procedure for estimating head fire rate of spread and flame length depends on whether or not the selected fuel model contains a live fuel component. For fuel models without live fuel, nomographs for low and high wind speeds are printed on the same page, and the only inputs needed are effective midflame wind speed (from previous step) and dead fuel moisture content. For fuel models with a live fuel component, charts for low wind speeds and high wind speeds are on separate pages. An additional input, live fuel moisture content, is required to use these charts. The different procedures for using these nomographs are presented in the following sections.

Fuel Models Without a Live Component

The use of a nomograph to estimate fire behavior in the heading direction for a fuel model without a live fuel component will be illustrated by continuing the previous example: Fuel model TL5, slope steepness 60 percent; midflame wind speed 7 mi/h; and wind direction 135 degrees clockwise from upslope (quarter-downslope). Resulting effective midflame wind speed was 5.8 mi/h. Additionally, we will use a dead fuel moisture content of 5 percent. Inputs and outputs for this example are displayed on a Fire Behavior Nomograph Worksheet (fig. 3, Projection Point A).

1) **Determine head fire rate of spread and flame length.**

a) Draw a vertical line beginning from the bottom axis of the chart at a value corresponding to the dead fuel moisture content – 5 percent in this example (fig. 4, line g).

b) Mark the point where this vertical line crosses the line for the effective midflame wind speed determined in the previous example (5.8 mi/h). If necessary, interpolate between lines for effective midflame wind speed. The lines are labeled at the right-hand axis. For example, place the mark 80 percent of the way between the lines for 5 and 6 mi/h effective midflame wind speeds. Draw a horizontal line from this point to the left-hand axis. Use the faint gray lines as a guide (fig. 4, line h).

c) Read the head fire rate of spread (ch/h) from the left-hand axis (fig. 4, point i). The result for this example is 6 ch/h.

d) Read the head fire flame length (feet) by interpolating between the curving gray lines representing flame length (fig. 4, point j). The result for this example is 2.5 ft.

Fuel Models With a Live Component

The following example inputs will be used to illustrate the use of a nomograph to estimate head fire behavior for a fuel model with a live fuel component: Fuel model SH5; slope steepness 60 percent; no canopy cover; 20-ft wind speed 7 mi/h; upslope wind direction; live woody moisture content 110 percent; and dead fuel moisture content 5 percent. Input and outputs are recorded on a Fire Behavior Nomograph Worksheet (fig. 3, Projection Point B). For this example we will repeat the first step, vectoring wind and slope, to illustrate the process for the upslope wind direction.

1) **Select nomograph and wind vectoring chart.**
Select the nomograph for SH5, low wind speeds.

2) **Determine effective midflame wind speed**
We first need to determine midflame wind speed from the 20-ft wind speed. Because there is no canopy cover, WAF is determined from table 1. For SH5, WAF is 0.55. Therefore, midflame wind speed is 7 x 0.55, or 3.9 mi/h. Manual vectoring of wind and slope effects is most difficult with wind blowing directly upslope or downslope, as it is in this example.

   a) Draw a vertical line from the origin of the concentric circles to the point on the line corresponding to the slope steepness. Interpolate between tick marks as necessary (fig. 5, line a).

   b) Draw another vertical line from the origin of the concentric circles to the circle representing the midflame wind speed. To avoid overlapping the line drawn in 2a, you may need to offset this line slightly (fig. 5, line b).

   c) Now, draw a clone of line a (same length) beginning at the upper end of line b (fig. 5, line c).

d) Read the effective midflame wind speed by noting where the tip of line c falls (fig. 5, point d). In this example, the effective midflame wind speed is 5.9 mi/h. With upslope winds, direction of maximum spread is always upslope.

3) **Select a specific chart on the page**
The nomograph pages for fuel models with live fuel consist of five separate charts, each for a different live fuel moisture content. For fuel models with both herbaceous and woody live fuel load, live fuel moisture refers to the live herbaceous moisture content. Live woody moisture content is assumed to be 30 percent higher than live herbaceous fuel. Select the chart matching the live moisture content value and follow steps a through d for the "no live fuel" nomographs to determine spread rate and flame length. If you need to determine spread rate or flame length for a live moisture content value between the values for which a chart is available, make the calculations using the two charts that bracket the value and interpolate. The following example illustrates the interpolation process.

4) **Determine head fire rate of spread and flame length**

a) Draw a vertical line from the bottom of the nomograph corresponding to the specified dead fuel moisture content. In this example, we need to interpolate between two nomographs, so draw this vertical line on the two charts that bracket the desired LWMC (fig. 5, lines e).

b) On both charts, mark the point where this vertical line crosses the line for the effective midflame wind speed estimated above (5.9 mi/h in this example). If necessary, interpolate between lines (labeled at the right-hand axes) for effective midflame wind speed. Draw horizontal lines from these points to the common y-axis. Use the faint gray lines as a guide. Do this for both charts (fig. 5, lines f).

c) Read the rate of spread (ch/h) for both charts, and then interpolate between them. In this example, rate of spread for 100 percent LWMC is about 66 ch/h, and for 120 percent LWMC is about 56 ch/h. Therefore, rate of spread for 110 percent LWMC would be about halfway between those two estimates, or 61 ch/h (fig. 5, point g).

d) Read the flame length for each chart separately by interpolating between the curving gray lines representing flame length. The separate flame length estimates are about 14.5 ft for 100 percent LWMC and about 13.5 ft for 120 percent LWMC; the resulting interpolation for 110 percent LWMC is therefore 14 ft (fig. 5, points h).

Step 3: Non-heading rate of spread and flame length

We determined potential head fire rate of spread and flame length in previous examples. In this section we will demonstrate how to adjust those predictions for other parts of an elliptical fire using the "Fire Behavior in Non-heading Directions Nomograph." The equations used for estimating non-heading rate of spread and flame length are documented in Appendix A. For this example we will use the results from the example (fuel models with a live component) to estimate rate of spread and flame length at the flank of the fire. In that example, effective midflame wind speed was 5.9 mi/h; head fire rate of spread was 61 ch/h; and head fire flame length was 14 ft.

1) Beginning with the right-hand chart of the nomograph, draw a vertical line from the bottom axis to the top at the effective midflame wind speed (fig. 6, line a).

2) Read the corresponding value for length-to-breadth ratio from the top axis. The length-to-breadth ratio for this example is 2.5 (fig. 6, point b). This value will be useful in plotting a point-source fire on a map.

3) Next, draw a horizontal line from the intersection of the vertical line drawn in step 5a and the line corresponding to the desired spread direction. Ensure the line goes all the way to the left-axis of the left-hand chart (fig. 6, line c).

4) Read the resulting fraction of head fire rate of spread from the left-axis of the left-hand chart. Multiply the head fire rate of spread by this fraction (0.21 in this example) to estimate flanking spread rate. The result for this example is 13 ch/h (figure 6, point d).

5) Draw a vertical line from the intersection of line 5c and the curving line in the left-hand chart to the bottom axis (fig. 6, line e).

6) Read the resulting fraction of head fire flame length from the bottom axis. Multiply the head fire flame length by this fraction (0.49 in this example) to estimate flame length in the chosen spread direction. The result for this example is 7 ft (fig. 6, point f).

Fire Behavior Worksheet with Examples for Nomograms

[This content not transcribed because it is out-dated]

Surface Fire Spread Nomograms

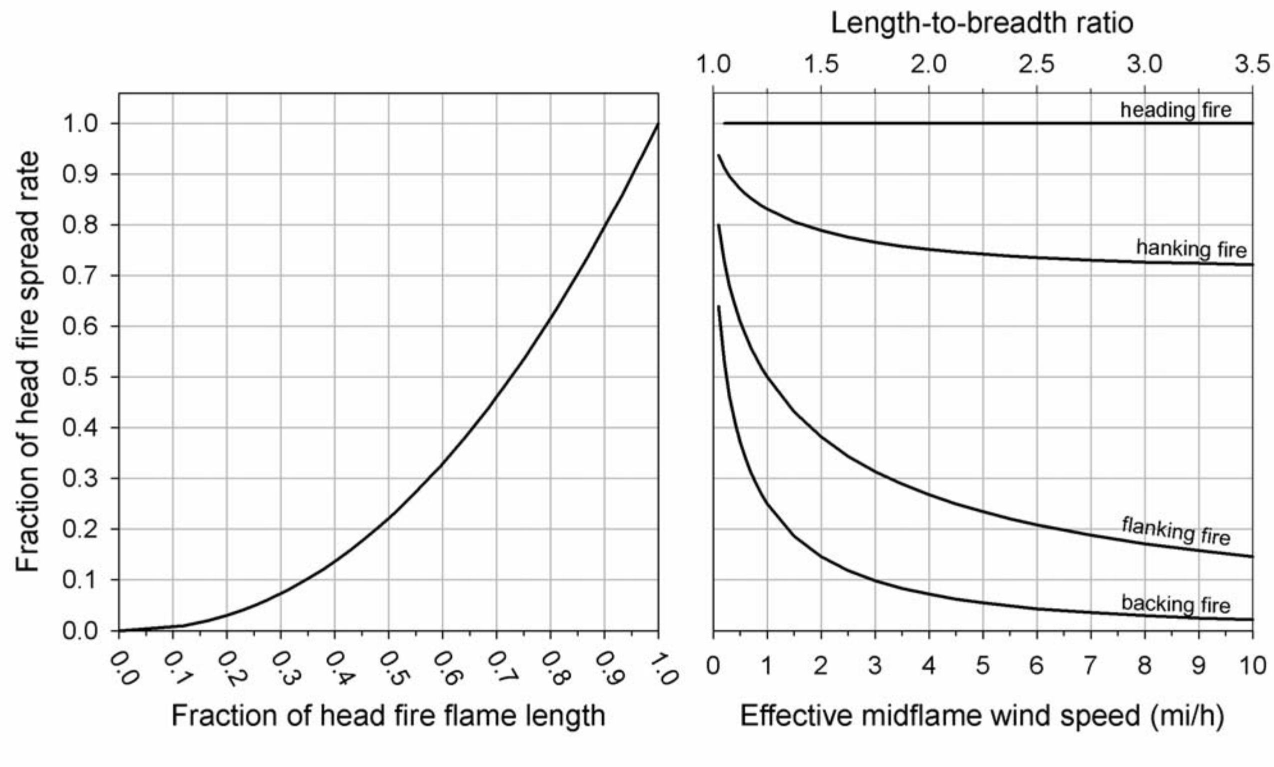
[no content to transcribe]

Cross-slope fire spread

[this content not transcribed because it is outdated; I recommend including instructions and examples for the new nomographs and BehavePlus, which give identical answers. The instructions in the current FB reference guide and S490 is not technically correct, and is more difficult to implement than the revised format.]

[Non-heading fire behavior]

[This is a new chart and description based on the new nomograph format, but can be applied to any fire behavior simulation. Contact Joe Scott to obtain an electronic document with instructions.]



Probability of Ignition Chart

Shading (Percent)	Dry-Bulb Temp. (°F)	FINE DEAD FUEL MOISTURE (PERCENT)															
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Unshaded <50%	110+	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	100-109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
Shaded >50%	110+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	30-39	80	80	60	50	50	40	30	30	20	20	20	10	10	10	10	10

[Dan, you can recreate this chart in BehavePlus if needed]

Manual Spotting worksheet and spotting nomograms

[content not transcribed]

Fire Intensity required to cause crown combustion

Critical fireline intensity for intiation of crown combustion (Btu/ft/sec)
versus
Height to live crown base and foliar moisture content

Height to Live Crown Base (ft)	Foliar Moisture Content (I)											
	70	80	90	100	110	120	130	140	150	160	170	180
50	1873	2202	2548	2911	3290	3684	4093	4515	4952	5401	5863	6338
45	1599	1880	2176	2486	2809	3146	3494	3855	4228	4612	5006	5412
40	1340	1576	1823	2083	2354	2636	2929	3231	3543	3865	4196	4535
35	1097	1289	1492	1705	1927	2158	2340	2644	2900	3163	3434	3712
30	870	1023	1184	1353	1529	1712	1902	2099	2301	2510	2725	2946
25	662	778	901	1029	1163	1303	1447	1596	1751	1910	2073	2241
20	474	551	645	737	832	932	1035	1142	1253	1366	1483	1603
15	308	362	419	478	541	605	673	742	814	887	963	1041
10	168	197	228	260	294	330	366	404	443	483	524	567
5	59	70	81	92	104	116	129	143	157	171	185	200

Minimum flame length for initiation of crown combustion (ft)
versus
Height to live crovn base and foliar moisture content

Height to Live Crown Base (ft)	Poliar Moisture Content (%)											
	70	80	90	100	110	120	130	140	150	160	170	180
50	14.4	15.5	16.6	17.6	18.7	19.7	20.6	21.6	22.5	23.5	24.4	25.2
45	13.4	14.4	15.4	16.4	17.4	18.3	19.2	20.1	21.0	21.8	22.6	23.5
40	12.4	13.3	14.2	15.1	16.0	16.9	17.7	18.5	19.3	20.1	20.9	21.6
35	11.3	12.1	13.0	13.8	14.6	15.4	16.0	16.9	17.6	18.3	19.0	19.7
30	10.1	10.9	11.7	12.4	13.1	13.8	14.5	15.2	15.8	16.5	17.1	17.7
25	8.9	9.6	10.3	10.9	11.6	12.2	12.8	13.4	14.0	14.5	15.1	15.6
20	7.7	8.2	8.8	9.4	9.9	10.5	11.0	11.5	12.0	12.5	12.9	13.4
15	6.3	6.8	7.2	7.7	8.1	8.6	9.0	9.4	9.8	10.2	10.6	11.0
10	4.8	5.1	5.5	5.8	6.2	6.5	6.8	7.1	7.4	7.7	8.0	8.3
5	2.9	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2

[Flame length required to cause crown combustion]

Canopy Base Ht (feet)	Foliar Moisture Content (percent)						
	70	80	90	100	110	120	130
1	1	1	1.1	1.2	1.2	1.3	1.4
2	1.6	1.7	1.8	1.9	2	2.1	2.2
3	2.1	2.2	2.4	2.5	2.7	2.8	2.9
4	2.5	2.7	2.9	3.1	3.3	3.4	3.6
6	3.3	3.6	3.8	4.1	4.3	4.5	4.8
8	4	4.4	4.7	5	5.2	5.5	5.8
10	4.7	5.1	5.4	5.8	6.1	6.4	6.8
15	6.2	6.7	7.2	7.6	8.1	8.5	9
20	7.6	8.2	8.8	9.3	9.9	10.4	10.9
30	10.1	10.8	11.6	12.3	13.1	13.8	14.4
40	12.3	13.2	14.2	15.1	15.9	16.8	17.6
50	14.3	15.4	16.5	17.6	18.6	19.6	20.5

[Dan, I used BehavePlus to make this table]

Canopy bulk density required for active crown fire

Canopy Bulk Dens kg/m3	Critical Crown ROS ch/h	Crowning Index[1] (mi/h)		
		Normal summer	Drought summer	Late summer severe drought
0.02	447.4			
0.04	223.7			
0.06	149.1			
0.08	111.8			
0.1	89.5			
0.12	74.6			
0.14	63.9			
0.16	55.9			
0.18	49.7			
0.2	44.7			
0.22	40.7			
0.24	37.3			
0.26	34.4			
0.28	32			
0.3	29.8			
0.32	28			
0.34	26.3			
0.36	24.9			
0.38	23.5			
0.4	22.4			

[1]20-ft wind speed above which active crown fire can occur

[Dan, I can make this chart with NEXUS if you want]

Scorch height estimation

[content not transcribed]

Crown Fire Worksheet

[content not transcribed]

Crown Fire Nomograms

[Dan, I can make a new crown fire nomograph based on new format for the fuel models. It would be very easy to get to a crown fire rate of spread, but wouldn't necessarily include the flame length calcs (those could be included on a separate chart).]

VII. Interpretation

Interpreting Fire Behavior and predicting fire growth

Fire Characteristics Chart

The calculations displayed on the fire behavior worksheet have definite meanings and interpretations. Their meaning, however, is not always easy to understand, especially when many numbers are displayed at once. Several methods have been developed to aid interpretation and understanding of the numbers. One of these is a map of fire growth; another is the fire characteristics chart developed by Andrews and Rothermel (1982). The fire characteristics chart has the unique capability of displaying four basic fire characteristics—rate of spread, heat per unit area, flame length, and fireline intensity—as a single point on a chart. Rate of spread is plotted on the vertical axis and heat per unit area on the horizontal axis. The curved lines represent fireline intensity and flame length. It is interesting to examine the severity (fire severity is used in a general sense; no specific definition is intended) of fires on the chart. If the heat released per unit area is taken as the measure of severity, then fires that plot further to right are more severe. If rate of spread is the accepted measure of severity, then fires that plot highest on the graph are more severe. If fireline intensity or flame length is the measure (as is done in the National Fire Danger Rating System, where it is expressed as the Burning Index), then fires that plot in bands of equal flame length successively farther from the origin are more severe. In general, the farther a fire's position from the origin, the more severe it will be in terms describing the behavior of surface fires.

Many fires or projection points from a single fire can be plotted on the same chart. A quick glance will explain differences in fire behavior. Fast-spreading fires with low intensity will be near the vertical axis, illustrating the threat is due to rapid spread. High-intensity, slow-spreading fires such as might occur in old logging slash, will lie to the right near the horizontal axis. Fast-spreading fires with high intensity, such as produced by chaparral or red slash, will be in the center of the graph well away from the origin. Interpretations of fireline intensity and flame length in terms of difficulty of control and potential for severe fire behavior (Roussopoulos and Johnson 1975) are illustrated by characters and color shadings on some fire characteristics charts.

The order in which the output values are displayed by the TI-59 calculator makes it easy to use the fire characteristics chart. Rate of spread, the first output, is located on the vertical axis. Heat per unit area, the second output is located on the horizontal axis. The intersection of lines drawn into the chart from these two points gives fireline intensity and flame length, which are the next two calculator outputs. You will not be able to plot every fire behavior prediction on this graph. Some points will be beyond the scale. For those areas of the country that have fuels that tend to produce higher heat per unit area values, but lower spread rates, an alternative chart is available. The only difference between the charts is the length of the axis. If you want to have one chart that will accommodate all fires, a log-scale version is available. Note that log scales are not linear and more care must be taken when interpreting the position of the points. Fires with high intensity will show little change in position for a significant change in intensity, whereas low-intensity fires which may be very similar will scatter all over the lower left corner.

Although fires are represented by single points on the chart, it must be remembered that this is only an estimate of fire behavior and a circle would be a better representation of the uncertainty of the calculation. The more non-uniform the fuels and the more uncertainty about the weather forecast, the larger the circle should be. There is no simple way to calculate the uncertainty that is applicable for field use.

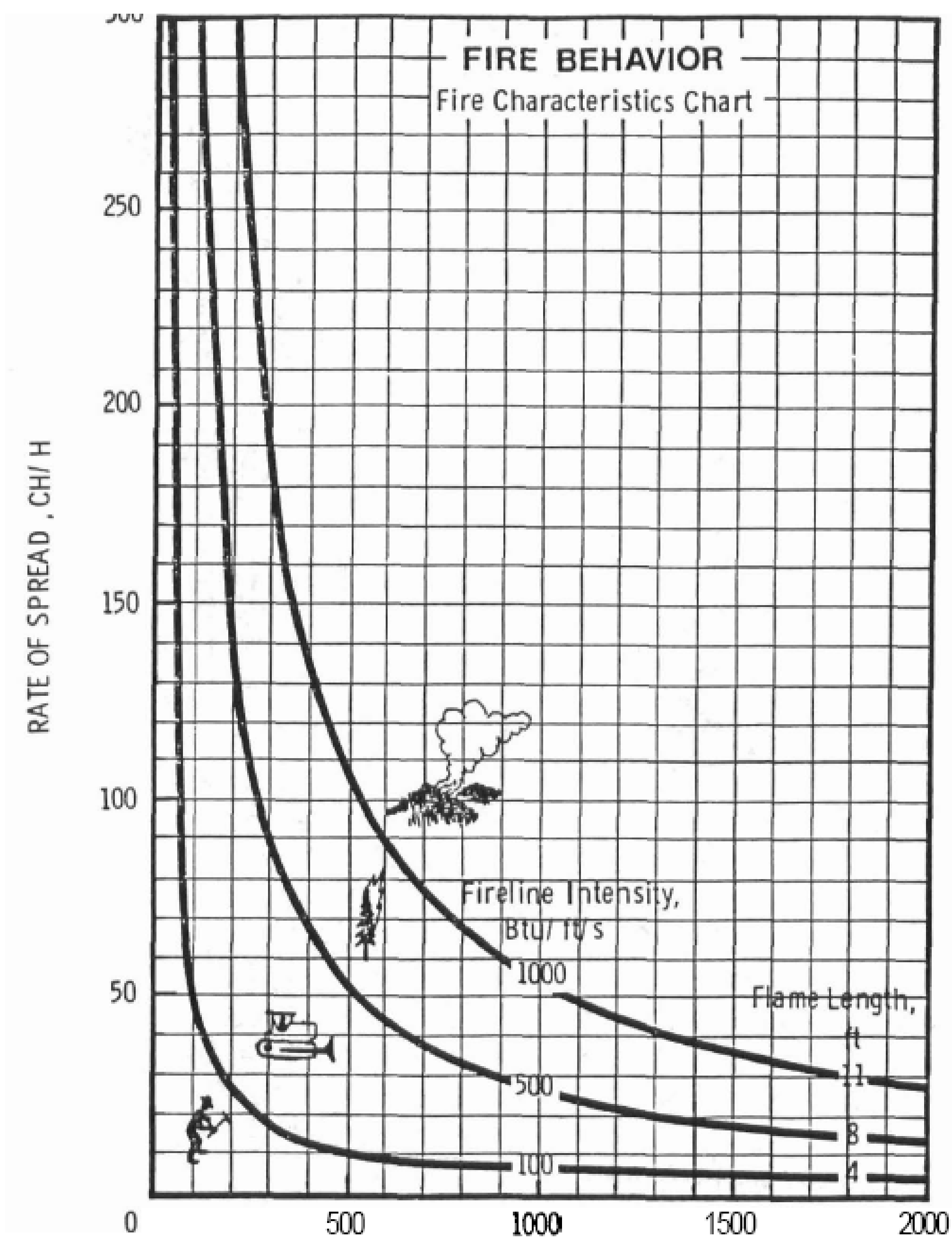
Fire suppression interpretations

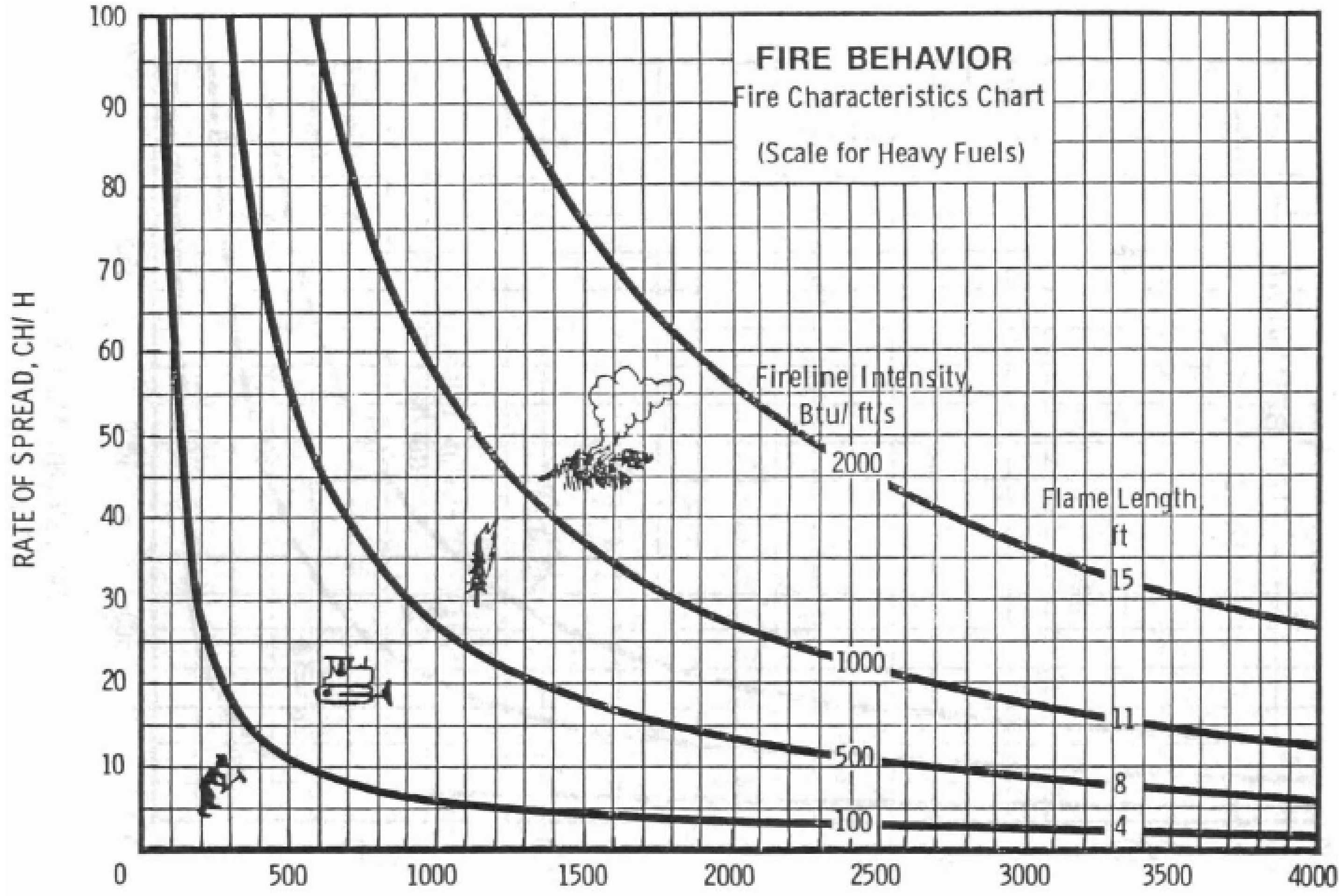
CAUTION: These are not guides to personal safety. Fires can be dangerous at any level of intensity. Wilson (1977) has shown that most fatalities occur in light fuels on small fires or isolated sectors of large fires.

Flame length (feet)	Fireline intensity (BTU/ft-s)	Interpretations
< 4	< 100	Fires can generally be attacked at the head or flanks by persons using handtools. Hand line should hold the fire.
4 – 8	100-500	Fires are too intense for direct attack on the head by persons using handtools. Hand line cannot be relied on to hold fire. Equipment such as dozers, pumpers, and retardant aircraft can be effective.
8 – 11	500-1000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
> 11	>1000	Crowning, spotting, and

		major fire runs are probable. Control efforts at head of fire are ineffective.

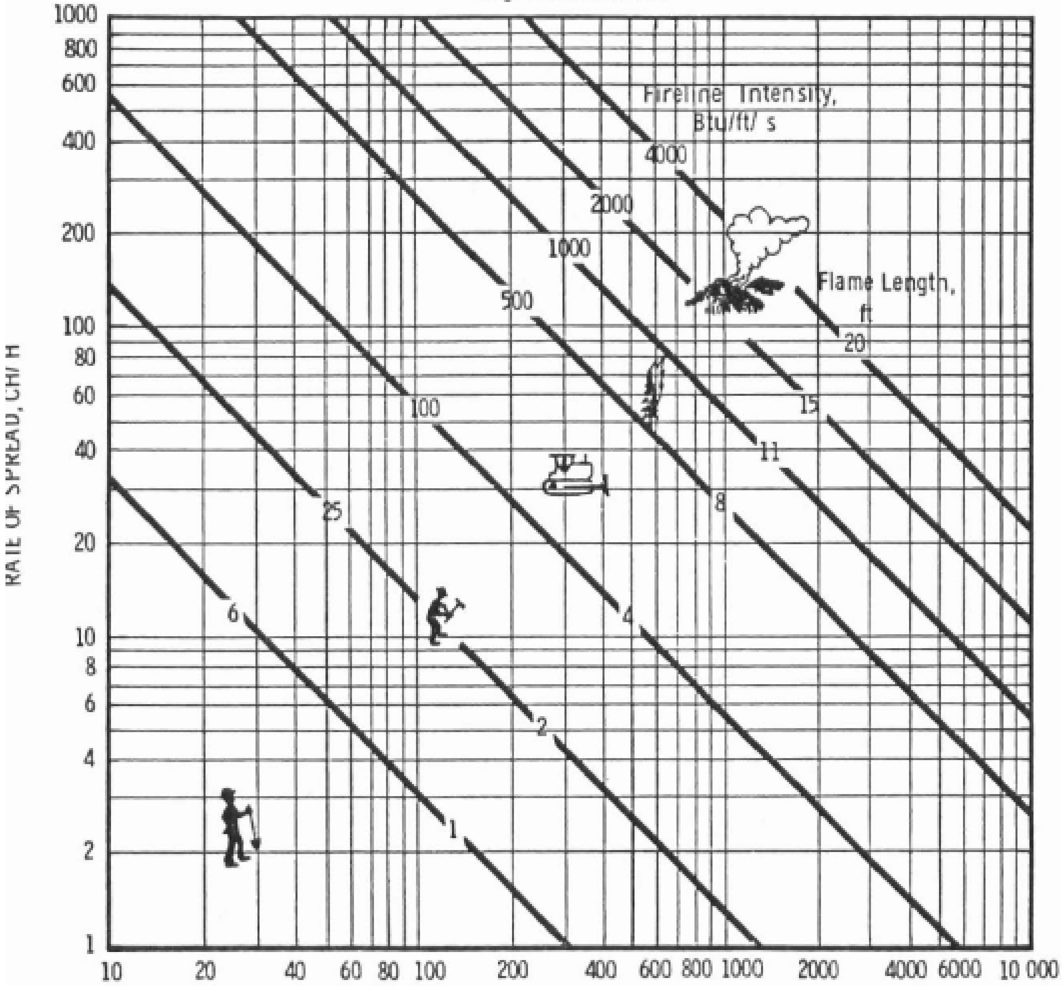
Based on: Roussopoulos, Peter J.; Johnson. Von J. Help in making fuel management decisions. Res. Pap. NC-1 12. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1975. 16 p.




FIRE BEHAVIOR
Fire Characteristics Chart
(Scale for Heavy Fuels)
Fireline Intensity,
Btu/ ft/s
2000
1000
500
100
Flame Length,
ft
15
11
8
4
RATE OF SPREAD, CH/ H
0
10
20
30
40
50
60
70
80
90
100
500
1000
1500
2000
2500
3000
3500
4000

FIRE BEHAVIOR

Fire Characteristics Chart
(Logarithmic Scale)

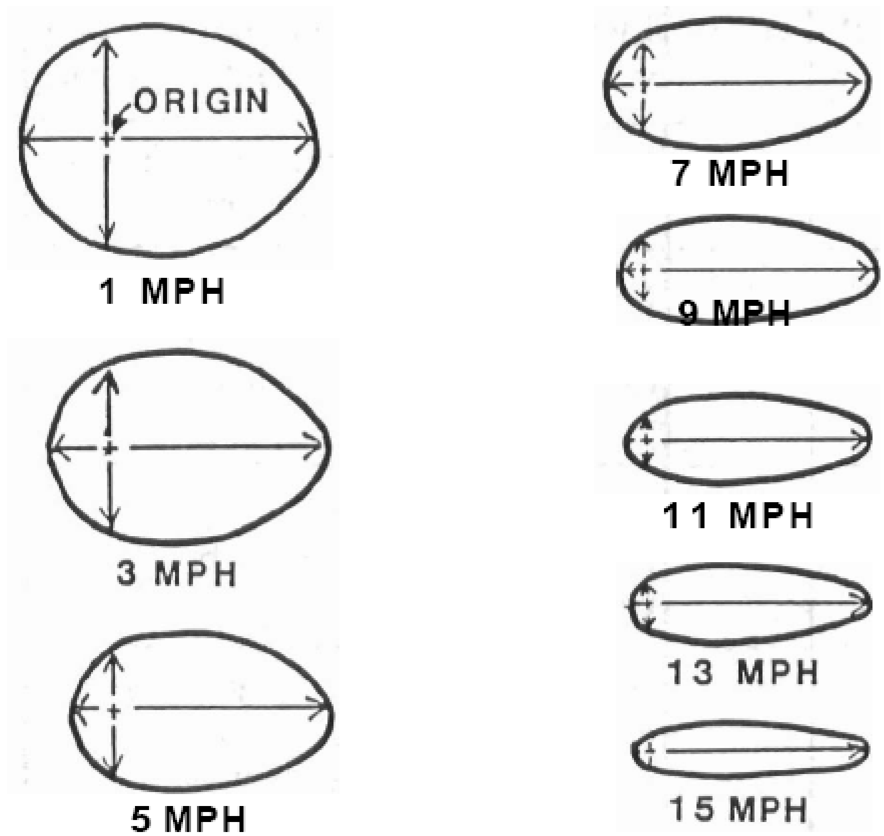


HEAT PER UNIT AREA, BTU/ FT ^{2}

Fire Severity Related to Fuel Moisture

RH (%)	1-h F.M. (%)	10-h F.M. (%)	Relative ease of chance ignition and spotting, general burning conditions.
> 60	> 20	> 15	Very little ignition; some spotting may occur with winds above 9 mi/h.
45 – 60	15 – 19	12 – 15	Low ignition hazard—campfires become dangerous; glowing brands cause ignition when RH < 50 percent.
30 – 45	11 – 14	10 – 12	Medium ignitability—matches become dangerous; "easy" burning conditions.
26 – 40	8 – 10	8 – 9	High ignition hazard—matches always dangerous; occasional crowning, spotting caused by gusty winds; "moderate" burning conditions.
15 – 30	5 – 7	5 – 7	Quick ignition, rapid buildup, extensive crowning; any increase in wind causes increased spotting, crowning, loss of control; fire moves up bark of trees igniting aerial fuels; long-distance spotting in pine stands; dangerous burning conditions.
< 15	< 5	< 5	All sources of ignition dangerous; aggressive burning, spot fires occur often and spread rapidly, extreme fire behavior probably; critical burning conditions.

Fire Shapes associated with effective wind speed



Area estimation for point-source fires (ac)

Forward Spread Dist. (ch)	Effective Midflame Wind Speed (mi/h)							
	1	3	5	7	9	11	13	15
1	0.1	0.1	0	0	0	0	0	0
2	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1
3	0.9	0.5	0.3	0.3	0.2	0.2	0.2	0.2
4	1.6	0.9	0.6	0.5	0.4	0.3	0.3	0.3
5	2.5	1.4	1	0.8	0.6	0.5	0.5	0.4
6	3.5	1.9	1.4	1.1	0.9	0.8	0.7	0.6
7	4.8	2.7	1.9	1.5	1.2	1.1	0.9	0.8
8	6.3	3.5	2.5	2	1.6	1.4	1.2	1.1
9	8	4.4	3.1	2.5	2.1	1.8	1.5	1.4
10	9.8	5.4	3.9	3.1	2.5	2.2	1.9	1.7
11	11.9	6.6	4.7	3.7	3.1	2.6	2.3	2
12	14.1	7.8	5.6	4.4	3.7	3.1	2.7	2.4
13	16.6	9.2	6.6	5.2	4.3	3.7	3.2	2.9
14	19.2	10.6	7.6	6	5	4.3	3.7	3.3
15	22.1	12.2	8.7	6.9	5.7	4.9	4.3	3.8
16	25.1	13.9	9.9	7.8	6.5	5.6	4.9	4.3
17	28.4	15.7	11.2	8.8	7.3	6.3	5.5	4.9
18	31.8	17.5	12.6	9.9	8.2	7	6.2	5.5
19	35.4	19.6	14	11.1	9.2	7.8	6.9	6.1
20	39.3	21.7	15.5	12.2	10.2	8.7	7.6	6.8
25	61.4	33.8	24.3	19.1	15.9	13.6	11.9	10.6
30	88.4	48.7	35	27.6	22.8	19.6	17.1	15.2
35	120.3	66.3	47.6	37.5	31.1	26.6	23.3	20.7
40	157.1	86.7	62.2	49	40.6	34.8	30.4	27.1
45	198.8	109.7	78.7	62	51.4	44	38.5	34.2
50	245.4	135.4	97.1	76.6	63.5	54.3	47.5	42.3
55	297	163.8	117.5	92.6	76.8	65.7	57.5	51.2
60	353.4	195	139.9	110.2	91.4	78.2	68.4	60.9
65	414.8	228.8	164.1	129.4	107.2	91.8	80.3	71.5
70	481.1	265.4	190.4	150	124.4	106.4	93.1	82.9
75	552.2	304.6	218.5	172.2	142.8	122.2	106.9	95.1
80	628.3	346.6	248.6	196	162.4	139	121.7	108.2
85	709.3	391.3	280.7	221.2	183.4	157	137.3	122.2
90	795.2	438.7	314.7	248	205.6	176	154	137
95	886	488.8	350.6	276.3	229.1	196.1	171.6	152.6
100	981.8	541.6	388.5	306.2	253.8	217.2	190.1	169.1

Perimeter estimation for point-source fires (ch)

Forward Spread Dist. (ch)	Effective Midflame Wind Speed (mi/h)							
	1	3	5	7	9	11	13	15
1	4	3	2	2	2	2	2	2
2	7	6	5	5	5	4	4	4
3	11	8	7	7	7	7	6	6
4	14	11	10	9	9	9	9	9
5	18	14	12	12	11	11	11	11
6	21	17	15	14	14	13	13	13
7	25	19	17	16	16	15	15	15
8	28	22	20	19	18	18	17	17
9	32	25	22	21	20	20	19	19
10	35	28	25	23	23	22	22	21
11	39	30	27	26	25	24	24	23
12	43	33	30	28	27	26	26	26
13	46	36	32	30	29	29	28	28
14	50	39	35	33	32	31	30	30
15	53	41	37	35	34	33	32	32
16	57	44	40	37	36	35	35	34
17	60	47	42	40	38	37	37	36
18	64	50	45	42	41	40	39	38
19	67	52	47	44	43	42	41	41
20	71	55	50	47	45	44	43	43
25	89	69	62	59	56	55	54	53
30	106	83	74	70	68	66	65	64
35	124	97	87	82	79	77	76	75
40	142	110	99	94	90	88	86	85
45	160	124	112	105	101	99	97	96
50	177	138	124	117	113	110	108	107
55	195	152	137	129	124	121	119	117
60	213	166	149	140	135	132	130	128
65	230	180	161	152	147	143	140	139
70	248	193	174	164	158	154	151	149
75	266	207	186	176	169	165	162	160
80	284	221	199	187	180	176	173	171
85	301	235	211	199	192	187	184	181
90	319	249	223	211	203	198	194	192
95	337	262	236	222	214	209	205	203
100	355	276	248	234	226	220	216	213

Area estimation for crown fires in the northern Rocky Mountains

[I tried to reproduce this table using BehavePlus but can't seem to figure out the exact assumptions used in the example. The answer is probably in Rothermel (1991).]

VIII. Fire Behavior Specialist Duties

Elements of a fire behavior forecast

HEADING INFORMATION

Forecast No.

Fire Name

Time/Date

Shift (Day or Night)

FBA (Signature)

Forest or Work Unit (Region, District, or Area)

WEATHER SUMMARY

You can summarize fire WX forecast if fire WX unit is not yet operating, or write in: "See WX forecast No. attached."

FIRE BEHAVIOR (GENERAL)

Short narrative for general fire area

FIRE BEHAVIOR (SPECIFIC)

For specific or designated parts of the fire, i.e., divisions, north side, south side, etc.

AIR OPERATIONS

Briefly discuss: smoke, turbulence, and density altitude.

SAFETY

Specify any danger areas or situations that need special emphasis.

Fire Behavior Forecast form

[not transcribed]

Contents of Planning Meeting

By Areas of Significant Difference*

I. Previous Weather (trends/normal)
II. Previous Fire Behavior
    A. Fuel
    B. Topography
    C. Weather
    D. Behavior
III. Present Fire Status
    A. Active vs. Inactive Areas
    B. How actual Fire Behavior compared with predictions and why difference, if any.
IV. Predicted Fire Behavior
    A. Fuel
    B. Topography
    C. Weather
    D. Behavior (vs. time)
        1. Intensity
        2. Rate of spread
        3. Extreme Fire Behavior (whirls, spotting, crowning)
    E. Perimeter (vs. time)
V. Strategy Implications (vs. time)
    A. Opportunities for:
        1. Method of attack (direct or indirect)
        2. Burn out/back fire
        3. Fireline location
        4. Line standards
        5. Success probability of manpower/equipment
        6. Air Operations (probability of use vs. time)
            a) Visibility (applying to transportation, men, supplies, tactical use, etc.
            b) Turbulence
VI. Safety
    A. Reburn Potential
    B. High Risk Locations
    C. High Smoke Concentrations
    D. Reinforce confidence level
    E. Air Operations

*Areas of significant difference may be an area, branch, division, or any combination of these.

Contents of Operational Period briefing

By area of significant difference*

1. What fire has done since they have been there.
2. Why it did what it did previously.
3. Weather (trends/normal)
4. Fuels
5. Topography
6. What is fire forecasted to do and when?
7. Safety
    A. Extreme Behavior Potential
        1. Signals to watch out for.
    B. Your expectations of line overhead - this includes meteorological needs, feedback, etc.

*Area of significant difference may be an area, branch, division, or any combination of these.

IX. Forms

Fire Behavior Forecast Form

[not transcribed]

Fire Weather Special Forecast Request

[not transcribed]

Fire Weather Forecast Form

[not transcribed]

Planning Meeting Outline Form

[not transcribed]

Operational Period Briefing Outline Form

[not transcribed]

X. References

National Weather Service Offices Directory

[not transcribed]