Welcome to the presentation describing the new set of fire behavior fuel models. This presentation is designed to be browsed by an individual at a personal computer. The material presented here is documented in a US Forest Service report of the same title.

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A comprehensive set of standard fire behavior fuel models for use with Rothermel's spread model

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Abstract

As you may have just guessed, this text box will contain comments similar to what a live presenter would speak to the audience.

- In this presentation we introduce a new set of fire behavior fuel models, describe their characteristics and relationship to the original 13 models, and present tools for learning the new set

Prepared by Joe H. Scott, SEM

What is a fuel model?

A fuel model is a complete set of fuel inputs needed by a fire model. There are three kinds of fuel model in use today.

- Set of fuel inputs needed by a fire model

What is a fuel model?

Fire behavior fuel models drive Rothermel's surface fire spread model. The original set consists of 13 models.

- Set of fuel inputs needed by a fire model
  - Fire behavior fuel models

What is a fuel model?

The National Fire Danger Rating System (NFDRS) uses a set of 20 fuel models.

- Set of fuel inputs needed by a fire model
  - Fire behavior fuel models
  - NFDRS fuel models

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What is a fuel model?

Fuel Loading Models (in development) will be used as input to Albini's Burnup model.

- Set of fuel inputs needed by a fire model
  - Fire behavior fuel models
  - NFDRS fuel models
  - Fuel Loading Models

What is a fuel model?

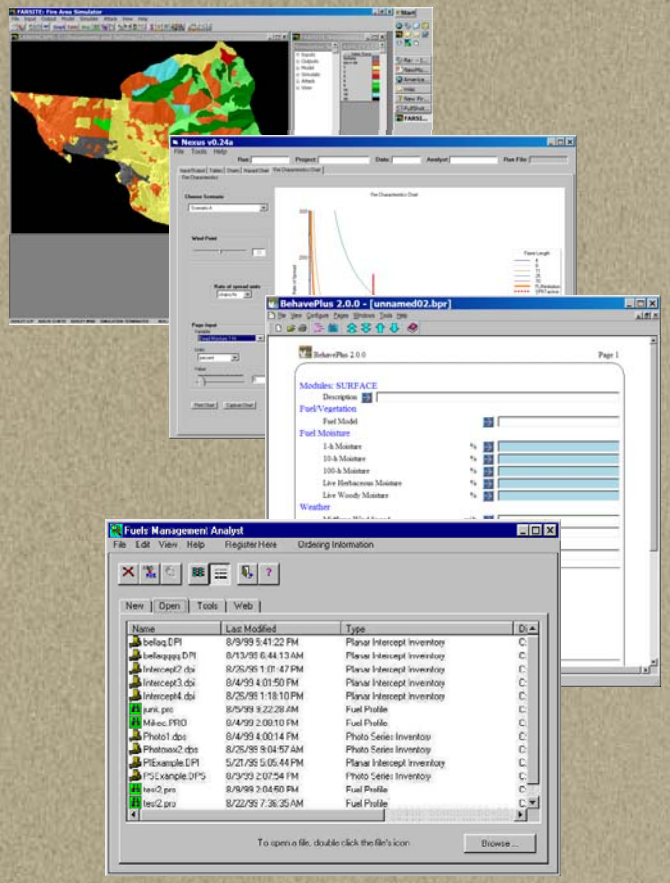
These three fuel model sets are NOT interchangeable. This presentation addresses only fire behavior fuel models.

- Set of fuel inputs needed by a fire model
  - Fire behavior fuel models
  - NFDRS fuel models
  - Fuel Loading Models

Systems

Fire behavior fuel models are used in a variety of fire management applications. The applications listed at right have already been updated to use the new fuel model set described here.

Check with the developers of other applications to see if they are compatible with the new fuel model set.



- BehavePlus
- FARSITE
- FFE-FVS
- FlamMap
- FMAplus
- NEXUS

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History

With the publication of his spread model in 1972, Rothermel listed 11 sets of fuel inputs to the spread model, which he called fuel models. They were not numbered or named at that time. Extinction moisture content was 30% for all models.

Table 1.--*Values for input parameters of 11 preliminary fuel models for the National Fire-Danger Rating System*[1]

Fuel types	Total loading	Dead fuel: Fine		Dead fuel: Medium		Dead fuel: Large		Living fuel		Fuel depth
		σ	w_o	σ	w_o	σ	w_o	σ	w_o	
	Tons/acre	*Ft.*$^{-1}$	*Lb./ft.*^{2}	*Ft.*$^{-1}$	*Lb./ft.*^{2}	*Ft.*$^{-1}$	*Lb./ft.*^{2}	*Ft.*$^{-1}$	*Lb./ft.*^{2}	*Ft.*
Grass (short)	0.75	3,500	0.034	--	--	--	--	--	--	1.0
Grass (tall)	3.0	1,500	.138	--	--	--	--	--	--	2.5
Brush (not chaparral)	6.0	2,000	.046	109	0.023	--	--	1,500	0.092	2.0
Chaparral	25.0	2,000	.230	109	.184	30	.092	1,500	.230	6.0
Timber (grass and understory)	4.0	3,000	.092	109	.046	30	.023	1,500	.023	1.5
Timber (litter)	15.0	2,000	.069	109	.046	30	.115	--	--	0.2
Timber (litter and understory)	30.0	2,000	.138	109	.092	30	.230	1,500	.092	1.0
Hardwood (litter)	15.0	2,500	.134	109	.019	30	.007	--	--	0.2
Logging slash (light)	40.0	1,500	.069	109	.207	30	.253	--	--	1.0
Logging slash (medium)	120.0	1,500	.184	109	.644	30	.759	--	--	2.3
Logging slash (heavy)	200.0	1,500	.322	109	1.058	30	1.288	--	--	3.0

[1] For all models $S_t = 0.0555$, $S_e = 0.010$, $h = 8{,}000$ B.t.u./lb., $\rho_b = 32.0$ lb./ft.^{3}, $(M_x)_{dead} = 0.30$, $(M_x)_{living}$ determined by equation 88.

History

Albini added 2 fuel models (6 and 7) to create what we call the “original 13”. He also made extinction moisture content a variable parameter.

Table 7.--*Description of fuel models used in constructing the nomographs*

Model	Typical fuel complexes	Surface-to-volume ratio (ft^{-1})/Loading (lb/ft^2): Dead fuel 1-h	Dead fuel 10-h	Dead fuel 100-h	Live fuel (Foliage)	Depth (ft)	Moisture of extinction, dead fuel (percent)
				GRASS AND GRASS-DOMINATED			
1	Short grass (1 ft)	3500/.034	--	--	--	1.0	12 .74
2	Timber (grass and understory)	3000/.092	109/.046	30/.023	1500/.023	1.0	15 4.01
3	Tall grass (2.5 ft)	1500/.138	--	--	--	2.5	25 3.00
				CHAPARRAL AND SHRUBFIELDS			
4	Chaparral (6 ft)	2000/.230	109/.184	30/.092	1500/.230	6.0	20 16.0
5	Brush (2 ft)	2000/.046	109/.023	--	1500/.092	2.0	20 3.5
6	Dormant brush, hardwood slash	1750/.069	109/.115	30/.092	--	2.5	25 6.01
7	Southern rough	1750/.052	109/.086	30/.069	1550/.017	2.5	40 4.88
				TIMBER LITTER			
8	Closed timber litter	2000/.069	109/.046	30/.115	--	0.2	30 5.01
9	Hardwood litter	2500/.134	109/.019	30/.007	--	.2	25 3.48
10	Timber (litter and understory)	2000/.138	109/.092	30/.230	1500/.092	1.0	25 12.02
				LOGGING SLASH			
11	Light logging slash	1500/.069	109/.207	30/.253	--	1.0	15 11.52
12	Medium logging slash	1500/.184	109/.644	30/.759	--	2.3	20 34.6
13	Heavy logging slash	1500/.322	109/1.058	30/1.288	--	3.0	25 58.1

History

In 1982 Anderson published a guide to the original 13 fuel models, including a selection guide (key) and photographs.

Fuel model	Typical fuel complex	Fuel loading: 1 hour	10 hours	100 hours	Live	Fuel bed depth	Moisture of extinction dead fuels
		Tons/acre				Feet	Percent
	Grass and grass-dominated						
1	Short grass (1 foot)	0.74	0.00	0.00	0.00	1.0	12
2	Timber (grass and understory)	2.00	1.00	.50	.50	1.0	15
3	Tall grass (2.5 feet)	3.01	.00	.00	.00	2.5	25
	Chaparral and shrub fields						
4	Chaparral (6 feet)	5.01	4.01	2.00	5.01	6.0	20
5	Brush (2 feet)	1.00	.50	.00	2.00	2.0	20
6	Dormant brush, hardwood slash	1.50	2.50	2.00	.00	2.5	25
7	Southern rough	1.13	1.87	1.50	.37	2.5	40
	Timber litter						
8	Closed timber litter	1.50	1.00	2.50	0.00	0.2	30
9	Hardwood litter	2.92	.41	.15	.00	.2	25
10	Timber (litter and understory)	3.01	2.00	5.01	2.00	1.0	25
	Slash						
11	Light logging slash	1.50	4.51	5.51	0.00	1.0	15
12	Medium logging slash	4.01	14.03	16.53	.00	2.3	20
13	Heavy logging slash	7.01	23.04	28.05	.00	3.0	25

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History

We did not consider allowing those inputs to vary among the new set either. Their effect on fire behavior in Rothermel's model is small.

- Rothermel (1972) – 11 fuel models
- Albini (1976) – added two models to create the original 13
- Anderson (1982) – described each fuel model
- Many fuel inputs have always been constant for all fuel models
  - 10-h and 100-h dead fuel SAV ratio
  - Total and effective mineral fraction
  - Ovendry fuel particle density

Need

- Cover wider range of seasons

The original fuel model set was designed to be used at the peak of the fire season. For example, the original grass fuel models 1 and 3 are fully cured, with no live component. We wanted to somehow have the new set be better able to predict fire behavior outside the peak fire season (for fire use applications, for example).

Need

- Cover wider range of seasons
- Fill gaps in each fuel type

Within a fuel type (grass, shrub, etc.) there are only a few fuel model choices. In forested fuel types, for example, there were often only two reasonable fuel model choices: 8 and 10. We wished to have more fuel models available in each type.

Need

- Cover wider range of seasons
- Fill gaps in each fuel type
- Better simulate fuel treatments

Many fire management decisions require us to simulate fire behavior before and after treatment. This was difficult with the original set because there were so few choices within a fuel type. For example, fuel treatments in forested fuels were often simulated as model 10 before and model 8 after treatment, only because there were no other choices. We can better simulate fuel treatments just be having more fuel model choices. Also, the new set includes fuel models that predict very low fire behavior, suitable for immediate post-treatment fuels.

Need

- Cover wider range of seasons
- Fill gaps in each fuel type
- Better simulate fuel treatments
- Better drive crown fire initiation models

As currently modeled in fire management applications, the potential for crown fire is determined in part by the predicted surface fire intensity (flame length). Accurate results were difficult to obtain with so few fuel model choices. For example, model 8 predicts very low intensity and therefore low crown fire initiation potential, whereas model 10 predicts much higher intensity and corresponding higher crown fire potential. More fuel models means we can better simulate crown fire initiation.

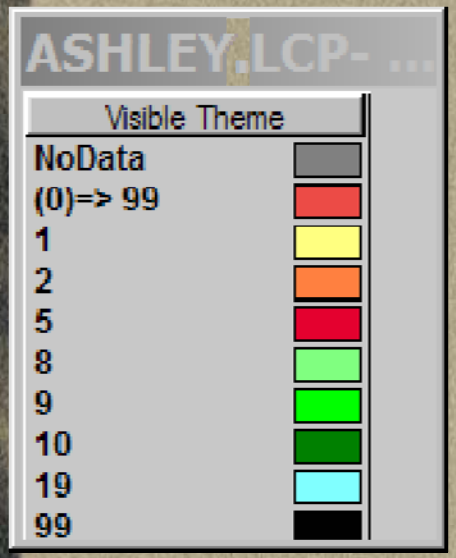
Need

Of course, having a larger set of STANDARD fuel models means that there will be fewer instances where custom fuel modeling is necessary.

- Cover wider range of seasons
- Fill gaps in each fuel type
- Better simulate fuel treatments
- Better drive crown fire initiation models
- Reduce need for custom fuel models

New set: characteristics

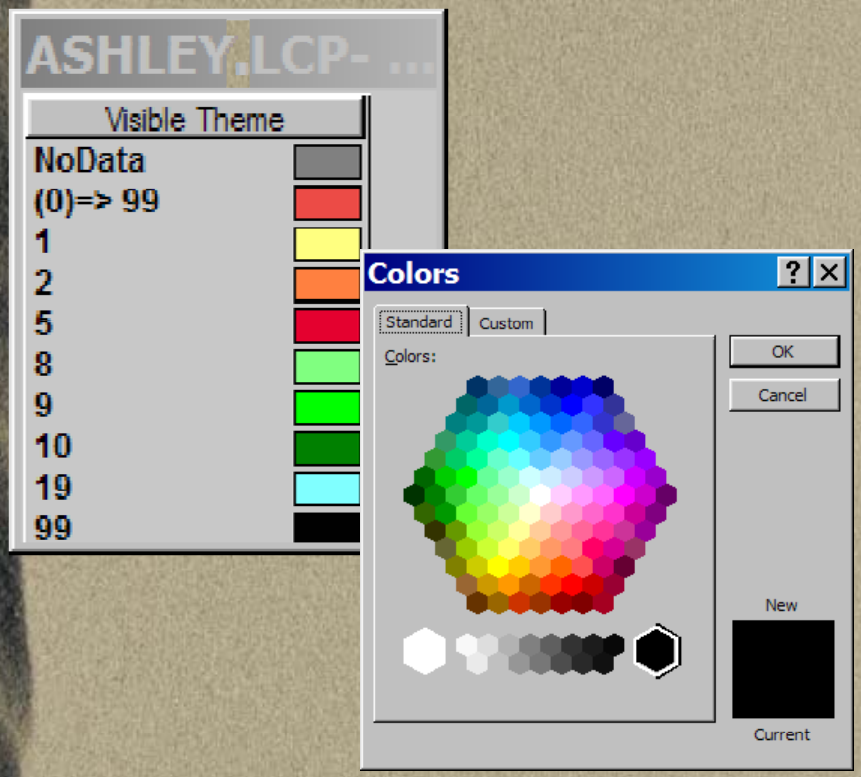
A fuel model set is like a color palette (various combinations of red, green and blue). Using the original 13 fuel models is like shopping for paint at the corner hardware store – they have only a few shades of each color, but there are reds, and greens and blues.



New set: characteristics

Using the new fuel model set is like shopping for paint at a paint store with a huge color wheel. They still have the basic reds and greens and blues, but there are more shades of them.

Also, the EXACT shade of red from the local hardware store is not repeated at the paint store, but there will be several similar shades to choose from.



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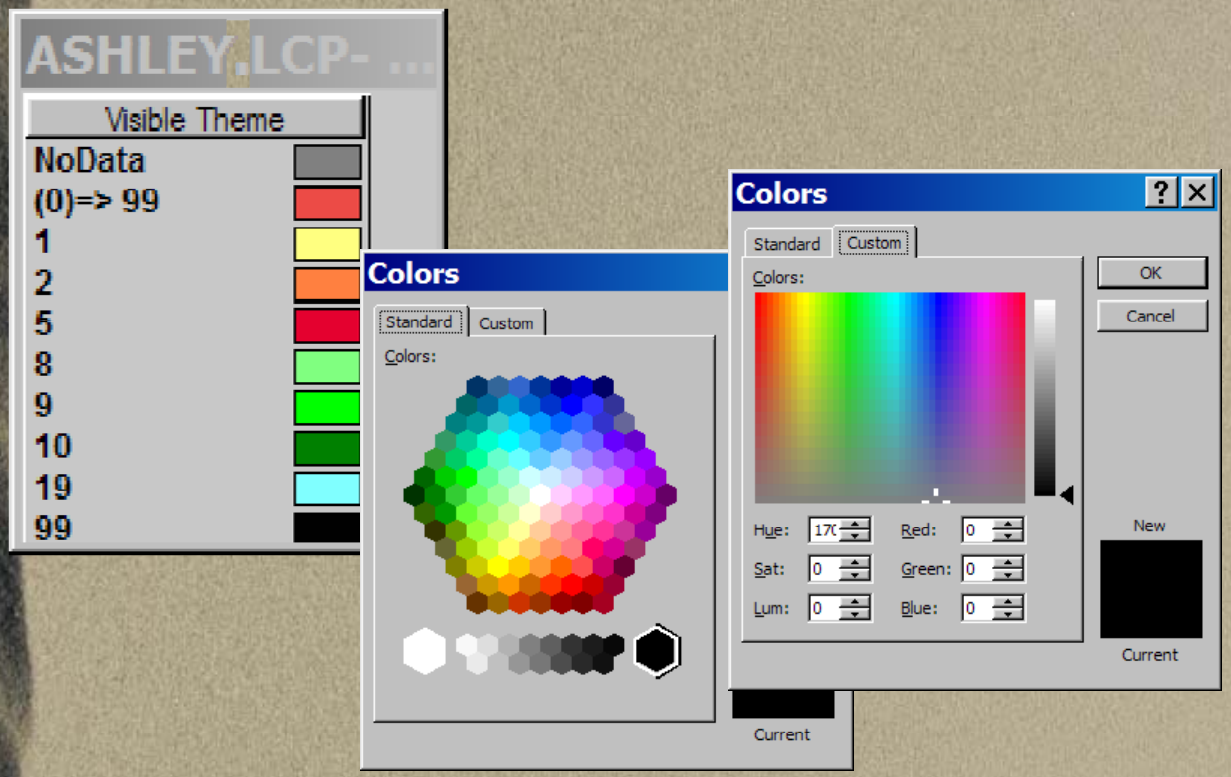
New set: characteristics

When all else fails and you can't find the right standard color at either store, then you can mix a custom paint color. The same is true for fuel models – if no standard fuel model fits the situation, then you can consider creating a custom fuel model.



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Scope

The scope of this project is limited to fuel modeling. We do not address any deficiencies in the fire model itself.

- Not *fire* modeling

Scope

The new fuel model set, like the original, addresses only surface fuels -- not canopy (aerial) fuels, and not ground fuels.

- Not *fire* modeling
- Surface fuel only

Scope

- Not *fire* modeling
- Surface fuel only
- Rothermel's surface fire spread model only

Not only is the set limited to surface fuels, but it is also limited to Rothermel's surface fire spread model. Testing would be required to confirm if the fuel models would be appropriate for any other spread model.

Scope

- Not *fire* modeling
- Surface fuel only
- Rothermel's surface fire spread model only
- Same fuelbed assumptions

The same assumptions of homogeneity, continuity and uniformity apply to the new fuel model set as well as the original. In fact, those assumptions really apply to Rothermel's fire spread model (including custom fuel models), not the fuel models.

Development

We began by compiling data from the Natural Fuel Photo Series Volumes and other sources, using those data to suggest the range of fuel characteristics for which we needed fuel models.

- Natural Fuels Photo Series

Development

- Natural Fuels Photo Series
- Grouped data subjectively

Second, we subjectively assigned characteristics like fuel type, moisture of extinction and fuelbed depth, then made groups according to that rough classification.

This process resulted in 50-60 apparently distinct groups.

Development

Next, we created draft fuel models based loosely on data from each group.

- Natural Fuels Photo Series
- Grouped data subjectively
- Created draft fuel models

Development

- Natural Fuels Photo Series
- Grouped data subjectively
- Created draft fuel models
- Eliminated models

We simulated fire behavior for each of our draft fuel models and discovered that, although the groups appeared to be distinct in terms of fuels, they were too similar in terms of fire behavior to retain in the set. We therefore eliminated models with similar fire behavior.

Development

Also, there were still gaps in fire behavior that we wanted to be able to simulate with the new set. We added a couple of stylized fuel models (not based on fuel data) to predict specific fire behaviors.

- Natural Fuels Photo Series
- Grouped data subjectively
- Created draft fuel models
- Eliminated models
- Added models

Development

- Natural Fuels Photo Series
- Grouped data subjectively
- Created draft fuel models
- Eliminated models
- Added models
- Adjusted fuel model parameters

With the set nearly complete, we then adjusted fuel model parameters of individual fuel models to coordinate fire behavior among models in a fuel type. For example, if there were three models in progression, we adjusted parameters such that the middle model in the group simulated fire behavior roughly half-way between the similar fuel models.

Development

Finally, we took input from about three dozen fire behavior researchers and fire managers.

- Natural Fuels Photo Series
- Grouped data subjectively
- Created draft fuel models
- Eliminated models
- Added models
- Adjusted fuel model parameters
- Incorporated input

Characteristics

- Designed to stand alone

This new set of fuel models is designed to stand alone – it is a complete set by itself. None of the original 13 fuel models is repeated exactly in the new set (there are several choices similar to each original fuel model). A fuel model selection guide in the printed documentation points to a new fuel model only, not one of the original 13.

Characteristics

- Designed to stand alone
- Original 13 still available

However – this is important if you're nearing retirement and don't want to learn new things – the original 13 fuel models are still available for use in the fire behavior systems. There is no immediate need to convert existing fire behavior analyses to the new fuel models. However, you should consider using the fuel models when starting a new fire behavior analysis.

Characteristics

- Designed to stand alone
- Original 13 still available
- Specifies fuelbeds not vegetation

Any one fuel model can be applied in a great variety of vegetation types, so we refer to fuelbeds rather than vegetation ("heavy load of tall shrubs", not "Chaparral").

Also, different fuel models may be applied to the same nominal vegetation type in different regions. Vegetation type can be important for selecting a fuel model, but that effort must be done at the local or regional level.

Naming

- Three-part naming convention

We devised a three-part naming convention for the new fuel model set. We needed to satisfy both beginning fire modelers and spatial analysts; each group has different requirements.

Naming

- Three-part naming convention
  - Fuel model code

The fuel model code is a three-place alpha-numeric code designed for user communication. The first two places indicate the fire-carrying fuel type. For example, GR1 (say “grass one” or “GEE-ARR ONE”) is in the grass fuel type.

The numeric values of the code indicate the relative ranking of the fuel models within a fuel type. The ranking is based on heat per unit area (HPA) at given fuel moisture contents. This ranking does not necessarily hold true for spread rate or intensity.

Naming

- Three-part naming convention
  - Fuel model code

For backwards compatibility in some fire behavior applications, the original 13 fuel models may be numbered 1-13 without any alpha characters. In reports and other documents, the characters FM, FBFM, or NFFL preceding a fuel model number indicate one of the original 13 fuel models.

Naming

- Three-part naming convention
  - Fuel model code
  - Fuel model number

Each fuel model also has been assigned an 8-bit number (between 1 and 256). This number is used in mapping (GIS) and computer applications. Ideally, only programmers or spatial analysts need to know the fuel model numbers, but others may occasionally need to use them as well.

The fuel model numbers are grouped by fuel type. The numbering scheme can accommodate future standard fuel models as well as custom fuel models.

Naming

The new fuel model set includes 5 “non-burnable” fuel models: urban, snow/ice, agricultural, water and bare ground. These are included to help with orientation on a fuel model map.

To be consistent with FARSITE, the “non-burnable” models are numbered in the 90s; 98 and 99 still refer to water and rock.

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	94-95	90, 96-97
CR	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

Prepared by Joe H. Scott, SEM

Naming

Fuel models are grouped in similar fashion to the original 13.

First are the grass models...

Then the shrub models...

Then the timber models...

And finally the slash/blowdown 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	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

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Naming

The hybrid grass-shrub (GS) models are between the GR and SH models

The timber models with a grass or shrub understory are between the TL and SH 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	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

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Naming

A set of 20 fuel model numbers is assigned to each of the six fuel types.

For example, fuel model numbers 100-119 refer to GR fuel models. Of that block, 101-109 (corresponding to GR1-GR9) are used in the standard set. Numbers 110-112 are reserved for possible future standard models, and 113-119 (and 100) are available for numbering custom fuel models.

This system allow easy crosswalk between code and number – for example, 165 is TU5.

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	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

Naming

- Three-part naming convention
  - Fuel model code
  - Fuel model number
  - Fuel model name

The last part of the naming convention is a descriptive name of the fuel model – Heavy load tall brush, for example. The name may include a reference to climate (arid vs. humid). Arid-climate fuel models tend to have lower extinction moisture contents, whereas humid-climate fuel models tend to have higher extinction moisture contents.

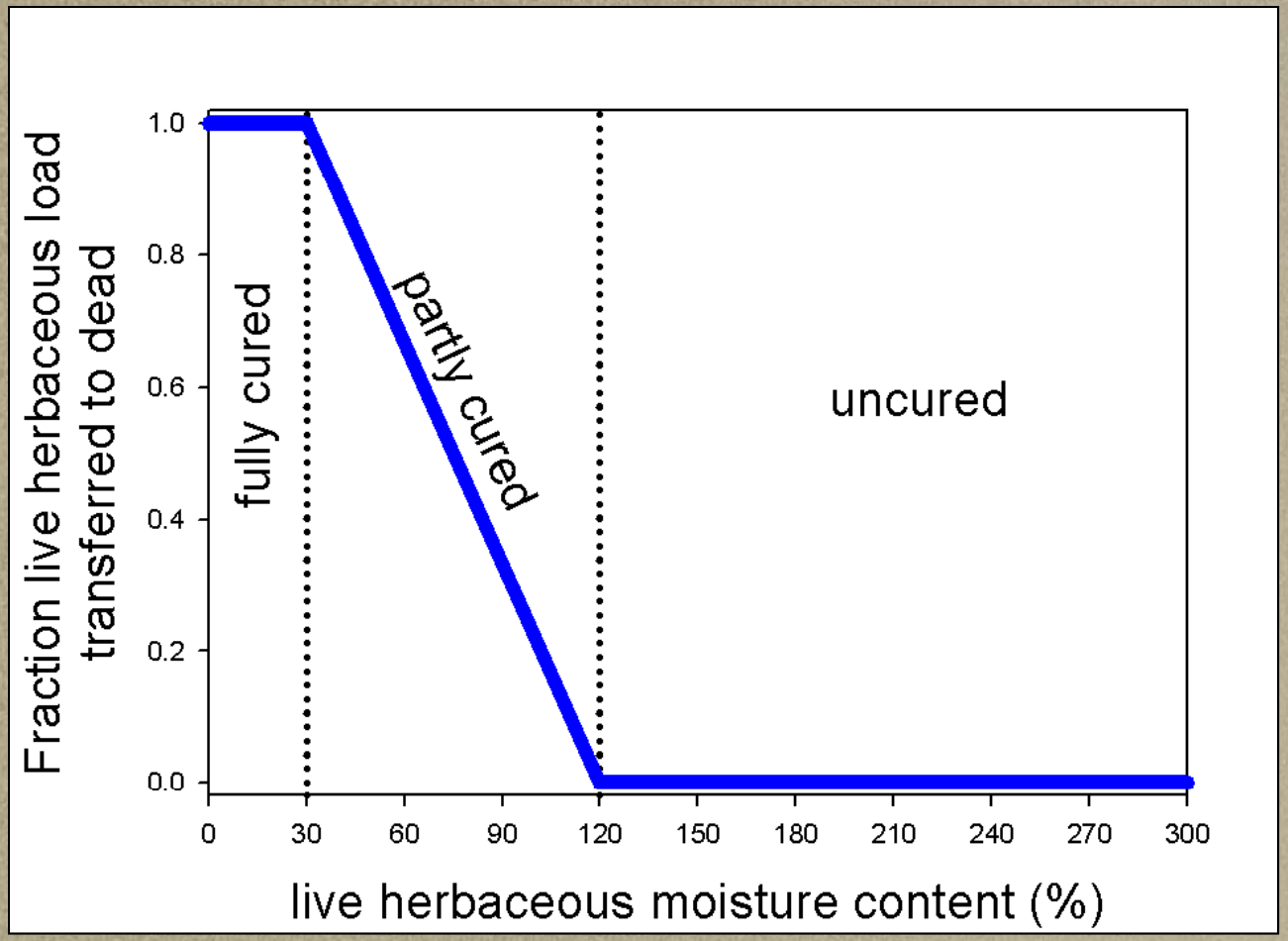
Dynamic fuel models

- Transfer of herbaceous load from live to dead

With this new fuel model set we have employed the dynamic fuel model concept previously used in NFDRS to fire behavior modeling. Dynamic fuel modeling is the transfer of herbaceous (grass) load between live and dead categories. In the new set, all herbaceous load is specified as live, then the dynamic modeling transfers all or some of that load to dead.

Dynamic fuel models

The transfer of load from live to dead is a simple function of live herbaceous moisture content (LHMC).



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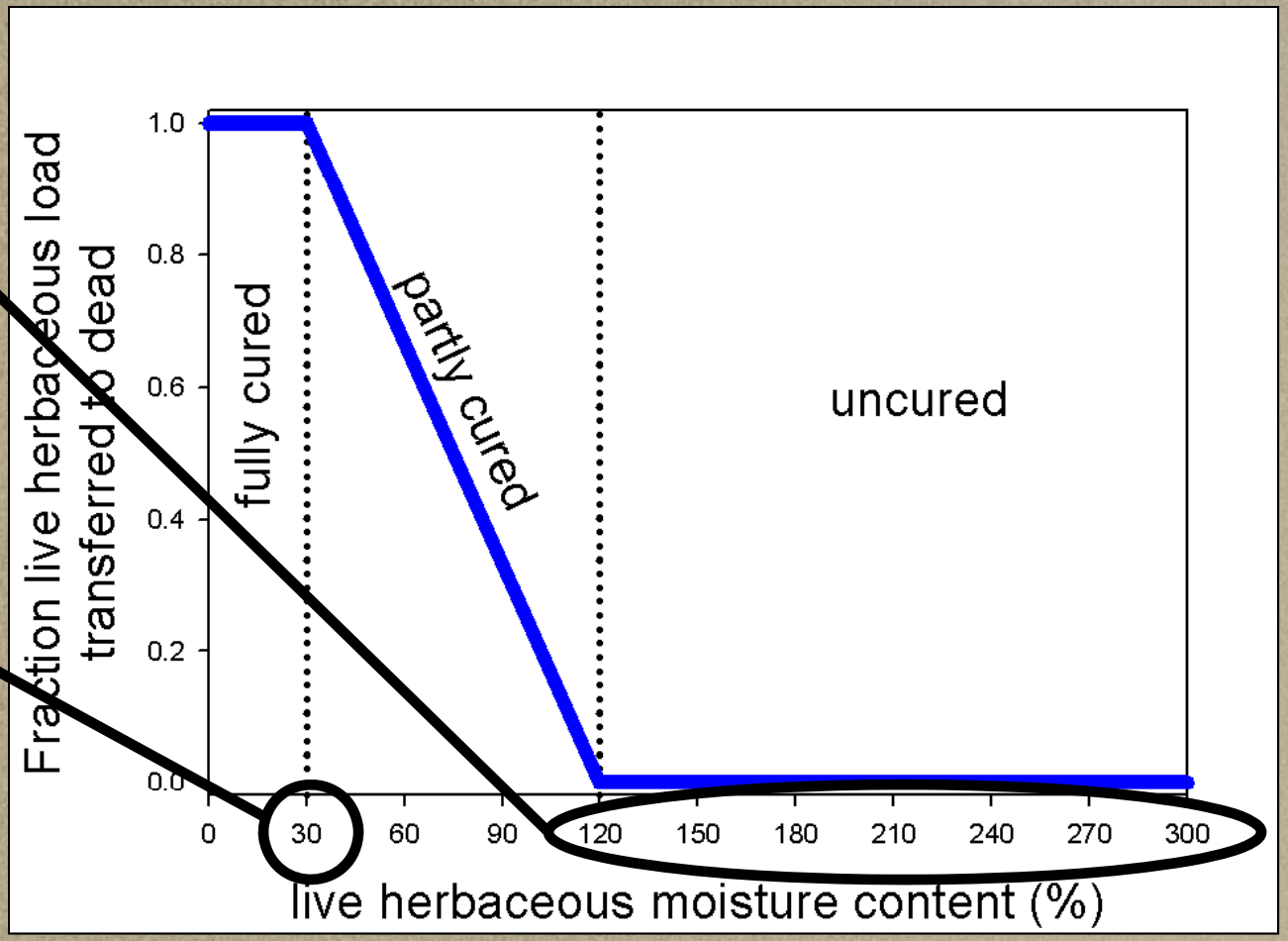
Dynamic fuel models

For LHMC greater than 120 percent, herbaceous fuels are considered UNCURED (fully green), and none of the load is transferred to dead.

For LHMC of 30 percent (fully cured), ALL of the live herb load is transferred to dead (fraction transferred = 1.0); none remains in the live category.



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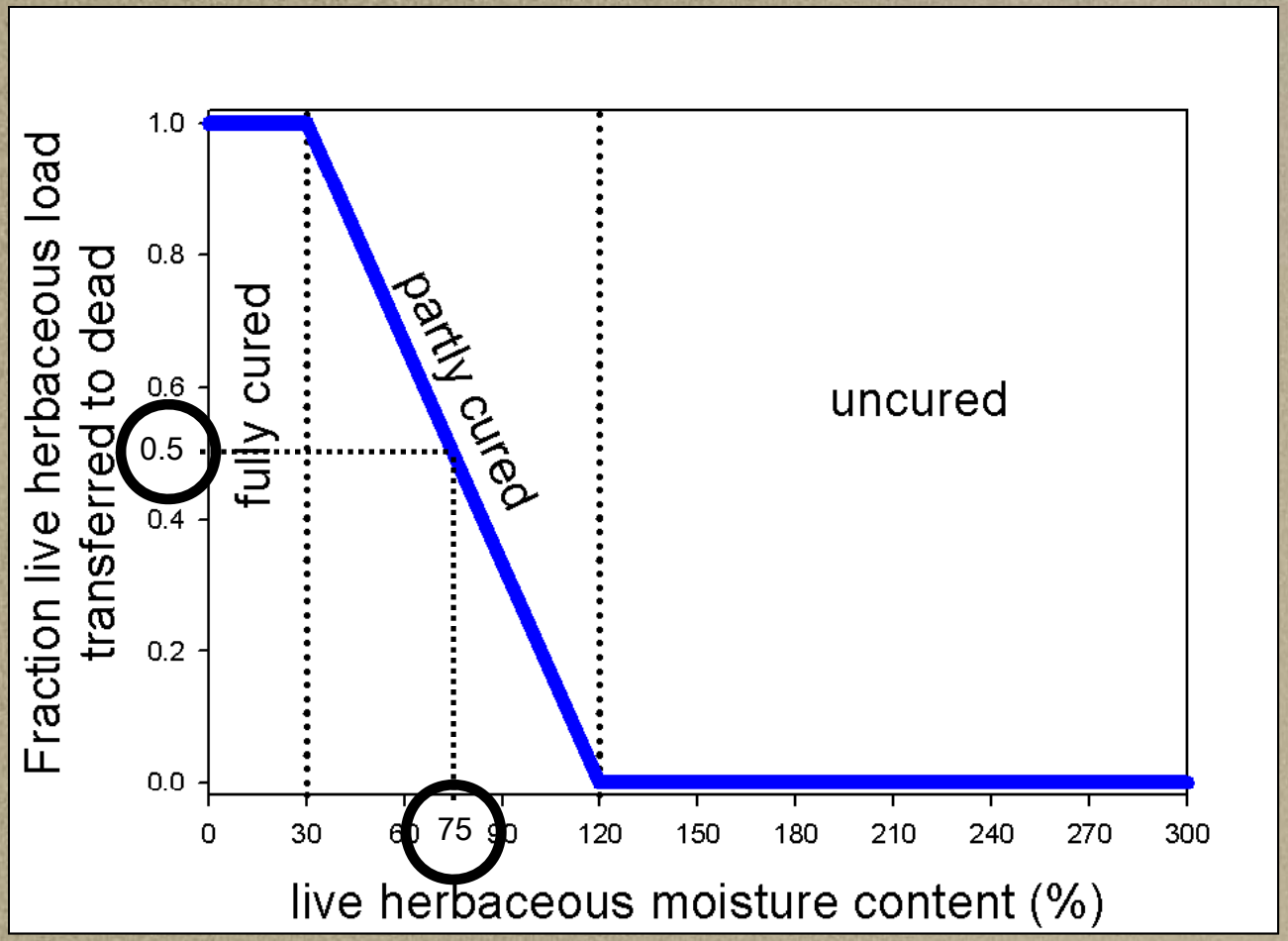
Dynamic fuel models

For LHMC between 30 and 120 percent, the fuelbed is considered partly cured. The fraction of load transferred is proportional to how far the LHMC is from 30 and 120 percent.

For example, at 75 percent LHMC (half-way between 30 and 120 percent), half of the live herb load (fraction transferred = 0.5) is transferred to dead.



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Dynamic fuel models

For convenience in the fire behavior processors, the herbaceous load transferred to dead is given the same moisture content value as the dead 1-h timelag class already specified. You need not (and can not) specify a moisture content value specifically for the dead herbaceous fuel.

- Transfer of herbaceous load from live to dead
- Function of live herbaceous MC
- Takes on dead 1-hr MC

Dynamic fuel models

Although transferred load takes on the dead 1-h timelag moisture content, the surface-area-to-volume (SAV) ratio of the transferred herbaceous fuel is preserved after transfer – dead and live herbaceous fuel have the same SAV ratio, whereas dead 1-h timelag and dead herbaceous fuels may have different SAV ratios. Preserving SAV ratio of transferred load maintains a constant characteristic SAV ratio of the fuel model throughout all levels of curing.

- Transfer of herbaceous load from live to dead
- Function of live herbaceous MC
- Takes on dead 1-hr MC
- Preserves live herbaceous SAV ratio

Prepared by Joe H. Scott, SEM

Dynamic fuel models

Dynamic fuel modeling greatly improves our ability to simulate fire behavior in non-cured herbaceous fuels. However, we now have another very important fuel input – live herbaceous moisture content.

Don't worry about directly measuring or estimating LHMC. Instead, think first of the level of curing, then use the appropriate LHMC associated with that level of curing. For example, for a grass fuelbed observed to be about two-thirds cured, use LHMC = 60 percent.

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

- Increases ability (and difficulty)

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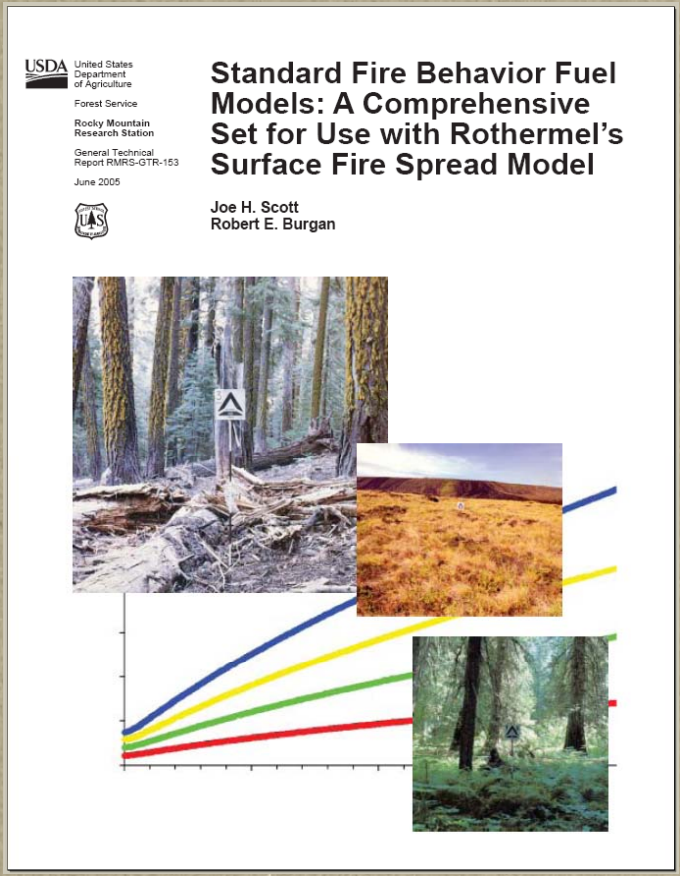
Documentation

The primary documentation of the new set of fuel models is GTR-153 (Scott and Burgan 2005). The report includes illustrative photos, a selection guide, crosswalks from the original to the new fuel models, fuel model descriptions, and charts of predicted fire behavior over a range of wind speeds. It is available at treesearch.fs.fed.us

- Printed GTR



USDA United States Department of Agriculture

Forest Service

Rocky Mountain Research Station

General Technical Report RMRS-GTR-153

June 2005

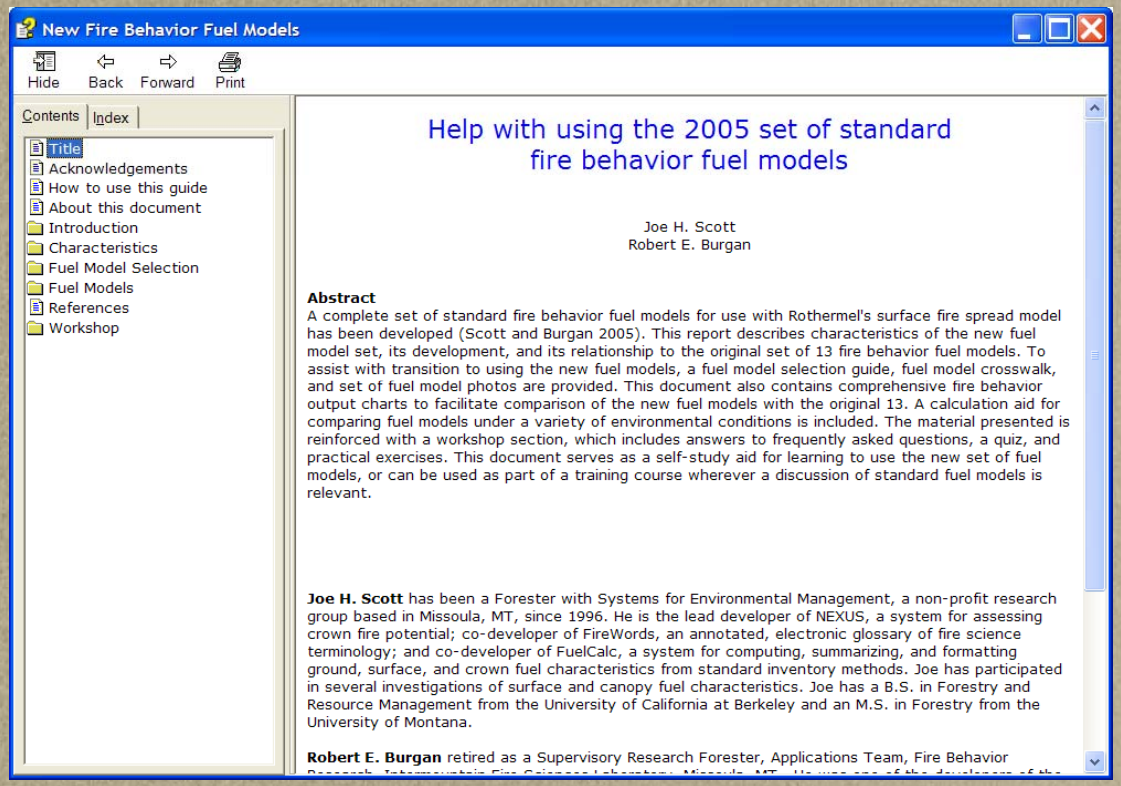
Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model

Joe H. Scott
Robert E. Burgan

Documentation

We have also created an HTML help file (similar to the help file for a computer program). The electronic file includes the content of the printed GTR (hyperlinked) plus a more comprehensive set of fire behavior charts, a Q&A section, quiz and exercises. The help file can be viewed on any Windows computer, and is available for download at frames.nbii.gov (in the fuels section).

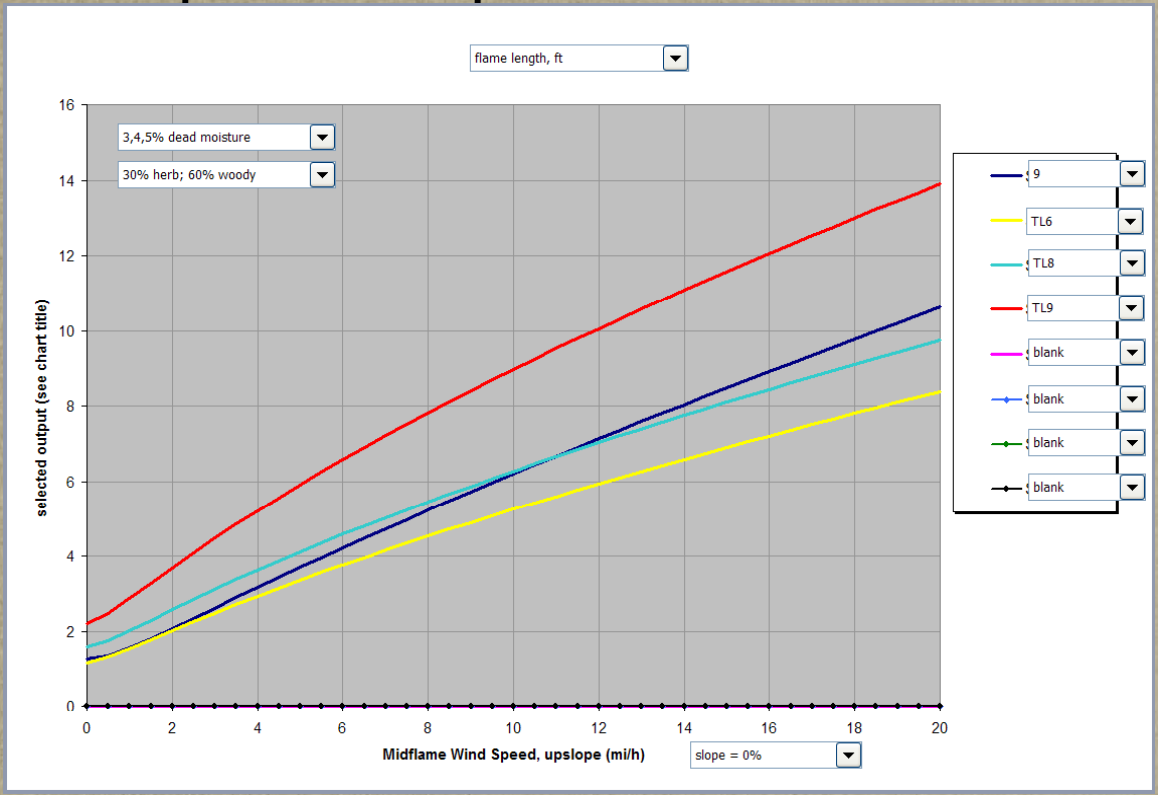
- Printed GTR
- HTML tech transfer document



Documentation

To assist in learning the relative behavior of the new models (with respect to each other and to the original 13 fuel models) we have created an Excel spreadsheet that allows you to explore the fire behavior characteristics for any of the original or new fuel models under a range of midflame wind speeds and fuel moisture contents. The spreadsheet is also available at the FRAMES website.

- Printed GTR
- HTML tech transfer document
- Comparison spreadsheet



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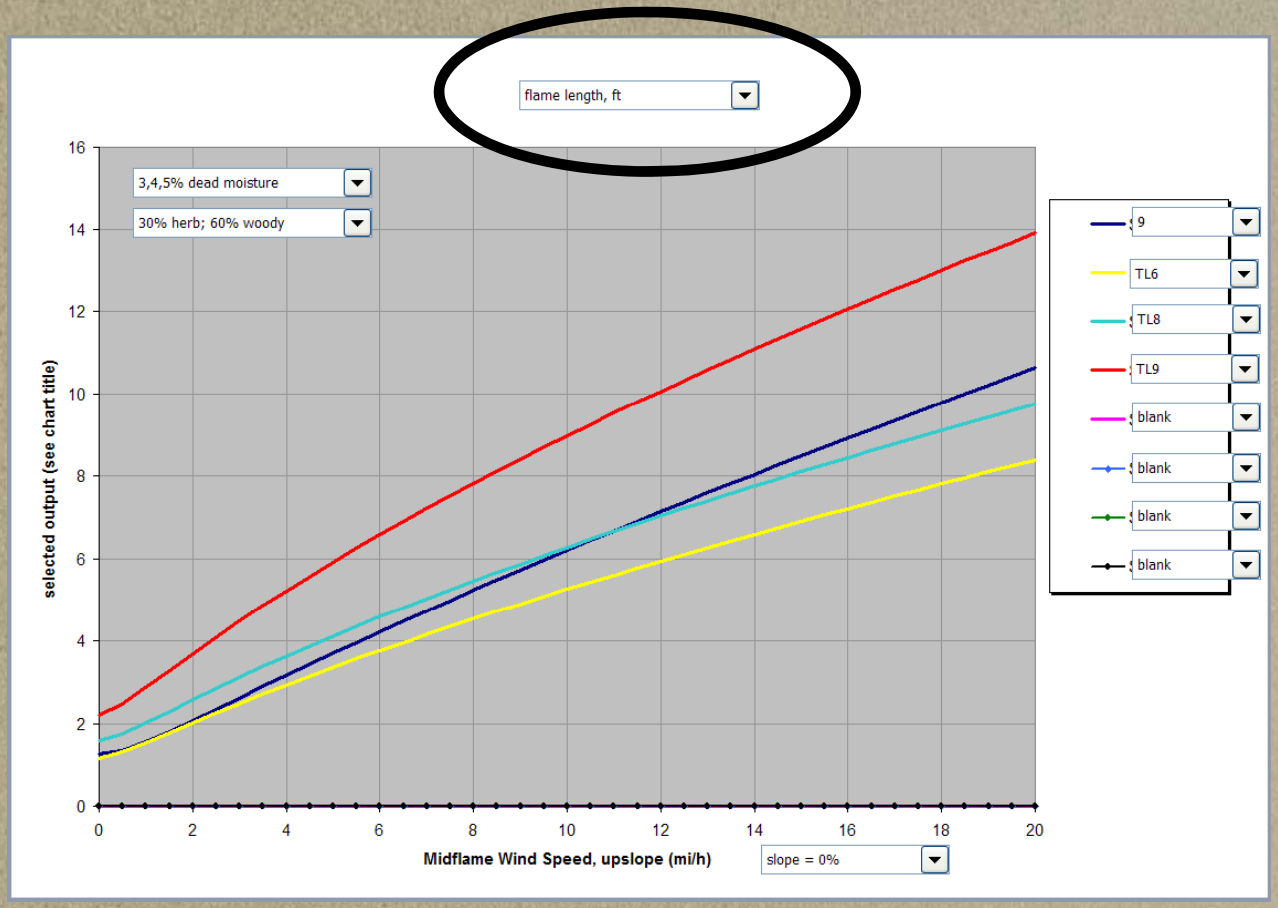
Documentation

Select the fire characteristic you would like to view at the top of the chart.

Choices are:

- rate of spread
- Fireline intensity
- Flame length
- Heat per unit area



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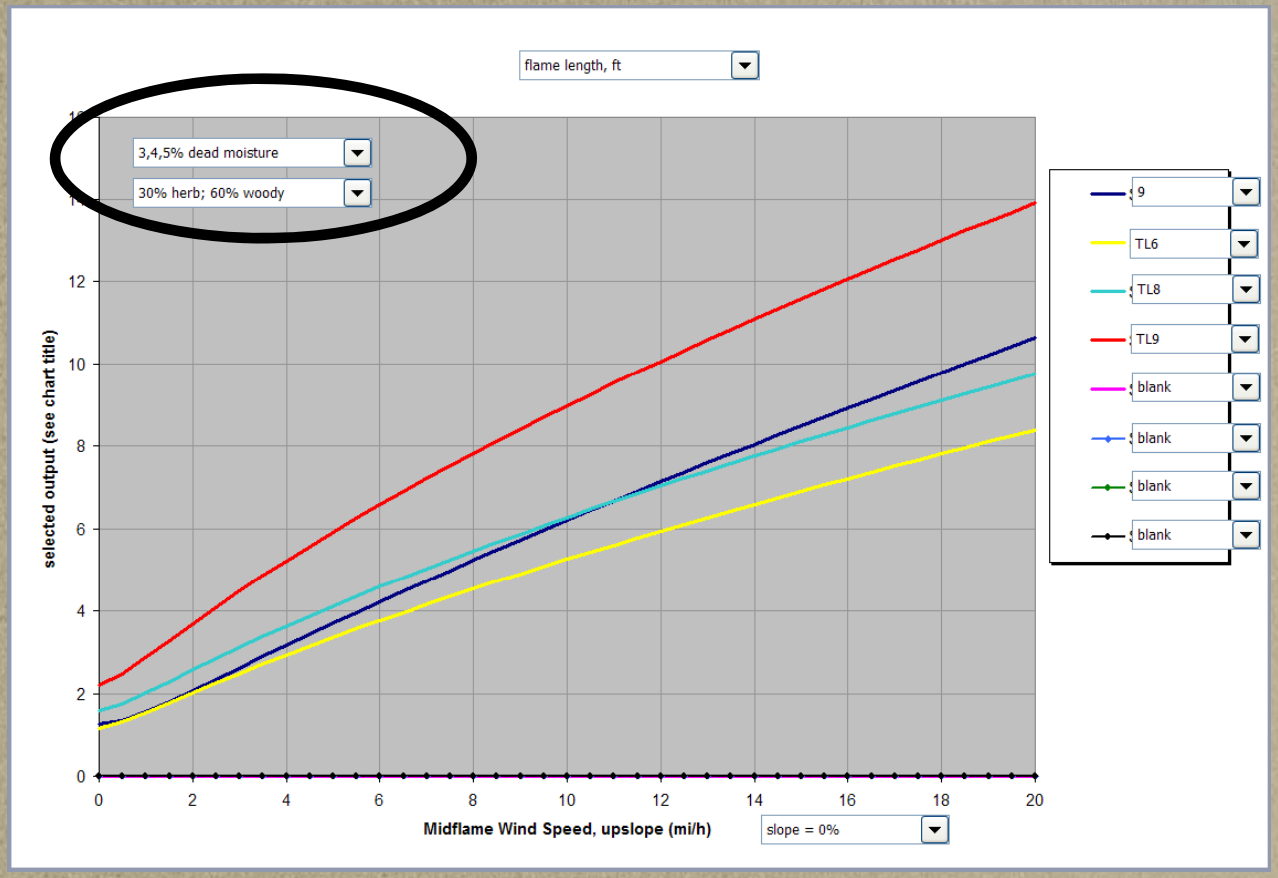
Documentation

Select the live and dead fuel moisture scenarios you would like to use. The moisture scenarios are described in both the help file and GTR.



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Documentation

Select the slope steepness to use. Wind direction is always assumed to be upslope. In most cases you will want to use flat ground (slope = 0 percent)

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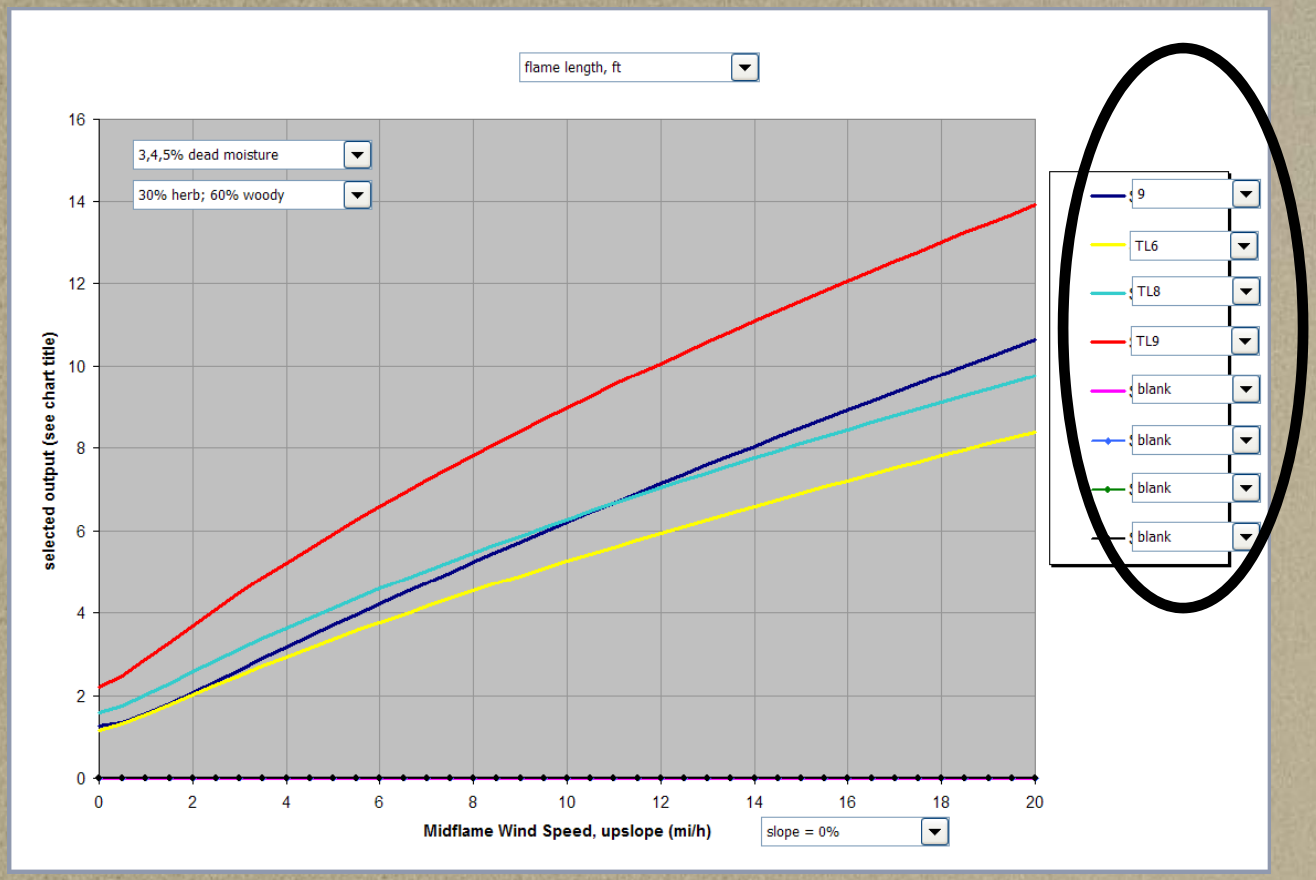
Documentation

Finally, select the combination of original and new fuel models to compare. You may compare up to 8 models at one time.

The chart is updated automatically whenever a change is made to any of the settings.



Prepared by Joe H. Scott, SEM

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- Funding from LANDFIRE

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- Work by SEM

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- Funding from LANDFIRE
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- Administration through Fire Behavior project
- Photos and data provided by PNW Research Station and other sources

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- Administration through Fire Behavior project
- Photos and data provided by PNW Research Station and other sources
- Tech transfer by WO fire technology transfer program

That's it. Thank you for taking the time to learn more about the new set of fire behavior fuel models. To learn more, please read the GTR and download the supporting help file and spreadsheet.

Prepared by Joe H. Scott, SEM

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Prepared by Joe H. Scott, SEM