PERFORMANCE OF FIRE BEHAVIOR FUEL MODELS DEVELOPED FOR THE ROTHERMEL SURFACE FIRE SPREAD MODEL

Robert Ziel[1] and W. Matt Jolly[2]

[1]Fire Management Specialist, Michigan Department of Natural Resources, Marquette, MI
[2]Ecologist, U.S. Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT
RZ is corresponding author; to contact, call (906) 249-1497 or email at zielr@michigan.gov

Abstract.—In 2005, 40 new fire behavior fuel models were published for use with the Rothermel Surface Fire Spread Model. These new models are intended to augment the original 13 developed in 1972 and 1976. As a compiled set of quantitative fuel descriptions that serve as input to the Rothermel model, the selected fire behavior fuel model has always been critical to the resulting modeled fire behavior. Fuel characteristics affect both the heat source and the heat sink factors in the spread model. While the original 13 models emphasized peak fire-season fuel combinations, the new set establishes a greater role for live fuels. Use of live fuel as a variable produces a broad range of modeled fire behavior related to seasonal vegetative development, especially for those fuel models that include herbaceous fuel loads. Intending to represent "greenup" and late season "curing," the new fuel models allow the user to transfer herbaceous fuels from live to dead. As fuel load transferred increases, the influence of moisture of extinction and wind limit produce dramatic changes in modeled spread and intensity. The new models present an important opportunity to model fire behavior under a wider range of fuel conditions, including fire use. However, the user needs to be aware of the live fuel components in the selected models and manage those inputs carefully.

INTRODUCTION

Wildland fire behavior is frequently described by the spread rates and burning intensity as it burns along the surface. The primary factors that influence this fire behavior are grouped into three categories: weather, topography, and fuels. The Rothermel (1972) surface fire spread model uses fuel moisture and wind to represent weather's influence, slope, and elevation to characterize the topographic factor, and a collection of characteristic inputs called fire behavior fuel models as variables describing fuel complex characteristics. In support of firefighter safety and risk management, the original 13 fuel models created by Rothermel (1972) and Albini (1976) were created to predict fire behavior under peak burning conditions. In these "worst-case scenarios," fires predicted are considered to be influenced primarily by dead fuels and their characteristics. Though four of these 13 models include live fuels, the condition of those fuels is generally of secondary importance overall. With the increasing interest in fire use under more moderate conditions during the growing season and the imperative placed on designing fuel management practices to protect values in the wildland/urban interface, accurate estimates of fire behavior with increased live fuel influence and modified fuelbeds require some additional fuel model choices. The comments in this paper are intended to provide the reader with insights into these 40 new fuel models, the opportunities they provide, and the effects of some underlying model relationships that they bring out.

PURPOSE OF 40 ADDITIONAL MODELS

Many of the more moderate conditions associated with fire use involve seasons and situations where live fuels can serve to reduce fire spread and intensity to varying degrees. To reflect these conditions, 27 of the 40 new fuel models developed by Scott and Burgan (2005) include live fuel loads, which result in a greater range of potential fire behavior for any given set of weather conditions.

Throughout the United States, most wildland fuelbeds need to be fairly dry to support active fire spread. However, in areas like the southeastern U.S., some fuels will ignite and continue to burn under much higher moisture regimes. Whereas the original 13 included only two fuel models that emphasized this characteristic, the new set of 40 include 14 models designated as humid-climate fuels with significantly higher moisture of extinction (ME) parameters. ME is the dead fuel moisture above which fires cannot actively spread.

In addition to creating two new categories of carrier fuels (grass-shrub and timber understory), the new set of fuel models includes from four to nine model choices within each carrier fuel category. The increased number of choices allows for more accurate reflection of the range of potential fire behavior among similar fuelbeds. In forested situations, models of crown fire potential and canopy scorch/mortality use surface fire intensity as a primary factor. Without accurate predictions of surface fire behavior, users will be unable to accurately evaluate the effectiveness of fuel reduction projects that are intended to reduce the probability and extent of damage to the forest canopy.

With these additional choices, users are more likely to find an appropriate fuel model within the carrier category that can be related to the vegetative cover on their site. More consistent and predictable relationships between cover and fuels will allow for more effective use of remote sensing techniques and automated updating of fuel classifications. The full potential of landscape assessment tools such as FARSITE, FLAMMAP, and FSPro will not be realized until classifications of fuels are accurate across entire landscapes.

FUEL MODEL CHARACTERISTICS

Table 1 lists all 53 fuel models and the characteristic model parameters for each. It can be used to make comparisons between familiar models among the original 13 and alternatives that may be considered among the 40 new models. Intrinsic characteristics of the fuel particles include the dead and live heat content and the dead fuel ME. Extrinsic characteristics are based on the size, shape, quantity, and arrangement of those fuel particles. They include the bed depth as well as the fuel loading and surface area to volume ratio (SAV) for each fuel size class (1-hr, 10-hr, 100-hr) and type (herbaceous and woody).

One new parameter has been added to designate fuel models that are dynamic; i.e., with herbaceous fuel loads that can be transferred between live and dead categories. Fuel models without herbaceous fuels are considered static. Figure 1 demonstrates the increased effect of the fuel load transfer between live and dead on resulting spread and intensity. While the original fuel model FB2 (timber grass and understory) shows only a limited influence of herbaceous fuel moisture, that influence in the new models (GR2, GR4, GR7, GR9) can be dramatic.

Each model has a characteristic ME. The 14 new models designated for humid climates have a ME of 30 percent or higher, allowing fuels to burn under much higher moisture content. Figure 2 shows an example of the difference between two fuel models with otherwise similar characteristics; GR4 has a ME of 15 percent, as compared to 40 percent for GR5. At 15 percent 1-hr fuel moisture, GR4 exhibits no spread while GR5 shows spread rates of 40 chains/hour and flame lengths between 8 and 9 feet.

INTERACTIONS WITH THE ROTHERMEL SURFACE FIRE SPREAD MODEL

Figure 3 depicts the Rothermel (1972) surface fire spread model. In the equation, the numerator, identified as the “Heat Source,” represents the heat available to ignite adjacent fuels, effectively promoting fire spread. The denominator, labeled the heat sink, estimates the heat needed to remove moisture and raise fuel particles to the ignition temperature. The calculations are fairly straightforward for wildland fuelbeds that contain predominantly dead fuels.

Fire modeling needs to recognize that the moisture content of live fuels is higher and varies over a wider range than that of dead fuels. Live fuels can burn at a higher moisture content but also can serve to impede spread. Rothermel’s model accounts for these differences by estimating the reaction intensity and heat of pre-ignition separately for live and dead fuels, then combining them.

Table 1.—Fuel model parameters for use with the Rothermel surface fire spread model; dynamic models are shaded

Carrier	FM #	FM Code	Fuel Model Name	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	Total Load	Dynamic	1hr SAV	Herb SAV	Woody SAV	Bed Depth	Moist Extinct	Dead Heat	Live Heat
GR	1	FB1	Short grass	0.7	0.0	0.0	0.0	0.0	0.7	static	3500	9999	9999	1.0	12	8000	8000
GR	2	FB2	Timber grass and understory	2.0	1.0	0.5	0.5	0.0	4.0	static	3000	1500	9999	1.0	15	8000	8000
GR	3	FB3	tall grass	3.0	0.0	0.0	0.0	0.0	3.0	static	1500	9999	9999	2.5	25	8000	8000
GR	101	GR1	Short, sparse dry climate grass	0.1	0.0	0.0	0.3	0.0	0.4	dynamic	2200	2000	9999	0.4	15	8000	8000
GR	102	GR2	Low load dry climate grass	0.1	0.0	0.0	1.0	0.0	1.1	dynamic	2000	1800	9999	1.0	15	8000	8000
GR	103	GR3	Low load very coarse humid climate grass	0.1	0.4	0.0	1.5	0.0	2.0	dynamic	1500	1300	9999	2.0	30	8000	8000
GR	104	GR4	Moderate load dry climate grass	0.3	0.0	0.0	1.9	0.0	2.2	dynamic	2000	1800	9999	2.0	15	8000	8000
GR	105	GR5	low load humid climate grass	0.4	0.0	0.0	2.5	0.0	2.9	dynamic	1800	1600	9999	1.5	40	8000	8000
GR	106	GR6	moderate load humid climate grass	0.1	0.0	0.0	3.4	0.0	3.5	dynamic	2200	2000	9999	1.5	40	9000	9000
GR	107	GR7	High load dry climate grass	1.0	0.0	0.0	5.4	0.0	6.4	dynamic	2000	1800	9999	3.0	15	8000	8000
GR	108	GR8	High load very coarse humid climate grass	0.5	1.0	0.0	7.3	0.0	8.8	dynamic	1500	1300	9999	4.0	30	8000	8000
GR	109	GR9	very high load humid climate grass	1.0	1.0	0.0	9.0	0.0	11.0	dynamic	1800	1600	9999	5.0	40	8000	8000
GS	121	GS1	low load dry climate grass-shrub	0.2	0.0	0.0	0.5	0.7	1.4	dynamic	2000	1800	1800	0.9	15	8000	8000
GS	122	GS2	moderate load dry climate grass-shrub	0.5	0.5	0.0	0.6	1.0	2.6	dynamic	2000	1800	1800	1.5	15	8000	8000
GS	123	GS3	moderate load humid climate grass-shrub	0.3	0.3	0.0	1.5	1.3	3.3	dynamic	1800	1600	1600	1.8	40	8000	8000
GS	124	GS4	high load humid climate grass-shrub	1.9	0.3	0.1	3.4	7.1	12.8	dynamic	1800	1600	1600	2.1	40	8000	8000
SH	4	FB4	chaparral	5.0	4.0	2.0	0.0	5.0	16.0	static	2000	9999	1500	6.0	20	8000	8000
SH	5	FB5	brush	1.0	0.5	0.0	0.0	2.0	3.5	static	2000	9999	1500	2.0	20	8000	8000
SH	6	FB6	dormant brush	1.5	2.5	2.0	0.0	0.0	6.0	static	1750	9999	9999	2.5	25	8000	8000
SH	7	FB7	southern rough	1.1	1.9	1.5	0.0	0.4	4.9	static	1750	9999	1500	2.5	40	8000	8000
SH	141	SH1	low load dry climate shrub	0.3	0.3	0.0	0.2	1.3	2.0	dynamic	2000	1800	1600	1.0	15	8000	8000
SH	142	SH2	moderate load dry climate shrub	1.4	2.4	0.8	0.0	3.9	8.4	static	2000	9999	1600	1.0	15	8000	8000
SH	143	SH3	moderate load humid climate shrub	0.5	3.0	0.0	0.0	6.2	9.7	static	1600	9999	1400	2.4	40	8000	8000
SH	144	SH4	low load humid climate timber-shrub	0.9	1.2	0.2	0.0	2.6	4.8	static	2000	1800	1600	3.0	30	8000	8000
SH	145	SH5	high load dry climate shrub	3.6	2.1	0.0	0.0	2.9	8.6	static	750	9999	1600	6.0	15	8000	8000
SH	146	SH6	low load humid climate shrub	2.9	1.5	0.0	0.0	1.4	5.8	static	750	9999	1600	2.0	30	8000	8000
SH	147	SH7	very high load dry climate shrub	3.5	5.3	2.2	0.0	3.4	14.4	static	750	9999	1600	6.0	15	8000	8000
SH	148	SH8	high load humid climate shrub	2.1	3.4	0.9	0.0	4.4	10.7	static	750	9999	1600	3.0	40	8000	8000
SH	149	SH9	very high load humid climate shrub	4.5	2.5	0.0	1.6	7.0	15.5	dynamic	750	1800	1500	4.4	40	8000	8000
TU	10	FB10	timber litter and understory	3.0	2.0	5.0	0.0	2.0	12.0	static	2000	9999	1500	1.0	25	8000	8000
TU	161	TU1	light load dry climate timber-grass-shrub	0.2	0.9	1.5	0.2	0.9	3.7	dynamic	2000	1800	1600	0.6	20	8000	8000
TU	162	TU2	moderate load humid climate timber-shrub	1.0	1.8	1.3	0.0	0.2	4.2	static	2000	9999	1600	1.0	30	8000	8000
TU	163	TU3	moderate load humid climate timber-grass-shrub	1.1	0.2	0.3	0.7	1.1	3.3	dynamic	1800	1600	1400	1.3	30	8000	8000
TU	164	TU4	dwarf conifer with understory	4.5	0.0	0.0	0.0	2.0	6.5	static	2300	9999	2000	0.5	12	8000	8000
TU	165	TU5	very high load dry climate timber-shrub	4.0	4.0	3.0	0.0	3.0	14.0	static	1500	9999	750	1.0	25	8000	8000
TL	8	FB8	compact timber litter	1.5	1.0	2.5	0.0	0.0	5.0	static	2000	9999	9999	0.2	30	8000	8000
TL	9	FB9	hardwood litter	2.9	0.4	0.2	0.0	0.0	3.5	static	2500	9999	9999	0.2	25	8000	8000
TL	181	TL1	Low load compact conifer litter	1.0	2.2	3.6	0.0	0.0	6.8	static	2000	9999	9999	0.2	30	8000	8000
TL	182	TL2	low load broadleaf litter	1.4	2.3	2.2	0.0	0.0	5.9	static	2000	9999	9999	0.2	25	8000	8000
TL	183	TL3	moderate load conifer litter	0.5	2.2	2.8	0.0	0.0	5.5	static	2000	9999	9999	0.3	20	8000	8000
TL	184	TL4	Small downed logs	0.5	1.5	4.2	0.0	0.0	6.2	static	2000	9999	9999	0.4	25	8000	8000
TL	185	TL5	high load conifer litter	1.2	2.5	4.4	0.0	0.0	8.1	static	2000	9999	1600	0.6	25	8000	8000
TL	186	TL6	moderate load broadleaf litter	2.4	1.2	1.2	0.0	0.0	4.8	static	2000	9999	9999	0.3	25	8000	8000
TL	187	TL7	Large downed logs	0.3	1.4	8.1	0.0	0.0	9.8	static	2000	9999	9999	0.4	25	8000	8000
TL	188	TL8	long-needle litter	5.8	1.4	1.1	0.0	0.0	8.3	static	1800	9999	9999	0.3	35	8000	8000
TL	189	TL9	very high load broadleaf litter	6.7	3.3	4.2	0.0	0.0	14.1	static	1800	9999	1600	0.6	35	8000	8000
SB	11	FB11	light slash	1.5	4.5	5.5	0.0	0.0	11.5	static	1500	9999	9999	1.0	15	8000	8000
SB	12	FB12	medium slash	4.0	14.0	16.5	0.0	0.0	34.6	static	1500	9999	9999	2.3	20	8000	8000
SB	13	FB13	heavy slash	7.0	23.0	28.1	0.0	0.0	58.1	static	1500	9999	9999	3.0	25	8000	8000
SB	201	SB1	low load activity fuel	1.5	3.0	11.0	0.0	0.0	15.5	static	2000	9999	9999	1.0	25	8000	8000
SB	202	SB2	moderate load activity or low load blowdown	4.5	4.3	4.0	0.0	0.0	12.8	static	2000	9999	9999	1.0	25	8000	8000
SB	203	SB3	high load activity fuel or moderate load blowdown	5.5	2.8	3.0	0.0	0.0	11.3	static	2000	9999	9999	1.2	25	8000	8000
SB	204	SB4	high load blowdown	5.3	3.5	5.3	0.0	0.0	14.0	static	2000	9999	9999	2.7	25	8000	8000

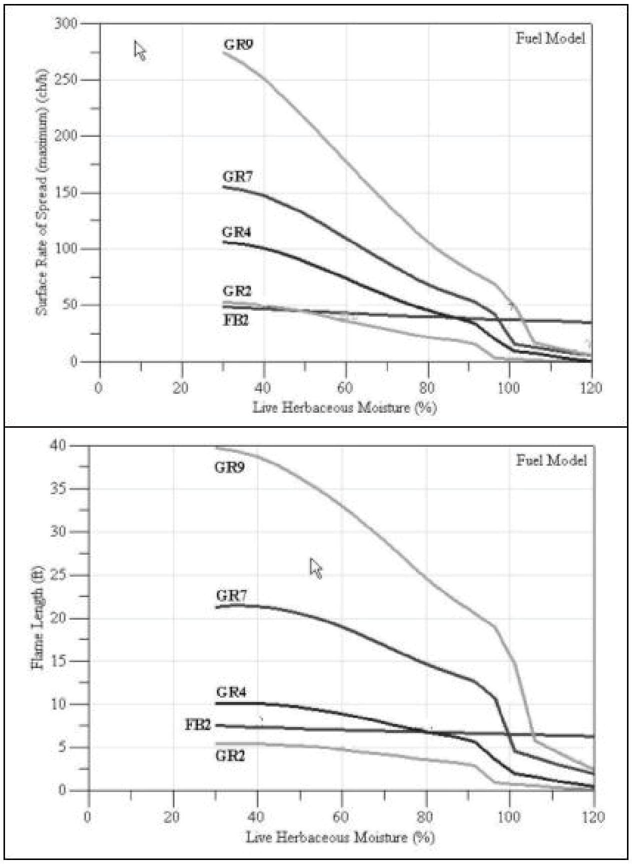

Figure 1.—Effect of dynamic fuel load transfer on surface fire behavior.

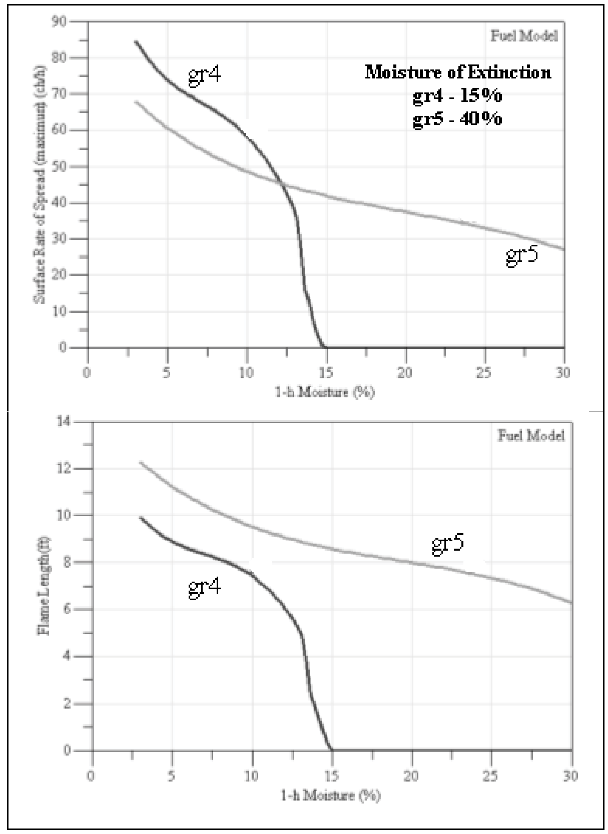

Figure 2.—Moisture of extinction effect on fire behavior.

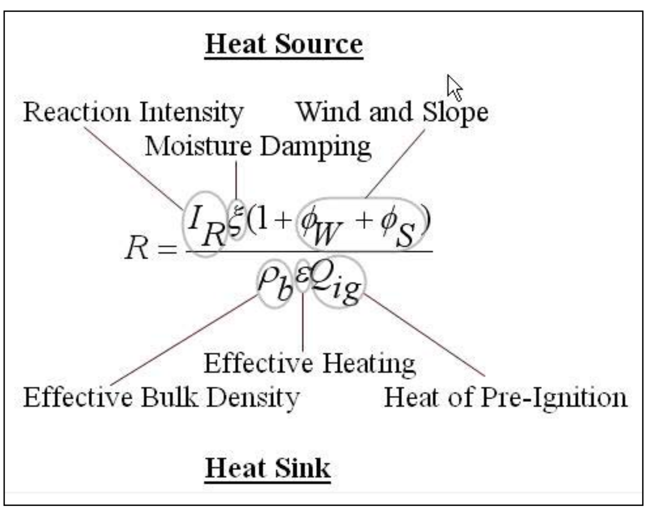

Figure 3.—Rothermel surface fire spread model.

HERBACEOUS FUEL LOAD TRANSFER

Grasses and forbs are highly variable as fuels, changing continuously from the beginning until the end of each fire season. They begin the year as largely dead surface fuels remaining from the previous season's growth, develop significant live fuel loading as they grow, and then become dead fuels through seasonal curing, drought, or frost damage. Until the new fuel models were developed, all live fuels were considered living, with no way to enter fuel moistures as low as those reached by dead fuels. The only way to capture the range of conditions described above was to utilize different fuel models at different stages in the season. For modeling efforts that span only short periods, fuel model classifications did not need to change. However, as landscape fire behavior models become more widely used and managers demand predictions over longer periods (weeks or months), fuel models must be responsive to these growing-season changes.

Table 2.—Surface fire behavior sensitivity to herbaceous load transfer

Rate of Spread (chains per hour)

Fuel Model	Herbaceous Fuel Moisture %									
	95	96	97	98	99	100	101	102	103	104
FB2	38	38	38	38	37	37	37	37	37	37
GR7	46	43	39	34	28	20	16	15	14	14
GR9	72	70	67	64	61	56	50	42	32	20

Flame Length (feet)

Fuel Model	Herbaceous Fuel Moisture %									
	95	96	97	98	99	100	101	102	103	104
FB2	6.6	6.6	6.6	6.5	6.5	6.5	6.5	6.5	6.5	6.5
GR7	12	11	10	9	7.5	5.4	4.5	4.4	4.2	4.1
GR9	20	19	19	18	17	16	15	13	9.8	6.3

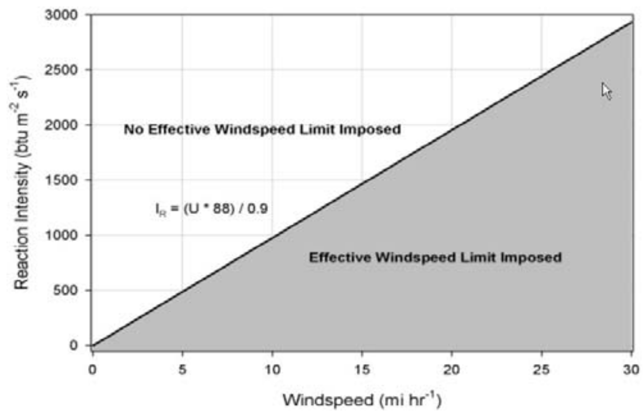

Figure 4.—Reaction intensity and windspeed, with and without windspeed limits.

With the original 13 fuel models, the effects of fuel characteristics and fuel moisture were related but separate, with fuel moisture affecting the moisture damping and heat of pre-ignition factors in the model. Seventeen of the 27 new models with live fuel loads are considered “dynamic.” They include an herbaceous fuel load that the user can designate as live, dead, or in proportionate combinations of live and dead. Of the original 13 models, only FB2 (timber grass and understory) has herbaceous loads. It does not accommodate herbaceous load transfer between live and dead fuels.

This dynamic feature was originally designed to operate much the same way that it does in the National Fire Danger Rating System (NFDRS), with the fuel load transfer determined by the estimated herbaceous fuel moisture. Using this method of transfer, the entire herbaceous fuel load is considered live when the herbaceous fuel moisture (HFM) is at least 120 percent and entirely dead at an HFM of 30 percent. Between those two HFM values, the load is distributed proportionately between live and dead.

Andrews et al. (2006) refer to numerous examples of grass fuels in Australia and New Zealand as evidence that the relationship may not be valid. Despite such criticism, most of the software systems that use these dynamic fuel models transfer the load automatically based on HFM. Table 2 highlights the sensitivity of spread and intensity to small changes in HFM. In this example using GR7, if HFM is changed from 101 percent to 98 percent, spread rate more than doubles from 16 to 34 chains per hour.

As this method of fuel load transfer is used in the dynamic models, the effects of fuel moisture extend to other parts of the equation and may have some unanticipated effects on predicted fire behavior. Several of these effects are discussed here.

Windspeed Limit

The most significant impact of the fuel load transfer is that associated with the windspeed limit applied by the model. Figure 4 (equation from Rothermel [1972]) illustrates this limit. For each combination of inputs, resulting reaction intensity is compared to the value represented by the limit. If it falls below the limit value for the input windspeed, the effective windspeed used in the spread equation will be based on the wind limit function. If it exceeds the limit, the actual windspeed is used.

For dynamic models that have relatively high herbaceous fuel loads and/or relatively low 1-hr fuel loads, calculated reaction intensities for most windspeeds will fall below the wind limit. As herbaceous fuel is transferred from live to dead, the calculated value will approach the limit value. Once the limit is exceeded, the windspeed influence increases and results in the rapid shift in spread rate and intensity seen in many of the dynamic models.

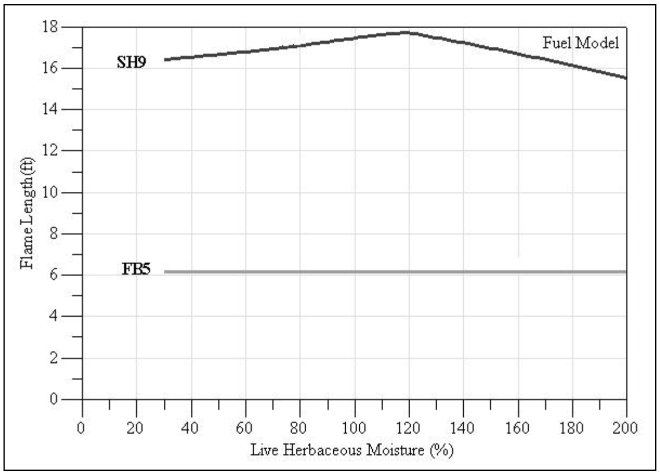

Figure 5.—Linked effect of Live Fuel Moisture on dead fuel characteristics.

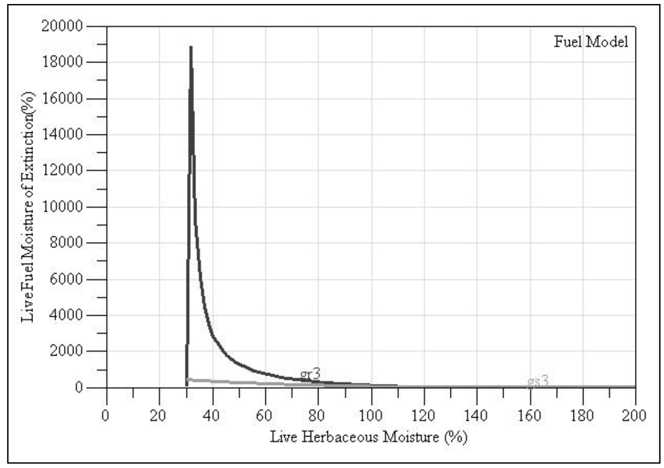

Figure 6.—Live Fuel Moisture and Live Fuel Moisture of Extinction.

Figure 1 illustrates this relationship, which cannot be supported by measurement in the field.

Dead Fuel Characteristics

As herbaceous fuel is transferred from the live category to the dead category, its characteristic SAV is retained. Fuel models that include significant loads of both 1-hr and herbaceous fuels that have different SAV values can have their combined dead SAV altered significantly as herbaceous load is transferred. In the case of SH9 (Very high load, humid climate, shrub), the effect is counter-intuitive, with the modeled spread leveling off and flame length actually decreasing as the herbaceous fuel moisture falls below 120 percent. Figure 5 demonstrates this unrealistic result.

Live Fuel Moisture of Extinction

As with the reaction intensity, separate moisture damping coefficients are calculated for live and dead fuels. Separate values of live and dead Reaction Intensity are calculated and then added together to produce an overall reaction intensity. Though the calculation is the same, there are some important differences. While the ME for dead fuels is a fuel model parameter, the live fuel ME is calculated from the dead fuel moisture, the dead fuel ME, and the ratio of live fuel load to dead fuel load. If the HFM determined the fuel load transferred, the ratio of live to dead load would decrease with decreasing herbaceous fuel moisture. The result can be rapidly increasing live fuel ME and increased Reaction Intensity contributions from live fuels. Figure 6 demonstrates this effect with GR3 (low load, very coarse, humid climate, grass).

Manual Fuel Load Transfer

Version 4 of BehavePlus allows the user to separate herbaceous fuel load transfer from HFM by creating an additional input called fuel load transfer portion if herbaceous fuels are present in the selected fuel model. With this option, the user can directly identify how much of the herbaceous fuel load is transferred from live (with a higher range of fuel moistures) to dead (with much lower fuel moistures possible). Figure 7 shows the relationship between two models of similar fuels, the static FB3 (tall grass) and the dynamic GR6 (moderate load, humid climate, grass). Using dead fuel moistures of 5 percent, 6 percent, and 7 percent, herbaceous fuel moisture of 100 percent, manual transfer of herbaceous load, midflame windspeed of 5 mph, and no slope, we can compare modeled spread rates and flame lengths. While the two fuel models have similar total fuel loads, FB3 loads are entirely in the 1-hr dead fuel class and GR6 loads are largely in the herbaceous fuel category. Modeled fire behavior converges only as the herbaceous fuel load in GR6 is nearly all converted from live to dead.

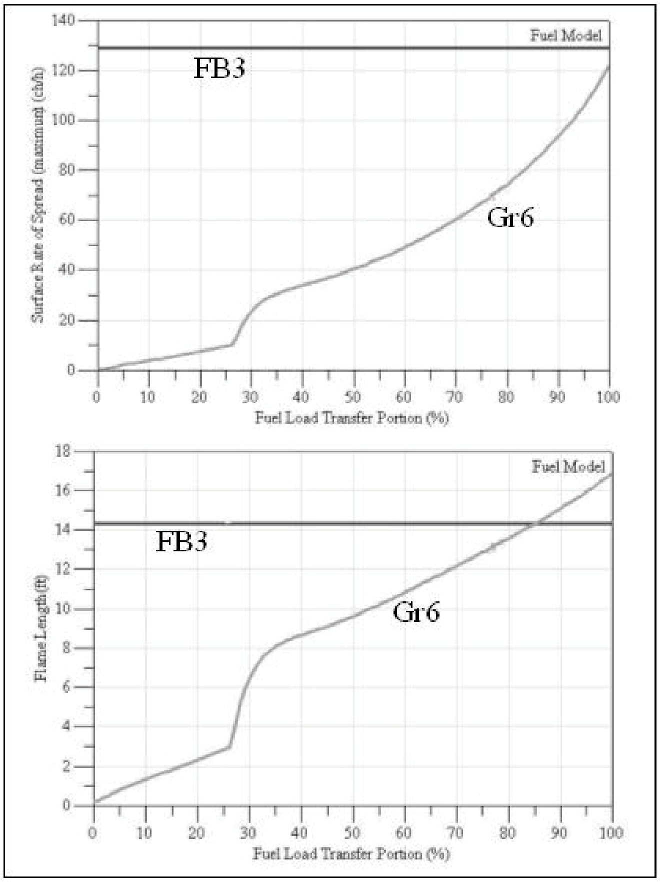

Figure 7.—Manual transfer of herbaceous fuel.

FUEL MODEL DESCRIPTIONS

Within each of the six fuel carrier categories, there are several important distinctions among the fuel models. We provide the following classification to help users select a model within each fuel carrier category:

Grass Fuels (GR)

Static

Dry	*Humid*
FB1-Short grass	FB3-Tall grass
FB2-Timber grass understory	

Dynamic

Dry	Humid
GR1-Short & sparse, dry climate, grass	GR3-Low load, very coarse, humid climate, grass
GR2-Low load, dry climate, grass	GR5-Low load, humid climate, grass
GR4-Moderate load, dry climate, grass	GR6-Moderatae 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 (GS)

All Dynamic

Dry	*Humid*
GS1-Low load, dry climate, grass-shrub	GS3-Mod. load, humid climate, grass-shrub
GS2-Mod. load, dry climate, grass-shrub	GS4-High load, humid climate, grass-shrub

Shrub (SH)

Static

Dry	*Humid*
FB4-Chaparral	FB7-Southern Rough
FB5-Brush	
FB6-Dormant brush	
SH2-Mod. load, dry climate, shrub	SH3-Mod. load, humid climate, shrub
SH5-High load, dry climate, shrub	SH4-Low load, humid climate, timber-shrub
SH7-Very high load, dry climate, shrub	SH6-Low load, humid climate, shrub
	SH8-High load, humid climate, shrub

Dynamic

Dry	*Humid*
SH1-Low load, dry climate, shrub	SH9-Very high load, humid climate, shrub

Timber Understory (TU)

Static

Dry	*Humid*
FB10-Timber litter and understory	
TU4-Dwarf conifer with understory	TU2-Mod. load, humid climate, timber-shrub
TU5-Very high load, dry climate, timber-shrub	

dynamic

Dry	*Humid*
TU1-Low load, dry, timber-grass-shrub	TU3-Mod. load, humid, timber-grass-shrub

Timber Litter (TL)

All Static

All have higher ME (25-30 percent).

Conifer	*Hardwood*
FB8-Compact timber litter	
TL4-Small downed logs	
TL7-Large downed logs	
TL1-Low load, compact conifer litter	FB9-Hardwood litter
TL3-Mod load, conifer litter	TL2-Low load, broadleaf litter
TL5-High load, conifer litter	TL6-Mod. load, broadleaf litter
TL8-Long needle litter	TL9-Very high load, broadleaf litter

Slash Blowdown (SB)

Original 13	*New 40*
FB11-Light slash	SB1-Low load activity fuel
FB12-Medium slash	SB2-Mod. load activity or low load blowdown
FB13-Heavy slash	SB3-High load activity or mod. load blowdown,
	SB4-High load blowdown

SELECTING APPROPRIATE FUEL MODELS

With 53 fuel models to choose from, making an individual selection may seem overwhelming. At this point, conventional wisdom suggests that users should keep the two sets (the original 13 models and the new 40) separate. Somewhat differently than outlined by Scott and Burgan (2005), we suggest that users consider the following issues to narrow the choices:

1) First, determine the primary carrier (grass, grass/shrub, shrub, timber understory, timber litter, or slash/blowdown). If at all possible, use the category that matches the vegetative cover type.
2) Evaluate the need to model herbaceous fuel load transfer. Such a model would be recommended for analyses that span longer periods or that include different seasons.
3) Consider moisture of extinction, especially for the grass, grass/shrub, and shrub categories. If the fuels that are burning continue to spread at high dead fuel moisture levels, the humid climate fuels should be considered. However, these fuel models may not accurately recognize the typical cessation of spread during the nighttime hours.
4) Match fuel load distribution, total loading, and bed depth. There may be several choices that represent a range of fire behavior, and these choices are likely to present an appropriate range for both spread and intensity outputs.
5) Finally, evaluate the resulting ranges of spread rate and fireline intensity based on expected weather (represented by wind and dead fuel moisture) and live fuel moisture condition. Comparing these results with expected/observed fire behavior will often make the choice clear. Users should examine model outputs for the range of possible temperature, relative humidity, and wind and slope conditions likely to be experienced. For fuel models with live fuels, examine the effect of live fuel moisture conditions for likely combinations of weather and terrain inputs to insure that results are as expected.

CONCLUSIONS

With the introduction of 40 additional fuel models, users of fire behavior prediction systems are confronted with new opportunities and the increased importance of several concepts. More fuel models are offered with high moisture of extinction distributed across the carrier categories. There are additional models with live fuel loads, especially herbaceous fuel loads that can be transferred from live to dead. This facility, whether handled automatically through linkage to the HFM or by directly entering a fuel load transfer portion, effectively allows the user to create new fuel models as the fuel load transferred changes. By selecting a "dynamic" fuel model, users who have never created or used custom fuel models will be assuming that responsibility. They should do so knowing the effects of that choice. Users should make fire behavior predictions for a range of anticipated or forecasted conditions to insure that the outputs effectively represent observed and potential fire behavior. BehavePlus can effectively be used to evaluate these relationships, especially Version 4, which allows for user designated transfer of herbaceous fuel loads.

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