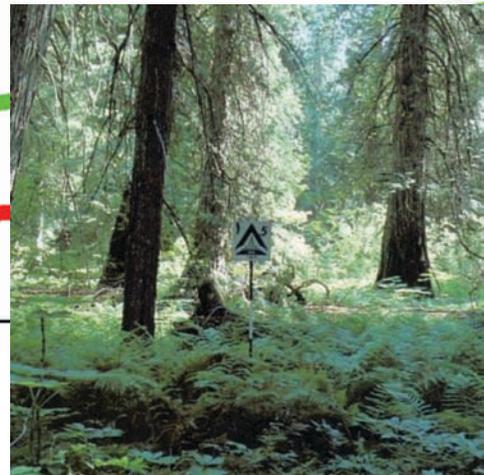
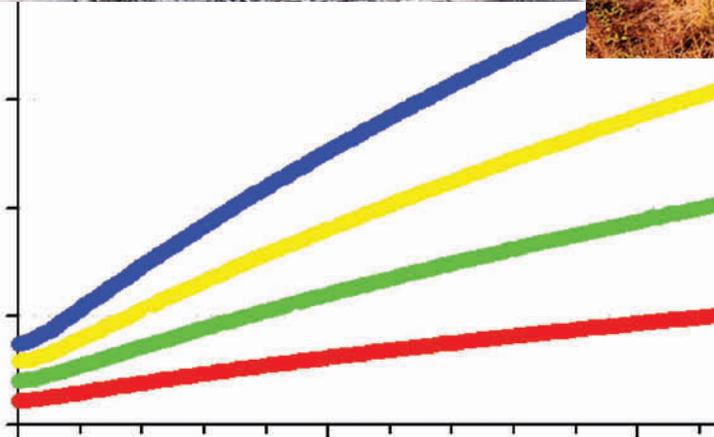
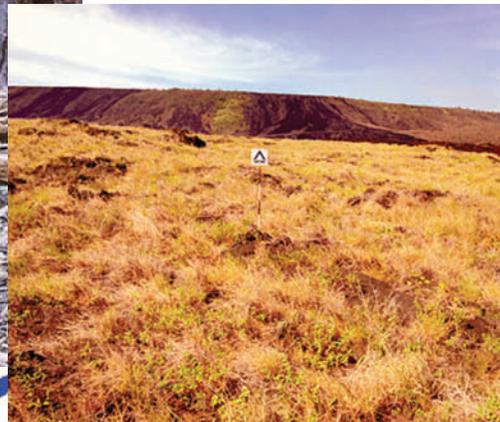




Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model

Joe H. Scott
Robert E. Burgan



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 <u>Fully cured</u> Very low	L2 <u>Two-thirds cured</u> Low	L3 <u>One-third cured</u> Moderate	L4 <u>Fully green (uncured)</u> 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 an area already designated as one of the 13 original fuel models and you want guidance on selecting one of the new models for that area. 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.

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 versus dry). That is, fuel models for dry areas tend to have lower dead fuel moistures of extinction, while fuel models for wet humid areas tend to have higher moistures of extinction.

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

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

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

Table 5—Adjective class definitions for predicted fire behavior.

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

The general fire-carrying fuel type is:

1. Nearly pure grass and/or forb type (Grass)

- a. Arid to semiarid climate (rainfall deficient in summer). Extinction moisture content is 15 percent.
 - i. **GR1** Grass is short, patchy, and possibly heavily grazed. Spread rate moderate; flame length low.
 - ii. **GR2** Moderately coarse continuous grass, average depth about 1 foot. Spread rate high; flame length moderate.
 - iii. **GR4** Moderately coarse continuous grass, average depth about 2 feet. Spread rate very high; flame length high.
 - iv. **GR7** Moderately coarse continuous grass, average depth about 3 feet. Spread rate very high; flame length very high.
- b. Subhumid to humid climate (rainfall adequate in all seasons). Extinction moisture content is 30 to 40 percent.
 - i. **GR1** Grass is short, patchy, and possibly heavily grazed. Spread rate moderate; flame length low.
 - ii. **GR3** Very coarse grass, average depth about 2 feet. Spread rate high; flame length moderate.
 - iii. **GR5** Dense, coarse grass, average depth about 1 to 2 feet. Spread rate very high; flame length high.
 - iv. **GR6** Dryland grass about 1 to 2 feet tall. Spread rate very high; flame length very high.
 - v. **GR8** Heavy, coarse, continuous grass 3 to 5 feet tall. Spread rate very high; flame length very high.
 - vi. **GR9** Very heavy, coarse, continuous grass 5 to 8 feet tall. Spread rate extreme; flame length extreme.

2. Mixture of grass and shrub, up to about 50 percent shrub coverage (Grass-Shrub)

- a. Arid to semiarid climate (rainfall deficient in summer). Extinction moisture content is 15 percent.
 - i. **GS1** Shrubs are about 1 foot high, low grass load. Spread rate moderate; flame length low.
 - ii. **GS2** Shrubs are 1 to 3 feet high, moderate grass load. Spread rate high; flame length moderate.
- b. Subhumid to humid climate (rainfall adequate in all seasons). Extinction moisture content is 30 to 40 percent.
 - i. **GS3** Moderate grass/shrub load, average grass/shrub depth less than 2 feet. Spread rate high; flame length moderate.
 - ii. **GS4** Heavy grass/shrub load, depth greater than 2 feet. Spread rate high; flame length very high.

3. Shrubs cover at least 50 percent of the site; grass sparse to nonexistent (Shrub)

- a. Arid to semiarid climate (rainfall deficient in summer). Extinction moisture content is 15 percent.
 - i. **SH1** Low shrub fuel load, fuelbed depth about 1 foot; some grass may be present. Spread rate very low; flame length very low.
 - ii. **SH2** Moderate fuel load (higher than SH1), depth about 1 foot, no grass fuel present. Spread rate low; flame length low.
 - iii. **SH5** Heavy shrub load, depth 4 to 6 feet. Spread rate very high; flame length very high.

- iv. **SH7** Very heavy shrub load, depth 4 to 6 feet. Spread rate lower than SH5, but flame length similar. Spread rate high; flame length very high.
- b. Subhumid to humid climate (rainfall adequate in all seasons). Extinction moisture content is 30 to 40 percent.
 - i. **SH3** Moderate shrub load, possibly with pine overstory or herbaceous fuel, fuel bed depth 2 to 3 feet. Spread rate low; flame length low.
 - ii. **SH4** Low to moderate shrub and litter load, possibly with pine overstory, fuel bed depth about 3 feet. Spread rate high; flame length moderate.
 - iii. **SH6** Dense shrubs, little or no herb fuel, depth about 2 feet. Spread rate high; flame length high.
 - iv. **SH8** Dense shrubs, little or no herb fuel, depth about 3 feet. Spread rates high; flame length high.
 - v. **SH9** Dense, finely branched shrubs with significant fine dead fuel, about 4 to 6 feet tall; some herbaceous fuel may be present. Spread rate high, flame length very high.

4. Grass or shrubs mixed with litter from forest canopy (Timber-Understory)

- a. Semiarid to subhumid climate. Extinction moisture content is 20 percent.
 - i. **TU1** Fuelbed is low load of grass and/or shrub with litter. Spread rate low; flame length low.
 - ii. **TU4** Fuelbed is short conifer trees with grass or moss understory. Spread rate moderate; flame length moderate.
 - iii. **TU5** Fuelbed is high load conifer litter with shrub understory. Spread rate moderate; flame length moderate.
- b. Humid climate. Extinction moisture content is 30 percent.
 - i. **TU2** Fuelbed is moderate litter load with shrub component. Spread rate moderate; flame length low.
 - ii. **TU3** Fuelbed is moderate litter load with grass and shrub components. Spread rate high; flame length moderate.

5. Dead and down woody fuel (litter) beneath a forest canopy (Timber Litter)

- a. Fuelbed is recently burned but able to carry wildland fire.
 - i. **TL1** Light to moderate load, fuels 1 to 2 inches deep. Spread rate very low; flame length very low.
- b. Fuelbed not recently burned.
 - i. Fuelbed composed of broadleaf (hardwood) litter.
 - 1. **TL2** Low load, compact. Spread rate very low; flame length very low.
 - 2. **TL6** Moderate load, less compact. Spread rate moderate; flame length low.
 - 3. **TL9** Very high load, fluffy. Spread rate moderate; flame length moderate.
 - ii. Fuelbed composed of long-needle pine litter.
 - 1. **TL8** moderate load and compactness may include small amount of herbaceous load. Spread rate moderate; flame length low.
 - iii. Fuelbed not composed broadleaf or long-needle pine litter.
 - 1. Fuelbed includes both fine and coarse fuels.
 - a. **TL4** Moderate load, includes small diameter downed logs. Spread rate low; flame length low.
 - b. **TL7** Heavy load, includes larger diameter downed logs. Spread rate low; flame length low.
 - 2. Fuelbed does not include coarse fuels.
 - a. **TL3** Moderate load conifer litter. Spread rate very low; flame length low.

- b. **TL5** High load conifer litter; light slash or mortality fuel. Spread rate low; flame length low.
- c. **TL9** Very high load broadleaf litter; heavy needle-drape in otherwise sparse shrub layer. Spread rate moderate; flame length moderate.

6. Activity fuel (slash) or debris from wind damage (blowdown) (Slash-Blowdown)

- a. Fuelbed is activity fuel.
 - i. **SB1** Fine fuel load is 10 to 20 tons/acre, weighted toward fuels 1 to 3 inches diameter class, depth is less than 1 foot. Spread rate moderate; flame length low.
 - ii. **SB2** Fine fuel load is 7 to 12 tons/acre, evenly distributed across 0 to 0.25, 0.25 to 1, and 1 to 3 inch diameter classes, depth is about 1 foot. Spread rate moderate; flame length moderate.
 - iii. **SB3** Fine fuel load is 7 to 12 tons/acre, weighted toward 0 to 0.25 inch diameter class, depth is more than 1 foot. Spread rate high; flame length high.
- b. Fuelbed is blowdown.
 - i. **SB2** Blowdown is scattered, with many trees still standing. Spread rate moderate; flame length moderate.
 - ii. **SB3** Blowdown is moderate, trees compacted to near the ground. Spread rate high; flame length high.
 - iii. **SB4** Blowdown is total, fuelbed not compacted, foliage still attached. Spread rate very high; flame length very high.

7. Insufficient wildland fuel to carry wildland fire under any condition (Nonburnable)

- a. **NB1** Urban or suburban development; insufficient wildland fuel to carry wildland fire.
- b. **NB2** Snow/ice.
- c. **NB3** Agricultural field, maintained in nonburnable condition.
- d. **NB8** Open water.
- e. **NB9** Bare ground.

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 (table 6).

Note: We computed the relative change in fire behavior between original and new models using 5 miles/hour 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.

There is a crosswalk table for each major fire-carrying fuel type of the original 13 fuel models. The crosswalk uses adjective classes to compare spread rate and flame length between the original 13 fuel models and their related models from the new set.

Fuel Model Page

A fuel model page consists of:

- The three-part fuel model naming
- A set of three photos
- A brief description of the fuel model
- A summary of computed fuel model characteristics
- A pair of charts depicting fire behavior over a range of midflame wind speeds

Further details follow.

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. The fuel model code is used for oral and written communication and for input to fire behavior models. The fuel model number is used internally by some fire behavior models and for mapping applications. The fuel model name is a brief description of the fuel model.

Photos—Up to three representative photos were selected to illustrate each fuel model. Conditions other than those illustrated may still be appropriate for the fuel model; use the photos as a general guide only.

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

Summary characteristics—Summary characteristics of each fuel model include fine fuel load, characteristic surface-area-to-volume ratio (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 the new set of 40 fuel models, fine fuel load ranges from 0.30 to 13.05 tons/acre.

Characteristic SAV is the average SAV across all fuel classes and categories, weighted by the surface area within each class and category. Characteristic SAV ranges from 1,144 to 2,216 1/ft in this new set of fuel models.

Packing ratio is the fraction of 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 determines (in part) fire behavior. Thus, for a given dead fuel moisture content, predicted fire spread increases with increasing extinction moisture content.

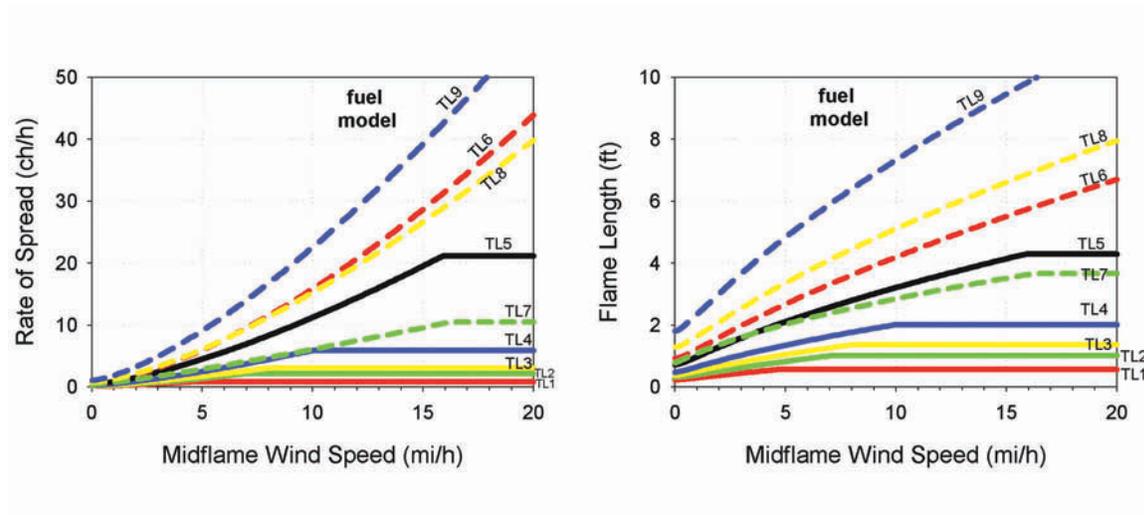
Fire behavior charts—A pair of charts depicts predicted fire behavior (spread rate and flame length) for each fuel model over a range of midflame wind speeds. All predictions use live moisture scenario L2 (60 percent live herbaceous moisture content, 90 percent live woody), which corresponds to a two-thirds cured herbaceous fuelbed. The four lines on each chart refer to dead fuel moisture scenarios (table 3).

Nonburnable Fuel Type Models (NB)

The nonburnable “fuel models” are included on the next five pages to provide consistency in how the nonburnable 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.

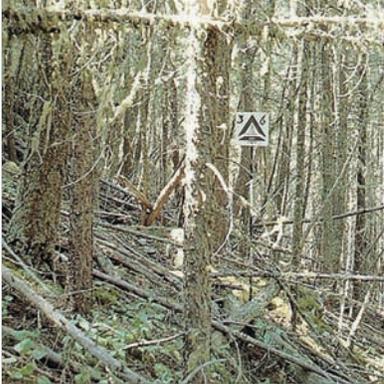
Timber Litter Fuel Type Models (TL)

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.



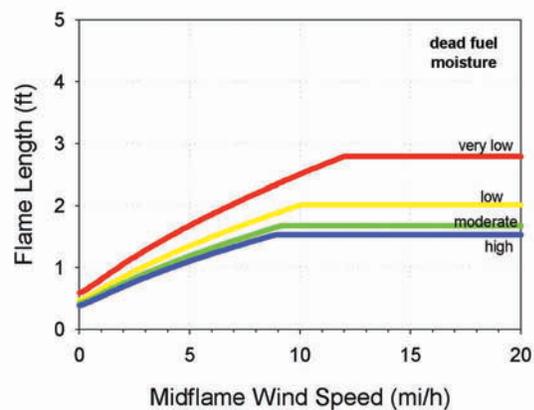
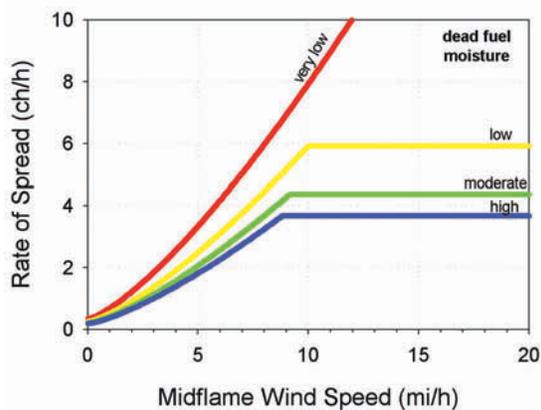
TL4 (184)

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.

Fine fuel load (t/ac)	0.50
Characteristic SAV (ft-1)	1568
Packing ratio (dimensionless)	0.02224
Extinction moisture content (percent)	25



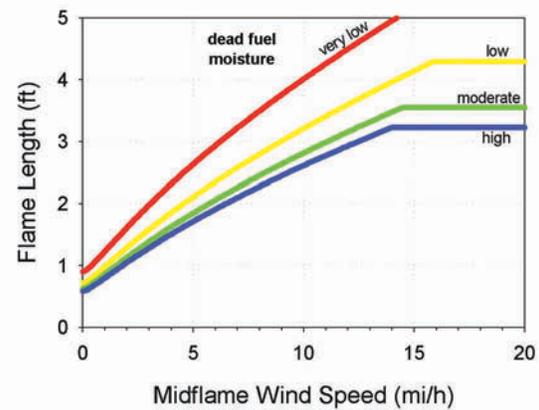
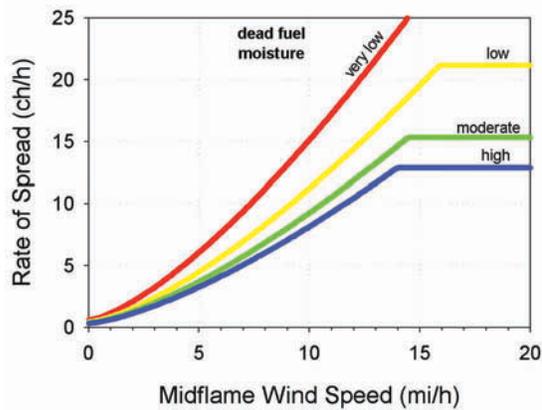
TL5 (185)

High Load Conifer Litter



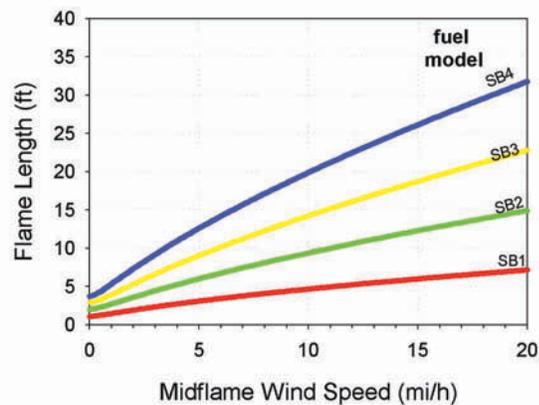
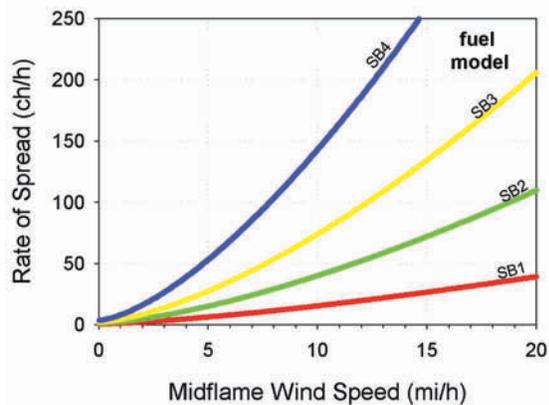
Description: The primary carrier of fire in TL5 is high load conifer litter; light slash or mortality fuel. Spread rate is low; flame length low.

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



Slash-Blowdown Fuel Type Models (SB)

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



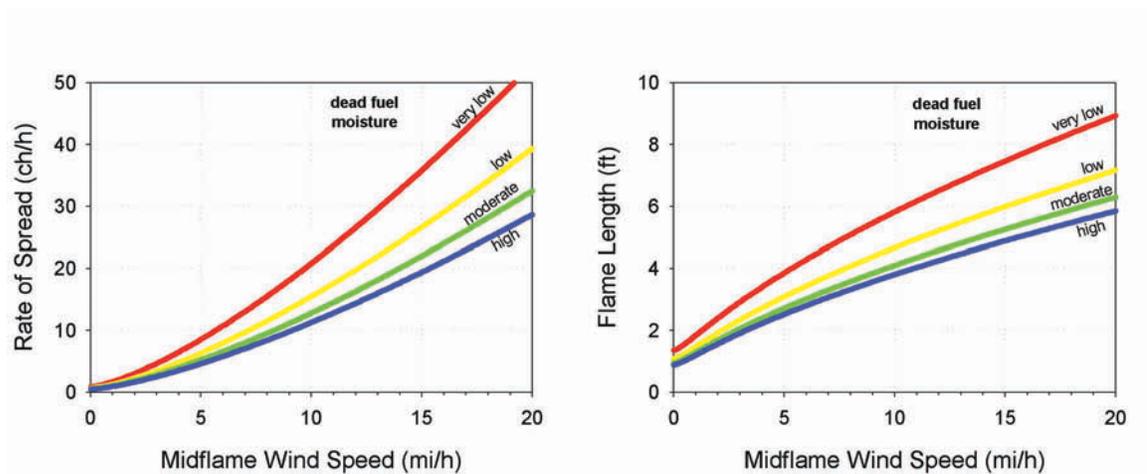
SB1 (201)

Low Load Activity Fuel



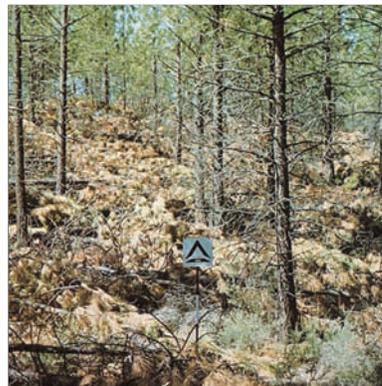
Description: The primary carrier of fire in SB1 is light dead and down activity fuel. Fine fuel load is 10 to 20 t/ac, weighted toward fuels 1 to 3 inches diameter class, depth is less than 1 foot. Spread rate is moderate; flame length low.

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



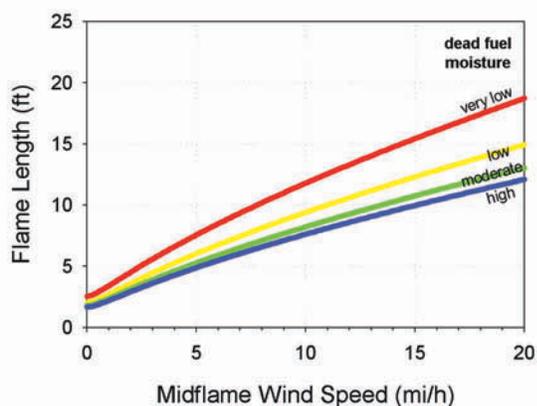
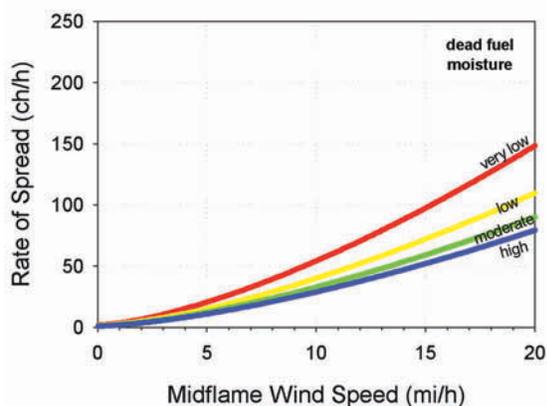
SB2 (202)

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 to 0.25, 0.25 to 1, and 1 to 3 inch diameter classes, depth is about 1 foot. Blowdown is scattered, with many trees still standing. Spread rate is moderate; flame length moderate.

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



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 to 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.

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

