Help with using the 2005 set of standard fire behavior fuel models

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Abstract
A complete set of standard fire behavior fuel models for use with Rothermel's surface fire spread model has been developed (Scott and Burgan 2005). This report describes characteristics of the new fuel model set, its development, and its relationship to the original set of 13 fire behavior fuel models. To assist with transition to using the new fuel models, a fuel model selection guide, fuel model crosswalk, and set of fuel model photos are provided. This document also contains comprehensive fire behavior output charts to facilitate comparison of the new fuel models with the original 13. A calculation aid for comparing fuel models under a variety of environmental conditions is included. The material presented is reinforced with a workshop section, which includes answers to frequently asked questions, a quiz, and practical exercises. This document serves as a self-study aid for learning to use the new set of fuel models, or can be used as part of a training course wherever a discussion of standard fuel models is relevant.

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How to use this guide

The entire contents of RMRS GTR-153, "Standard fire behavior fuel models: A comprehensive set for use with Rothermel's surface fire spread model", is included electronically in this guide. Hyperlinks in the selection guide, crosswalks, and fuel model descriptions facilitate non-linear fuel model exploration of the material in GTR-153. In addition, this guide includes several additional features for helping readers use the new set of fuel models

- comprehensive fire behavior chart browsing system
- tool for comparing relative behavior of any fuel models
- workshop

Do not print this guide. Instead, obtain a copy of GTR-153 for a hard-copy of the fuel model documentation; use this electronic document as a study aid and exploration tool.

About this document

This electronic help file is a living document; we plan to revise and update it to correct errors and add new information as necessary. This initial release is version 1.0. Please download a current version from the FRAMES website if a later version is available.

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Introduction

Predicting the potential behavior and effects of wildland fire is an essential task in fire management. Mathematical surface fire behavior and fire effects models and prediction systems are driven in part by fuelbed inputs such as load, bulk density, fuel particle size, heat content, and moisture of extinction. To facilitate use in models and systems, fuelbed inputs have been formulated into fuel models. A fuel model is a set of fuelbed inputs needed by a particular fire behavior or fire effects model. Different kinds of fuel models are used in fire science; this document addresses only fire behavior fuel models for use in the Rothermel (1972) surface fire spread model.

Fire behavior fuel models are used as input to the Rothermel (1972) fire spread model, which is used in a variety of fire behavior modeling systems. The fire behavior fuel model input set includes:

- fuel load by category (live and dead) and particle size class (0 - 0.25 inch, 0.25 - 1.0 inch, and 1.0 - 3.0 inches diameter)
- surface-area-to-volume (SAV) ratio by component and size class
- heat content by category
- fuelbed depth
- dead fuel moisture of extinction.

The National Fire Danger Rating System (NFDRS; Deeming and others 1977) uses Rothermel's (1972) spread model as its core. However, there are differences in the calculations that require the use of different fuel models than those for fire behavior prediction. Therefore, there is a separate set of fuel models for use within NFDRS. This paper does not address NFDRS fuel models; they are not affected by this work. The fuel models described here should not be used in the NFDRS.

Rothermel (1972) defined a fire behavior fuel model as a "complete set of [fuel] inputs for the mathematical fire spread model", and listed parameters for 11 fuel models. To assist in understanding the sensitivity of certain inputs, Rothermel held constant the fuel particle properties (total and effective mineral content, heat content, and particle density). Extinction moisture content was not listed for each fuel model separately, but instead held at 30 percent for all models. Thus, variation in predicted spread rate among models could be attributed to fuel load by size class, fuelbed depth, and fuel particle size. Parameters for 10- and 100- hr SAV were listed for each fuel model, but did not vary among models – 109 1/ft and 30 1/ft respectively.

Albini (1976) refined those 11 fuel models and added two others, Dormant Brush (6) and Southern Rough (7). His tabulated set became what is now called the original 13 fire behavior fuel models. Whereas extinction moisture content was held constant for Rothermel's 11 fuel models, Albini's fuel models specified this value for each fuel model. Albini noted that "other variables needed to complete the [fuel] descriptions are held constant for the entire set."

Anderson (1982) described the 13 fuel models listed by Albini and provided aids to selecting a fuel model. Fuel model parameters did not change from Albini's set. Anderson listed as model parameters only fuel load by size class, fuelbed depth, and dead fuel extinction moisture.

The BEHAVE fire behavior prediction and fuel modeling system (Burgan and Rothermel 1984, Andrews 1986) included fuel particle heat content as a fuel model parameter that could vary from model to model, whereas previous work had left that parameter constant. FARSITE (Finney 1998) and BehavePlus (Andrews and others 2003) allow the user to specify separate live and dead heat content values. The ability to specify heat content is primarily for greater precision when building a custom fuel model; the original 13 fuel models still used a single value of 8000 BTU/lb for live and dead heat content for all fuel models.

Although a fuel model technically includes all fuel inputs to the Rothermel surface fire spread model, several fuel inputs have never been subject to control by a user when creating a custom fuel model: total and effective mineral contents, and fuel particle density. The 10- and 100-hr SAVs were listed as model parameters for the original 13 fuel models, but are generally not subject to control of the user when making custom fuel models in fire modeling systems. For the above reasons, we did not consider using values for fuel particle properties or 10- and 100-hr SAVs other than the constant values originally published by Rothermel (1972). We list as parameters only those fuel model inputs that vary among models:

- Fuel load by size class and category
- Live woody, live herbaceous, and dead 1-hr SAV
- Fuelbed depth
- Dead fuel extinction moisture content
- Heat content of live and dead fuels

For all fuel models in this new set, 10-hr dead fuel SAV is 109 1/ft, and 100-hr SAV is 30 1/ft. Total mineral content is 5.55 percent; effective (silica-free) mineral content is 1.00 percent. Ovendry fuel particle density is 32 lb/ft3.

Need

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 overprediction.

- 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 wide variety of available fuel treatment options.

Scope

The development of a new set of standard fire behavior fuel models does not address deficiencies in the Rothermel surface fire spread model itself. Like the original set of 13, the new fire behavior fuel model set is applicable to fire modeling systems that use Rothermel's surface fire spread model. Any description of the presence or absence of overstory trees is due to their potential effect on surface fuels (for example, needle litter in a grass fuel model).

Also like the original fuel models, the new set is for simulating surface fire behavior at the flaming front only, not residual combustion that takes place after the flaming front has passed. Other methods of describing fuel and other types of fuel models are used for prediction of post-frontal combustion, fuel consumption, smoke production and crown fire behavior. The fuel model parameters presented in this set should not be used as fuelbed characteristics for fuel consumption models.

Finally, the same fuelbed assumptions of homogeneity and continuity apply to these as well as the original 13 fuel models (Rothermel 1972). Methods of addressing heterogeneous or discontinuous fuels are available in fire modeling systems.

Development

We compiled fuel complex information from the Natural Fuels Photo Series (Ottmar and Vihnanek 1998, 1999, 2000, 2002; Ottmar and others 1998, 2000, 2002, 2003; Wright and others 2003) and other sources. The range of fuel complex characteristics suggested the range of fuel conditions for which fuel models were needed. We subjectively assigned a fire-carrying fuel type and dead fuel extinction moisture content to each fuel complex, then grouped the complexes by fine fuel load, fuel type, and extinction moisture. We created one fuel model for each of the approximately 60 groups. Surface-area-to-volume ratio for 1-hr timelag, live herbaceous and live woody classes were assigned subjectively for each draft fuel model. Fuelbed depth was assigned after subjective interpretation of fuel complex data and visual inspection of photographs. Heat content of live and dead fuels is 8000 BTU/lb for all fuel models except GR6 (High Load, Humid Climate Grass), which is 9000 BTU/lb for both live and dead fuels.

Next, we made fire behavior simulations over a range of midflame wind speeds and several fuel moisture scenarios. Although the groups of fuel complexes appeared to be distinct from one another, the fuel models we created from them often led to similar flame length and rate of spread, so several models were eliminated. Also, after comparing fire behavior outputs from the draft fuel model set with outputs from the original 13 fuel models, we added stylized fuel models to simulate specific fire behavior characteristics not simulated by any of the draft models. Finally, we adjusted the parameters of many draft fuel models to better coordinate fire behavior outputs of related fuel models.

The draft fuel model set was sent to more than three dozen fire science researchers and managers for review; their comments were incorporated into the final fuel model set and its documentation, which was reviewed again by a smaller cadre.

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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 nondynamic fire behavior processor, that approach does not produce the intended result. Using the dynamic fuel models in a nondynamic 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

To facilitate both communication and computation, we use a three-part fuel model reference scheme:

- fuel model number (between 1 and 256; for use in computer code and mapping applications)
- fuel model code (3-digits; used for oral and written communication and input to fire modeling systems)
- fuel model name (any-length string of characters; used for description and long-hand written communication)

For example,

number	**code**	**name**
101	GR1	Short, sparse, dry climate grass

Within a fuel type, fuel models are ordered by increasing heat per unit area (at 8% dead, 75% 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 applications.

Each fuel type has been assigned a block of fuel model numbers (Table 1) so that fuel model maps colored by fuel type are simple to create. For example, a coarse-scale map for which identifying a specific fuel model is not required can be colored such that all fuel model numbers in a block are the same color. Only a portion of each block is used by the new fuel model set. The unused fuel model numbers are reserved for future standard fuel models and for custom fuel models. This allows future standard and custom fuel models to be in the correct fuel type number block.

Table 1 -- assignment of current fuel model numbers to standard and custom fuel models.

fuel type	fuel model number block	used in original or new set	reserved for future standard fuel models	available for custom fuel models
	1-13	1-13		
	14-89			14-89
NB	90-99	91-93, 98-99[a]	94-95	90, 96-97
GR	100-119	101-109	110-112	100, 113-119
GS	120-139	121-124	125-130	120, 131-139
SH	140-159	141-149	150-152	140, 153-159
TU	160-179	161-165	166-170	160, 171-179
TL	180-199	181-189	190-192	180, 193-199
SB	200-219	201-204	205-210	200, 211-219
	220-256			220-256

a The gap in the NB numbering sequence is to retain fuel model numbers 98 as open water and 99 as "rock" (bare ground), as has been convention in FARSITE.

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.

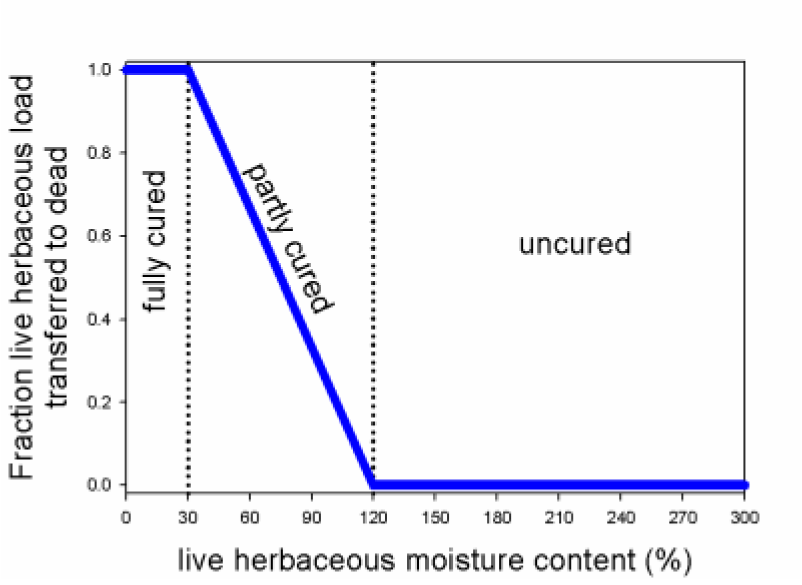
Dynamic Fuel Models

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. In the "Fuel Models" section, refer to 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) and outlined and illustrated below, with graphic presentation in figure 1.

- 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.

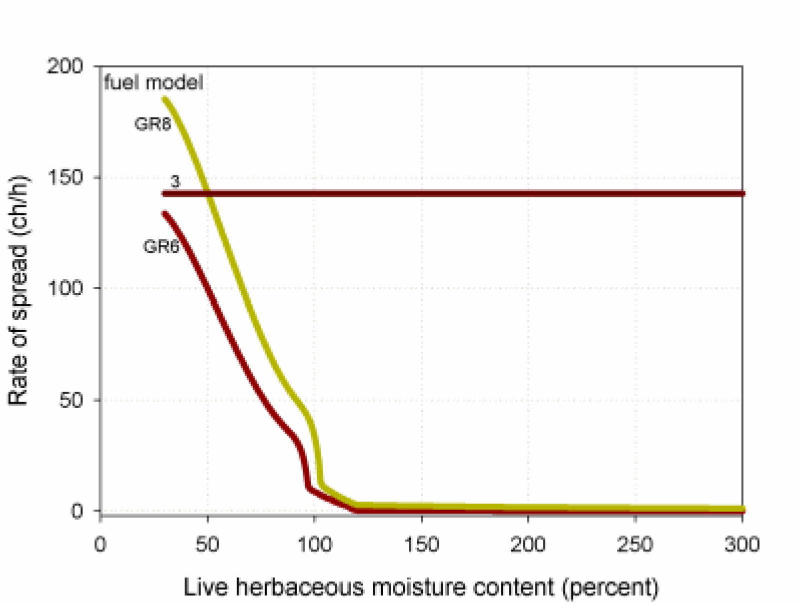
When evaluating dynamic models, be aware that live herbaceous moisture content significantly affects fire behavior because herbaceous load shifts between live and dead, and dead fuel usually has a much lower moisture content than live. It will often be preferable to estimate live herbaceous moisture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

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

level of curing		live herbaceous moisture content
uncured	0%	120% 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.

Moisture Scenarios

To facilitate standard comparisons of the new fire behavior fuel models with the original 13 fuel models and with each other, we developed standard dead (table 3) and live (table 4) fuel moisture scenarios. Separate live and dead scenarios were needed so that live and dead fuels could vary independently. There are 16 unique moisture scenario combinations. However, fire behavior predicted with fuel models without a live fuel component is not affected by the live moisture scenario. Live moisture scenarios cover a range of live herbaceous moisture corresponding to fully cured (30 percent) to uncured (fully green; 120 percent).

Table 3 -- Dead fuel moisture content values (percent) for the dead fuel moisture scenarios.

	D1 **Very low**	D2 **Low**	D3 **Moderate**	D4 **High**
1-hr	3	6	9	12
10-hr	4	7	10	13
100-hr	5	8	11	14

Table 4 -- Live fuel moisture content values (percent) for the live fuel moisture scenarios.

	L1 fully cured **Very low**	L2 two-thirds cured **Low**	L3 one-third cured **Moderate**	L4 fully green (uncured) **High**
live herbaceous	30	60	90	120
live woody	60	90	120	150

Fuel Model Selection

This document contains two aids to fuel model selection: a fuel model selection guide and a set of crosswalks. Use the crosswalks if you have areas already designated as one of the 13 original fuel models and you want guidance on selecting one of the new models for those areas. Use the fuel model selection guide for assistance in selecting a fuel model from knowledge of general fuelbed properties.

Both the selection guide and crosswalks offer suggestions to consider, not conclusive results. The final fuel model selection must be made by the user based on experience with fire behavior in the fuelbed under consideration.

Use the Fuel Model Selection Guide
Use the Fuel Model Crosswalks

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Fuel Model Selection Guide

To select 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, follow a link to its description and associated fire behavior comparison charts 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 6 -- 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

click here to enter the fuel model selection guide

Fuel Model Crosswalks

These crosswalks will help users of the original 13 fuel models make the transition to using the new set. For each of the 13 original fuel models we suggest one or more fuel models from the new set to consider. However, you are not limited to these choices; always use the fuel model that provides the best fit for fire behavior prediction.

The crosswalks use adjective classes to compare spread rate and flame length between the original fuel models and their related models from the new set.

Note: we computed the relative change in fire behavior between original and new models using 5 mi/h midflame wind speed, low dead fuel moisture, two-thirds cured herbaceous fuels, and low live woody fuels (moisture scenario D2L2). Relative change among fuel models might be different for different environmental conditions; use these crosswalks as a guide only.

Table 6 -- Adjective class definitions for fire behavior comparisons.

Adjective Class	Relative change in fire behavior (percent change from original model)
Comparable	0-15
Slightly higher/lower	15-50
Higher/lower	50-100
Much higher/lower	100-200
Significantly higher/lower	200+

There is a crosswalk for each major fuel type of the original 13 models:

- grass
- shrub
- timber
- slash

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Grass fuel type

Consider using one of these fuel models from the new set...	... if you used one of these models from the original set.		
	1 short grass	2 timber grass and understory	3 tall grass
GR1	For very sparse or heavily grazed grass; for lower spread rate and flame length		
GR2	For slightly lower spread rate and comparable flame length	For comparable spread rate and slightly lower flame length	
GR3			For lower spread rate and slightly lower flame length
GR4	For slightly lower spread rate and much higher flame length	For higher spread rate and slightly higher flame length	
GR5			For lower spread rate and slightly lower flame length
GR6			For slightly lower spread rate and comparable flame length
GR7	For comparable spread rate and significantly higher flame length	For much higher spread rate and flame length	For comparable spread rate and slightly higher flame length
GR8			For comparable spread rate and higher flame length
GR9			For higher spread rate and much higher flame length
GS1		For slightly lower spread rate and lower flame length	
GS2		For slightly lower spread rate and flame length	

note: all grass fuel models from the new set are dynamic fuel models, which means that herbaceous load is transferred between live and dead categories according to live herbaceous moisture content. Original models 1 and 3 have only a dead component. Original fuel model 2 has a live herbaceous component but is static. Exact fire behavior comparisons between original and new grass models can only be made when live herbaceous moisture content is 30 percent or less. These comparisons were made with a live herbaceous moisture content of 60 percent (two-thirds cured).

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Shrub fuel type

Consider using one of these fuel models from the new set...	... if you used one of these models from t		
	4 Chaparral	5 brush	
SH1		For lower spread rate and flame length	For lower sp
SH2		For lower spread rate and slightly lower flame length	For lower s
SH3			
SH4			For sligh com
SH5	For slightly lower spread rate and flame length	For much higher spread rate and flame length	
SH6			For slightly l
SH7	For slightly lower spread rate and flame length	For slightly higher spread rate and much higher flame length	
SH8			
SH9			
TU5		For lower spread rate and slightly higher flame length	
GS2		For comparable spread rate and slightly lower flame length; with grass component	

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Timber fuel type

Consider using one of these fuel models from the new set...	... if you used one of these models from the original set.		
	8 Compact Timber Litter	9 Hardwood Litter	10 Timber (understory)
TL1	For lower spread rate and slightly lower flame length		
TL2		for lower spread rate and flame length	
TL3	For comparable spread rate and flame length		
TL4	For slightly higher spread rate and flame length		
TL5	For much higher spread rate and higher flame length		
TL6		For slightly lower spread rate and comparable flame length	
TL7	For slightly higher spread rate and higher flame length		
TL8		For slightly lower spread rate and slightly higher flame length	
TL9		For comparable spread rate and higher flame length	
TU1	For higher spread rate and flame length		For lower spread rate and flame length
TU2			For slightly higher spread rate and slightly lower flame length; high extinction moisture
TU3			For much higher spread rate and slightly higher flame length; high extinction moisture
TU4			For slightly higher spread rate and comparable flame length
TU5			For comparable spread rate and slightly higher flame length
SH2			For lower spread rate and flame length

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Slash fuel type

Consider using one of these fuel models from the new set...	... if you used one of these models from the original set.		
	11 Light Logging Slash	12 Medium Logging Slash	13 Heavy Logging Slash
TL5	For slightly lower spread rate and flame length		
SB1	For comparable spread rate and flame length	For lower spread rate and flame length	
SB2	For much higher spread rate and higher flame length	For comparable spread rate and slightly lower flame length	For comparable spread rate and slightly lower flame length
SB3		For much higher spread rate and comparable flame length	For higher spread rate and comparable flame length
SB4			For significantly higher spread rate and slightly higher flame length

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Fuel models

In this section we list the fuel models and their parameters, and describe each fuel model and fuel type. Two types of pages are used to describe the models: a fuel type page and a fuel model page.

Fuel Type Page
A fuel type page consists of a brief description of the fuel type followed by a link to charts depicting predicted spread rate and flame length over a range of midflame wind speeds.
Use the fuel type charts to compare the relative behavior of the various models within a fuel type, including one or two of the original 13 fuel models for comparison.

Fuel Model Page
A fuel model page consists of:

- The three-part naming convention
- A pair of photos
- A brief description of the fuel model
- A summary of computed fuel model characteristics
- A link to charts depicting spread rate and flame length over a range of midflame wind speeds

Naming -- The fuel model code and number (in parentheses) are displayed on the first line, followed on the next line by the full fuel model name.

Photos -- Two primary photos were selected to illustrate each fuel model. Click on the thumbnail to view a larger image.

Description -- Main characteristics of each fuel model are briefly described.

Summary characteristics -- Summary characteristics of each fuel model include fine fuel load, characteristic SAV, packing ratio, and extinction moisture content.

Fine fuel load is defined as the dead 1-hr load plus the live herbaceous and live woody loads. Across this new set of 40 fuel models, fine fuel load ranges from 0.30 to 13.05 tome/ac.

Characteristic SAV is the average SAV across all fuel classes and categories, weighted by the fuel surface area within each class and category. Characteristic SAV ranges from 1144 to 2216 1/ft in this new set of fuel models.

Packing ratio is the fraction of the fuelbed volume that is occupied by fuel particles, a function of fuel load, fuelbed depth, and fuel particle density. In this fuel model set, packing ratio varies from 0.00143 to 0.04878 (dimensionless).

Extinction moisture content is the weighted average dead fuel moisture content at which the fire spread model predicts spread will not take place. More important, the amount by which the extinction moisture content exceeds the actual moisture content determines (in part) fire behavior. Thus, for a given dead fuel moisture content, predicted fire spread increases with increasing extinction moisture content.

Fire Behavior Charts -- The fuel model page includes a link to a set of charts depicting spread rate and flame length for each fuel model under a range of fuel moistures and wind speeds. Use the navigation buttons to change among fuel models, between spread rate and flame length, and to view results for different live fuel moisture scenarios.

Fuel model parameters

Parameters of the new fuel models include load by class and component, surface-area-to-volume (SAV) ratio by class and component, fuel model type (static or dynamic), fuelbed depth, extinction moisture content, and fuel particle heat content (table 7). Parameters not listed are constant for the entire set: 10-hr dead fuel SAV is 109 1/ft, and 100-hr SAV is 30 1/ft. Total mineral content is 5.55 percent; effective (silica-free) mineral content is 1.00 percent. Ovendry fuel particle density is 32 lb/ft3.

Table 7 -- Fuel model parameters

fuel model code	1-h	10-h	100-h	herb	woody	fuel model type[a]	dead 1-h	live herb	live woody	fuel bed depth (ft)	ext. mois. cont. (pct)	heat cont. (BTU/lb)[c]
	----- fuel load (t/ac) ----						--SAV ratio (1/ft)[b]--					
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 to 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.

Fuel model list

Grass

GR1 Short, sparse dry climate grass
GR2 Low load, dry climate grass
GR3 Low load, very coarse, humid climate grass
GR4 Moderate load, dry climate grass
GR5 Low load, humid climate grass
GR6 Moderate load, humid climate grass
GR7 High load, dry climate grass
GR8 High load, very coarse, humid climate grass
GR9 Very high load, humid climate grass

Grass-shrub

GS1 Low load, dry climate grass-shrub
GS2 Moderate load, dry climate grass-shrub
GS3 Moderate load, humid climate grass-shrub
GS4 High load, humid climate grass-shrub

Shrub

SH1 Low load, dry climate shrub
SH2 Moderate load, dry climate shrub
SH3 Moderate load, humid climate shrub
SH4 Low load, humid climate timber-shrub
SH5 High load, dry climate shrub
SH6 Low load, humid climate shrub
SH7 Very high load, dry climate shrub
SH8 High load, humid climate shrub
SH9 Very high load, humid climate shrub

Timber-understory

TU1 Low load, dry climate timber-grass-shrub
TU2 Moderate load, humid climate timber-shrub
TU3 Moderate load, humid climate timber-grass-shrub
TU4 Dwarf conifer with moss
TU5 Very high load, dry climate timber-shrub

Timber litter

TL1 Low load, compact conifer litter
TL2 Low load, broadleaf litter
TL3 Moderate load, conifer litter
TL4 Small downed logs
TL5 High load, conifer litter
TL6 High load, broadleaf litter
TL7 Large downed logs
TL8 Long-needle litter
TL9 Very high load, broadleaf litter

Slash-blowdown

SB1 Low load activity fuel
SB2 Moderate load slash or low load blowdown
SB3 High load slash or moderate load blowdown
SB4 High load blowdown

Non-burnable

NB1 urban/developed
NB2 snow/ice
NB3 agriculture
NB8 water
NB9 bare ground

Non-burnable fuel type models (NB)

Description:
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. Select an NB model from the "Choose model" button below to view the 5 different choices for non-burnable fuel models. The gap in the NB numbering sequence is to retain fuel model numbers 98 as open water and 99 as "rock", as has been convention in the FARSITE system.

Expected fire behavior:
no fire spread

NB1 (91)

urban/developed

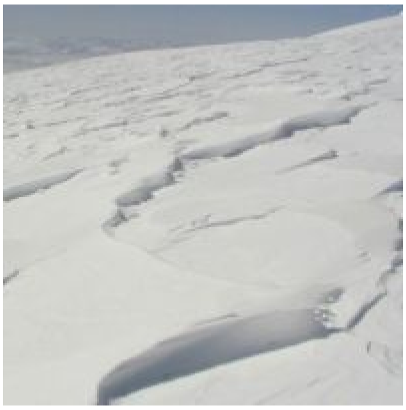
 

Description:
Fuel model NB1 consists of land covered by urban and suburban development. To be called NB1, the area under consideration must not support wildland fire spread. In some cases, areas mapped as NB1 may experience structural fire losses during a wildland fire incident; however, structure ignition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

Expected fire behavior:
no fire spread
version 1.0 (September 2005)

NB2 (92)

snow/ice



Description:
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.

Expected fire behavior:
no fire spread
version 1.0 (September 2005)

NB3 (93)

agricultural


Description:
Fuel model NB3 is agricultural land maintained in a non-burnable condition; examples include irrigated annual crops, mowed or tilled orchards, etc. 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.

Expected fire behavior:
no fire spread
version 1.0 (September 2005)

NB8 (98)

open water

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

Expected fire behavior:
no fire spread
version 1.0 (September 2005)

NB9 (99)

bare ground


Description:
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.

Expected fire behavior:
no fire spread
version 1.0 (September 2005)

Grass fuel type models (GR)

Description:
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. See the dynamic fuel models topic for more information.

Expected fire behavior:
Compare GR1-GR5 with others
Compare GR6-GR9 with others

GR1 (101)

Short, sparse dry climate grass (dynamic)

Description:
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 very low (compared to other GR fuel models).

Expected fire behavior:
GR1 fire behavior details
Compare GR1 with similar fuel models

Fine fuel load (t/ac)	0.40
Characteristic SAV (1/ft)	2054
Packing ratio (dimensionless)	0.00143
Extinction moisture content (percent)	15

version 1.0 (September 2005)

GR2 (102)

Low load, dry climate grass (dynamic)

Description:
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.

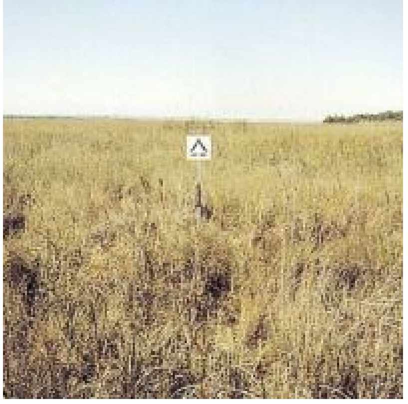
Expected fire behavior:
GR2 fire behavior details
Compare GR2 with similar fuel models

Fine fuel load (t/ac)	1.10
Characteristic SAV (1/ft)	1820
Packing ratio (dimensionless)	0.00158
Extinction moisture content (percent)	15

version 1.0 (September 2005)

GR3 (103)

Low load, very coarse, humid climate grass (dynamic)



Description:
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.

Expected fire behavior:
GR3 fire behavior details
Compare GR3 with similar fuel models

Fine fuel load (t/ac)	1.60
Characteristic SAV (1/ft)	1290
Packing ratio (dimensionless)	0.00143
Extinction moisture content (percent)	30

version 1.0 (September 2005)

GR4 (104)

Moderate load, dry climate grass (dynamic)

Description:
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.

Expected fire behavior:
GR4 fire behavior details
Compare GR4 with other similar fuel models

Fine fuel load (t/ac)	2.15
Characteristic SAV (1/ft)	1826
Packing ratio (dimensionless)	0.00154
Extinction moisture content (percent)	15

version 1.0 (September 2005)

GR5 (105)

Low load, humid climate grass (dynamic)

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

Expected fire behavior:
GR5 fire behavior details
Compare GR5 with other similar fuel models

Fine fuel load (t/ac)	2.9
Characteristic SAV (1/ft)	1631
Packing ratio (dimensionless)	0.00277
Extinction moisture content (percent)	40

version 1.0 (September 2005)

GR6 (106)

Moderate load, humid climate grass (dynamic)

Description:
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.

Expected fire behavior:
GR6 fire behavior details
Compare GR6 with other similar fuel models

Fine fuel load (t/ac)	3.5
Characteristic SAV (1/ft)	2006
Packing ratio (dimensionless)	0.00335
Extinction moisture content (percent)	40

version 1.0 (September 2005)

GR7 (107)

High load, dry climate grass (dynamic)

Description:
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.

Expected fire behavior:
GR7 fire behavior details
Compare GR7 with other similar fuel models

Fine fuel load (t/ac)	6.4
Characteristic SAV (1/ft)	1834
Packing ratio (dimensionless)	0.00306
Extinction moisture content (percent)	15

version 1.0 (September 2005)

GR8 (108)

High load, very coarse, humid climate grass (dynamic)

Description:
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.

Expected fire behavior:
GR8 fire behavior details
Compare GR8 with other similar fuel models

Fine fuel load (t/ac)	7.8
Characteristic SAV (1/ft)	1302
Packing ratio (dimensionless)	0.00316
Extinction moisture content (percent)	30

version 1.0 (September 2005)

GR9 (109)

Very high load, humid climate grass (dynamic)

Description:
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.

Expected fire behavior:
GR9 fire behavior details
Compare GR9 with other similar fuel models

Fine fuel load (t/ac)	10.0
Characteristic SAV (1/ft)	1612
Packing ratio (dimensionless)	0.00316
Extinction moisture content (percent)	40

version 1.0 (September 2005)

Grass-shrub fuel type models (GS)

Description:
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. See the dynamic fuel models topic for more information.

Expected fire behavior:
Compare GS1-4 with others

GS1 (121)

Low load, dry climate grass-shrub (dynamic)

Description:
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 high; flame length moderate. Moisture of extinction is low.

Expected fire behavior:
[GS1 fire behavior details]
[Compare GS1 with other similar fuel models]

Fine fuel load (t/ac)	1.35
Characteristic SAV (1/ft)	1832
Packing ratio (dimensionless)	0.00215
Extinction moisture content (percent)	15

version 1.0 (September 2005)

GS2 (122)

Moderate load, dry climate grass-shrub (dynamic)

Description:
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.

Expected fire behavior:
GS2 fire behavior details
Compare GS2 with other similar fuel models

Fine fuel load (t/ac)	2.1
Characteristic SAV (1/ft)	1827
Packing ratio (dimensionless)	0.00249
Extinction moisture content (percent)	15

version 1.0 (September 2005)

GS3 (123)

Moderate load, humid climate grass-shrub (dynamic)

Description:
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 very high; flame length high. Moisture of extinction is high.

Expected fire behavior:
GS3 fire behavior details
Compare GS3 with other similar fuel models

Fine fuel load (t/ac)	3.0
Characteristic SAV (1/ft)	1614
Packing ratio (dimensionless)	0.00259
Extinction moisture content (percent)	40

version 1.0 (September 2005)

GS4 (124)

High load, humid climate grass-shrub (dynamic)

Description:
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.

Expected fire behavior:
GS4 fire behavior details
Compare GS4 with other similar fuel models

Fine fuel load (t/ac)	12.4
Characteristic SAV (1/ft)	1674
Packing ratio (dimensionless)	0.00874
Extinction moisture content (percent)	40

version 1.0 (September 2005)

Shrub fuel type models (SH)

Description:
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. See the dynamic fuel models topic for more information.

Expected fire behavior:
Compare SH1-SH5 with others
Compare SH6-SH9 with others

SH1 (141)

low load dry climate shrub (dynamic)

Description:
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 high; flame length moderate.

Expected fire behavior:
SH1 fire behavior details
Compare SH1 with other similar fuel models

Fine fuel load (t/ac)	1.7
Characteristic SAV (1/ft)	1674
Packing ratio (dimensionless)	0.00280
Extinction moisture content (percent)	15

version 1.0 (September 2005)

SH2 (142)

moderate load dry climate shrub

Description:
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 moderate; flame length moderate.

Expected fire behavior:
SH2 fire behavior details
Compare SH2 with other similar fuel models

Fine fuel load (t/ac)	5.2
Characteristic SAV (1/ft)	1672
Packing ratio (dimensionless)	0.01198
Extinction moisture content (percent)	15

version 1.0 (September 2005)

SH3 (143)

moderate load humid climate shrub

Description:
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 moderate; flame length low.

Expected fire behavior:
SH3 fire behavior details
Compare SH3 with other similar fuel models

Fine fuel load (t/ac)	6.65
Characteristic SAV (1/ft)	1371
Packing ratio (dimensionless)	0.00577
Extinction moisture content (percent)	40

version 1.0 (September 2005)

SH4 (144)

low load humid climate timber-shrub

Description:
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 high.

Expected fire behavior:
SH4 fire behavior details
Compare SH4 with other similar fuel models

Fine fuel load (t/ac)	3.4
Characteristic SAV (1/ft)	1682
Packing ratio (dimensionless)	0.00277
Extinction moisture content (percent)	30

version 1.0 (September 2005)

SH5 (145)

high load dry climate shrub

Description:
The primary carrier of fire in SH5 is woody shrubs and shrub litter. Heavy shrub load, depth 4-6 feet. Spread rate is very high; flame length very high.

Expected fire behavior:
SH5 fire behavior details
Compare SH5 with other similar fuel models

Fine fuel load (t/ac)	6.5
Characteristic SAV (1/ft)	1252
Packing ratio (dimensionless)	0.00206
Extinction moisture content (percent)	15

version 1.0 (September 2005)

SH6 (146)

low load humid climate shrub

Description:
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.

Expected fire behavior:
SH6 fire behavior details
Compare SH6 with other similar fuel models

Fine fuel load (t/ac)	4.3
Characteristic SAV (1/ft)	1144
Packing ratio (dimensionless)	0.00412
Extinction moisture content (percent)	30

version 1.0 (September 2005)

SH7 (147)

very high load dry climate shrub


Description:
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 SH5, but flame length similar. Spread rate is very high; flame length very high.

Expected fire behavior:
SH7 fire behavior details
Compare SH7 with other similar fuel models

Fine fuel load (t/ac)	6.9
Characteristic SAV (1/ft)	1233
Packing ratio (dimensionless)	0.00344
Extinction moisture content (percent)	15

version 1.0 (September 2005)

SH8 (148)

high load humid climate shrub

Description:
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 very high.

Expected fire behavior:
SH8 fire behavior details
Compare SH8 with other similar fuel models

Fine fuel load (t/ac)	6.4
Characteristic SAV (1/ft)	1386
Packing ratio (dimensionless)	0.00509
Extinction moisture content (percent)	40

version 1.0 (September 2005)

SH9 (149)

very high load humid climate shrub (dynamic)


Description:
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 very high, flame length very high.

Expected fire behavior:
SH9 fire behavior details
Compare SH9 with other similar fuel models

Fine fuel load (t/ac)	13.05
Characteristic SAV (1/ft)	1378
Packing ratio (dimensionless)	0.00505
Extinction moisture content (percent)	40

version 1.0 (September 2005)

Timber-understory fuel type models (TU)

Description:
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. See the dynamic fuel models topic for more information.

Expected fire behavior:
Compare TU1-TU5 with others

TU1 (161)

Low load dry climate timber-grass-shrub

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

Expected fire behavior:
TU1 fire behavior details
Compare TU1 with other similar fuel models

Fine fuel load (t/ac)	1.3
Characteristic SAV (1/ft)	1606
Packing ratio (dimensionless)	0.00885
Extinction moisture content (percent)	20

version 1.0 (September 2005)

TU2 (162)

Moderate load humid climate timber-shrub

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

Expected fire behavior:
TU2 fire behavior details
Compare TU2 with other similar fuel models

Fine fuel load (t/ac)	1.15
Characteristic SAV (1/ft)	1767
Packing ratio (dimensionless)	0.00603
Extinction moisture content (percent)	30

version 1.0 (September 2005)

TU3 (163)

Moderate load humid climate timber-grass-shrub

Description:
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 high.

Expected fire behavior:
TU3 fire behavior details
Compare TU3 with other similar fuel models

Fine fuel load (t/ac)	2.85
Characteristic SAV (1/ft)	1611
Packing ratio (dimensionless)	0.00359
Extinction moisture content (percent)	30

version 1.0 (September 2005)

TU4 (164)

Dwarf conifer with understory

Description:
The primary carrier of fire in TU4 is short conifer trees with grass or moss understory (note). Spread rate is moderate; flame length moderate.

Expected fire behavior:
TU4 fire behavior details
Compare TU4 with other similar fuel models

Fine fuel load (t/ac)	6.5
Characteristic SAV (1/ft)	2216
Packing ratio (dimensionless)	0.01865
Extinction moisture content (percent)	12

version 1.0 (September 2005)

TU5 (165)

Very high load dry climate timber-shrub

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

Expected fire behavior:
TU5 fire behavior details
Compare TU5 with other similar fuel models

Fine fuel load (t/ac)	7.0
Characteristic SAV (1/ft)	1224
Packing ratio (dimensionless)	0.02009
Extinction moisture content (percent)	25

version 1.0 (September 2005)

Timber litter fuel type models (TL)

Description:
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.

Expected fire behavior:
Compare TL1-TL5 with others
Compare TL6-TL9 with others

TL1 (181)

low load compact conifer litter

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

Expected fire behavior:
TL1 fire behavior details
Compare TL1 with other similar fuel models

Fine fuel load (t/ac)	1.0
Characteristic SAV (1/ft)	1716
Packing ratio (dimensionless)	0.04878
Extinction moisture content (percent)	30

version 1.0 (September 2005)

TL2 (182)

low load broadleaf litter


Description:
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.

Expected fire behavior:
TL2 fire behavior details
Compare TL2 with other similar fuel models

Fine fuel load (t/ac)	1.4
Characteristic SAV (1/ft)	1806
Packing ratio (dimensionless)	0.04232
Extinction moisture content (percent)	25

version 1.0 (September 2005)

TL3 (183)

Moderate load conifer litter

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

Expected fire behavior:
[TL3 fire behavior details]
[Compare TL3 with other similar fuel models]

Fine fuel load (t/ac)	0.50
Characteristic SAV (1/ft)	1532
Packing ratio (dimensionless)	0.02630
Extinction moisture content (percent)	20

version 1.0 (September 2005)

TL4 (184)

Small downed logs

Description:
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.

Expected fire behavior:
TL4 fire behavior details
Compare TL4 with other similar fuel models

Fine fuel load (t/ac)	.50
Characteristic SAV (1/ft)	1568
Packing ratio (dimensionless)	0.02224
Extinction moisture content (percent)	25

version 1.0 (September 2005)

TL5 (185)

High load conifer litter

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

Expected fire behavior:
[TL5 fire behavior details](#)
[Compare TL5 with other similar fuel models](#)

Fine fuel load (t/ac)	1.15
Characteristic SAV (1/ft)	1713
Packing ratio (dimensionless)	0.01925
Extinction moisture content (percent)	25

version 1.0 (September 2005)

TL6 (186)

Moderate load broadleaf litter


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

Expected fire behavior:
TL6 fire behavior details
Compare TL6 with other similar fuel models

Fine fuel load (t/ac)	2.4
Characteristic SAV (1/ft)	1936
Packing ratio (dimensionless)	0.02296
Extinction moisture content (percent)	25

version 1.0 (September 2005)

TL7 (187)

Large downed logs

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

Expected fire behavior:
TL7 fire behavior details
Compare TL7 with other similar fuel models

Fine fuel load (t/ac)	0.30
Characteristic SAV (1/ft)	1229
Packing ratio (dimensionless)	0.03515
Extinction moisture content (percent)	25

version 1.0 (September 2005)

TL8 (188)

long-needle litter

Description:
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.

Expected fire behavior:
TL8 fire behavior details
Compare TL8 with other similar fuel models

Fine fuel load (t/ac)	5.8
Characteristic SAV (1/ft)	1770
Packing ratio (dimensionless)	0.03969
Extinction moisture content (percent)	35

version 1.0 (September 2005)

TL9 (189)

Very high load broadleaf litter

Description:
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.

Expected fire behavior:
TL9 fire behavior details
Compare TL9 with other similar fuel models

Fine fuel load (t/ac)	6.65
Characteristic SAV (1/ft)	1733
Packing ratio (dimensionless)	0.03372
Extinction moisture content (percent)	35

version 1.0 (September 2005)

Slash-blowdown fuel type models (SB)

Description:
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.

Expected fire behavior:
Compare SB1-2 with others
Compare SB3-4 with others

SB1 (201)

low load activity fuel

Description:
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.

Expected fire behavior:
[SB1 fire behavior details]
[Compare SB1 with other similar fuel models]

Fine fuel load (t/ac)	1.50
Characteristic SAV (1/ft)	1653
Packing ratio (dimensionless)	0.02224
Extinction moisture content (percent)	25

version 1.0 (September 2005)

SB2 (202)

moderate load activity fuel or low load blowdown

Description:
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.

Expected fire behavior:
[SB2 fire behavior details]
[Compare SB2 with other similar fuel models]

Fine fuel load (t/ac)	4.5
Characteristic SAV (1/ft)	1884
Packing ratio (dimensionless)	0.01829
Extinction moisture content (percent)	25

version 1.0 (September 2005)

SB3 (203)

high load activity fuel or moderate load blowdown


Description:
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.

Expected fire behavior:
SB3 fire behavior details
Compare SB3 with other similar fuel models

Fine fuel load (t/ac)	5.50
Characteristic SAV (1/ft)	1935
Packing ratio (dimensionless)	0.01345
Extinction moisture content (percent)	25

version 1.0 (September 2005)

SB4 (204)

high load blowdown

Description:
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.

Expected fire behavior:
SB4 fire behavior details
Compare SB4 with other similar fuel models

Fine fuel load (t/ac)	5.25
Characteristic SAV (1/ft)	1907
Packing ratio (dimensionless)	0.00744
Extinction moisture content (percent)	25

version 1.0 (September 2005)

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Workshop

The Workshop section of this document will help fire managers become more familiar with the new set of fuel models. It consists of two tools for comparing and using the new fuel models, a Q&A section, a quiz, and exercises.

The Fuel Model Comparison Tool allows the user to quickly and easily compare the relative behavior of up to 8 different original and new fuel models.

The Q&A section reinforces some of the information presented in the main sections of this document. It also contains valuable information not presented elsewhere. These questions are designed to instruct, not test knowledge.

The quiz section allows you to test your knowledge and understanding of the new fuel models and their relationships to other fuel model sets and fire models. Quiz questions cover all aspects of this document, including the Q&A. Try to answer the questions without looking up the answer, but feel free to look up answers to questions that stump you. Once you've finished taking the quiz, go ahead and look at the school solutions. Re-read material related to questions you missed.

Finally, the workshop has an Exercises section, which includes some practical applications of the fuel models to your home unit, like using the selection guide and fuel model crosswalk.

Fuel Model Comparison Tool

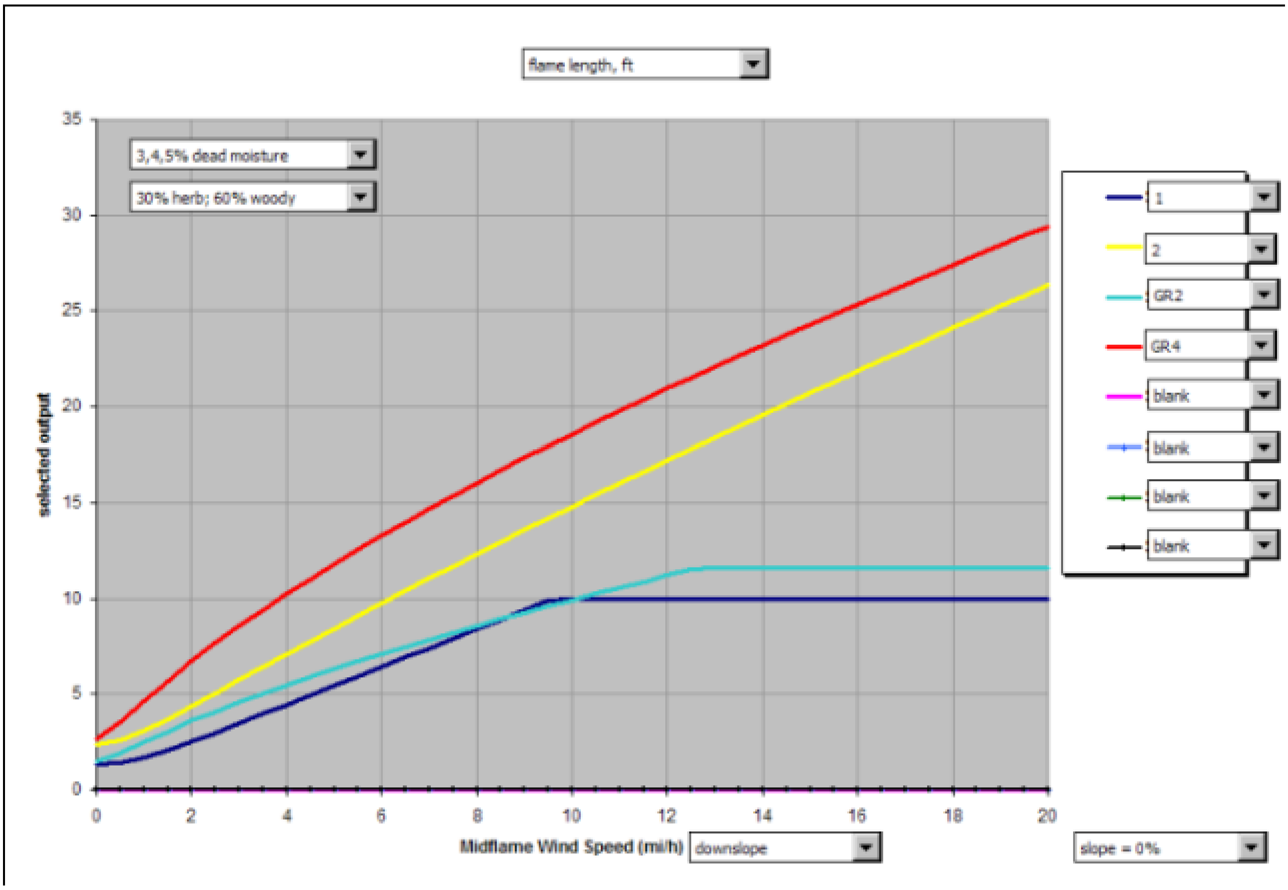
Standard comparisons of spread rate and flame length for original and new fuel models are available in the browsing system. To use that system, use the "Fuel Models" section and follow the links under the Expected Fire Behavior heading. In many cases, you will want to compare a different combination of fuel models than this system allows. For those cases we have included an interactive Microsoft Excel Chart that will allow you to compare up to 8 of the original or new fuel models. Unlike the browsing system, this tool allows you to analyze the effects of slope as well as wind speed and fuel moisture.

To open the Fuel Model Comparison Tool, use Windows Explorer to navigate to the folder on your hard drive where you downloaded this file, then double-click the file **CompareModelsFour.xls.**

To use the tool:

- Open the file in Excel or another program capable of reading an .xls file.
- Select the fuel models you would like to compare using the drop-down dialogs in the legend. To clear a fuel model from the chart, select "blank" from the list. Any combination of original and new fuel models can be compared.
- Select the fire behavior output to plot using the dialog at the top of the chart. Choices are: flame length (ft), rate of spread (ch/h), fireline intensity (BTU/ft-s) and heat per unit area (BTU/ft^2)
- Select the dead and live fuel moisture scenarios to use with the pair of drop-down lists located in the upper left corner of the chart. Use the top list to select the dead fuel moisture scenario, and the bottom list for the live moisture scenario.
- Select the slope class using the drop-down list at the bottom-right corner of the page.
- Finally, select the wind direction class using the drop-down list located in the X-axis label.

The chart is updated automatically whenever a change is made using one of these drop-down list boxes.



Q&A

I'm happy with the current fuel model map for my local area, which uses the original 13 fuel models. Do I have to change to the new set?

No. All of the original 13 fuel model are still available for use in fire behavior programs; you may continue to use them as long as they meet your needs.

I'd like to update the fuel model map for my local area, which now uses the 13 original fuel models. What resources are available to help me do this?

In this document are two tools to help make the transition to the new fuel model set. The Fuel Model Crosswalk lists each original fuel model and suggests one or more new fuel models that might be appropriate. Also, the Fuel Model Selection Guide will help you select a fuel model from the new set.

The fire behavior comparison charts are pretty cool, but shouldn't I just make the comparisons myself in BehavePlus or similar program?

For more-specific fire behavior comparisons, you SHOULD use a fire behavior processor rather than the charts. However, you can browse the more than 700 runs contained within the comparison system here in just a few minutes, so it's very easy to compare models. Setting up just the right runs in a processor like BehavePlus can take much more time. Also, see the fuel model comparison tool we provided with this document for comparing fire behavior among up to 8 different original or new fuel models.

Why doesn't the new fuel model set include any of the original fuel models?

From the beginning we knew we were going to have a set of 25-50 fuel models. If we kept the original models we'd have to re-number and probably rename them, so it would be hard to keep track of which ones were original and which were new.

My fire behavior predictions using fuel model 3 (Tall grass) are always spot-on for my local fuelbeds, but there's no model in the new set exactly like it. What should I do?

You could keep using fuel model 3 -- it's still there. BUT, is it really always spot-on? Because there are more fuel model choices in the new set, (and because the grass fuel models are now dynamic) it's likely that one of the new fuel models does as well or better than an original.

What is the relationship between this set of fuel models and the original 13 fuel models?

Each fuel model set stands alone. The selection guide for the new set points to models in the new set only. The range of fire behavior predicted using original 13 models is encompassed by the range predicted with the new set, so continuing to use the original set is not required. Nonetheless, the original 13 are still available for use.

What is the relationship between this set of fuel models and NFDRS fuel models?

National Fire Danger Rating System (NFDRS) fuel models are used in NFDRS only, and fire behavior fuel models are used in fire behavior models and systems only; therefore, this new set of standard fire behavior fuel models has no effect on NFDRS applications.

What is the relationship between this set of fire behavior fuel models and the Fuel Characteristic Classification System (FCCS)?

The FCCS is a system for defining and organizing fuel complex information and rating fire potential; it does not directly use the Rothermel fire spread model and therefore does not require a fire behavior fuel model for input. However, the FCCS developers plan to indicate a standard fuel model from this new set as an attribute of each FCCS fuelbed, so a fire behavior fuel model is an *output* of FCCS.

What is the relationship between this set of fuel models and fuel loading models?

Fuel Loading Models, as they are currently being called by their developers, are similar to fuel models for the Rothermel fire spread model but are for input to a different fire model. Fuel Loading Models are used as input to Albini's BURNUP model, which predicts fuel consumption and heat release. Fuel loading models and fire behavior fuel models cannot be used interchangeably. Fuel loading models have also been called "fire effects fuel models" (Andrews and Queen 2001).

Is this fuel model set considered a fuel classification?

No. A fuel model is an attribute that can be assigned to classes in a classification. A classification has two important characteristics. It must be mutually exclusive, meaning that the definition of a class must necessarily exclude all other classes. Fuel models are not defined in that way. Secondly, a classification must be totally exhaustive, meaning that every piece of ground must belong to a class. Again, this is not the case with this set of fuel models, which is one, reason custom fuel models are used.

There were suggested wind adjustment factors for each of the original fuel models. What should I do about estimating wind adjustment factor for the new fuel models?

Guidance on selection of an appropriate wind adjustment factor will come from the fire behavior modeling system or in separate training material. Each system may have its own application.

I have my own fire behavior calculation program that used the original 13 fuel models. Is there anything special I have to do to use the new fuel model set?

Maybe. The new fuel model set uses dynamic fuel models, which transfer live herbaceous load to dead herbaceous as a function of live herbaceous moisture content. That feature requires a change in fire behavior processor code. The old BEHAVE program accommodated dynamic fuel load transfer, but most other processors did not, and have been or must be updated.

I need a fuel model to use for Oakbrush, but nothing here suggests what to use for that or any other specific vegetation type. Where is the list of fuel models to use for each vegetation type?

We specifically avoided mentioning vegetation types whenever possible, for two reasons: 1) depending on local or regional conditions, the same vegetation type classification could be different fire behavior fuel models, and 2) the same fuel model can be used for a wide variety of vegetation types, so many that it's not practical to list them all. We expect that local or regional fuel managers will create fuel model-vegetation type crosswalks for their specific areas.

Why is it necessary to have both a fuel model number and a fuel model code?

The fuel model number facilitates mapping and computer programming applications, but it's too hard for most users to remember. The fuel model code is for everyday communication among people, and for input to fire modeling systems.

I expected the fuel model Crosswalk to list only ONE new fuel model to use for each of the original 13 model. Why so many choices?

If the crosswalks pointed only to the *single* best match, we'd only be using 13 of the 40 new fuel models when. Because the new set is larger than the original, we offer several choices for each of the original fuel models. Do not restrict your choice to those shown on the crosswalk -- some circumstances may indicate using a new fuel model not listed on the crosswalk.

A non-burnable fuel model? Really? What's the point?

When examining a fuel model map it may be important to discern WHY a certain area is non-burnable, not just that it won't burn. Having these non-burnable fuel models will aid in checking for registration errors in maps and identifying major landscape features without the need for overlaying ancillary geographic information.

I found the list of fuel model parameters for the new set, but I don't see the original 13 listed. Why not?

We did not list the original fuel model parameters for several reasons. First, the new set contains dynamic fuel models while the original set contains only static models, so direct comparison of parameters may be misleading. Second, we created the fuel model crosswalks, a better way of comparing new and original models.

What about the remaining fuel parameters needed for using Rothermel's model?

The fuel model parameters table lists only the fuel parameters that vary from one fuel model to another. The remaining parameters (10- and 100-hr surface-area-to-volume ratios, total and effective mineral content, and particle density) are treated as constants.

Quiz

Print this topic. Write your response to each question in the space allotted. Look up answers in the fuel model document only if necessary. When you have completed the quiz, compare your responses to the school solution, then study the sections you had trouble with.

1. What kind of fuel model does this document address? What kinds are not addressed?

2. The original 13 fuel models were designed for "the severe period of the fire season when wildfires pose greater control problems ...". How does using dynamic fuel models improve fire behavior predictions for times other than the most severe period of the fire season?

3. If you use a live herbaceous moisture content of 90%, what is the implied level of curing (percent)? What fraction of the live herbaceous fuel load is allocated to dead?

4. If your herbaceous fuelbed is approximately two-thirds cured, what live herbaceous moisture content should you use?

5. Describe the relationship between this new set of fuel models and the original set of 13 fuel models.

6. The fuel model naming convention contains three parts. Which part is designed for input to fire behavior programs and communication among wildland fire managers and scientists?

7. How can these new fuel models be used to predict fuel post-frontal smoldering consumption?

8. What two tools are provided to help fuel managers select a new fuel model?

9. Why are the fuel model numbers grouped by major fire-carrying fuel type? Why to the blocks of fuel numbers for each fuel type include more numbers than are currently used?

10. Why are several non-burnable fuel models included in the new set?

11. Why do fuel model names often refer to moisture level of the climate?

12. How were the fuel models ordered within a fire-carrying fuel type?

13. Should all agricultural land always be assigned to NB4?

14. Can fuel model NB2 (urban/developed) be used to simulate the spread rate and intensity of a wildland/urban interface fire?

To answer the following questions it will be necessary to refer to the fuel model documentation (fire behavior charts, crosswalks, or selection guide). A fire behavior processor that includes the new fuel models may be helpful, but is not necessary.

15. Which new fuel model is suggested if you want one that produces spread rate slightly lower than and flame length comparable to original fuel model 1 (short grass)?

16. Which fuel model is suggested if you want one as close as possible to original fuel model 8 (compact timber litter)?

17. Which fuel model does the fuel model selection guide suggest if the major fire-carrying fuel type is shrubs, the fuelbed is located in a dry climate, shrub load is very heavy, and depth is about 5 feet? How does fire behavior (spread rate and flame length) generally compare with original fuel model 4

(Chaparral)?

18. What is the approximate predicted flame length and spread rate using fuel model SH5 and moisture scenario D1L1 if the midflame wind speed is 6 mi/hr?

View school solutions

Exercises

1. In your home unit, visit at least three areas, each in a different fire-carrying fuel type in which you have observed fire behavior. Use the fuel model selection guide to determine which fuel model is suggested. Follow links for that fuel model to verify that predicted fire behavior matches your experience.

2. For your home unit, obtain a document that specifies one or more of the original 13 standard fire behavior fuel models and its location. For example, a prescribed burn plan, fuel treatment plan, or fuel hazard assessment may include a fuel model map, or a plot location where fuel model was identified. Use the fuel model crosswalk to determine which new fuel model is appropriate for each situation. You may need to visit the site and consult someone familiar with the fire behavior generally observed in the areas mapped.

3. Read the description of each non-burnable fuel model. Using aerial photos, existing maps, and local knowledge, identify the places where each non-burnable fuel model can be found in your local unit. Visit these areas to judge the accuracy of your assessment using only maps, photos and local experience. Verify that each area identified will not support a spreading wildland fire under any fuel moisture condition, or select an appropriate fuel model if wildland fire spread can take place.