United States Department of Agriculture

Forest Service

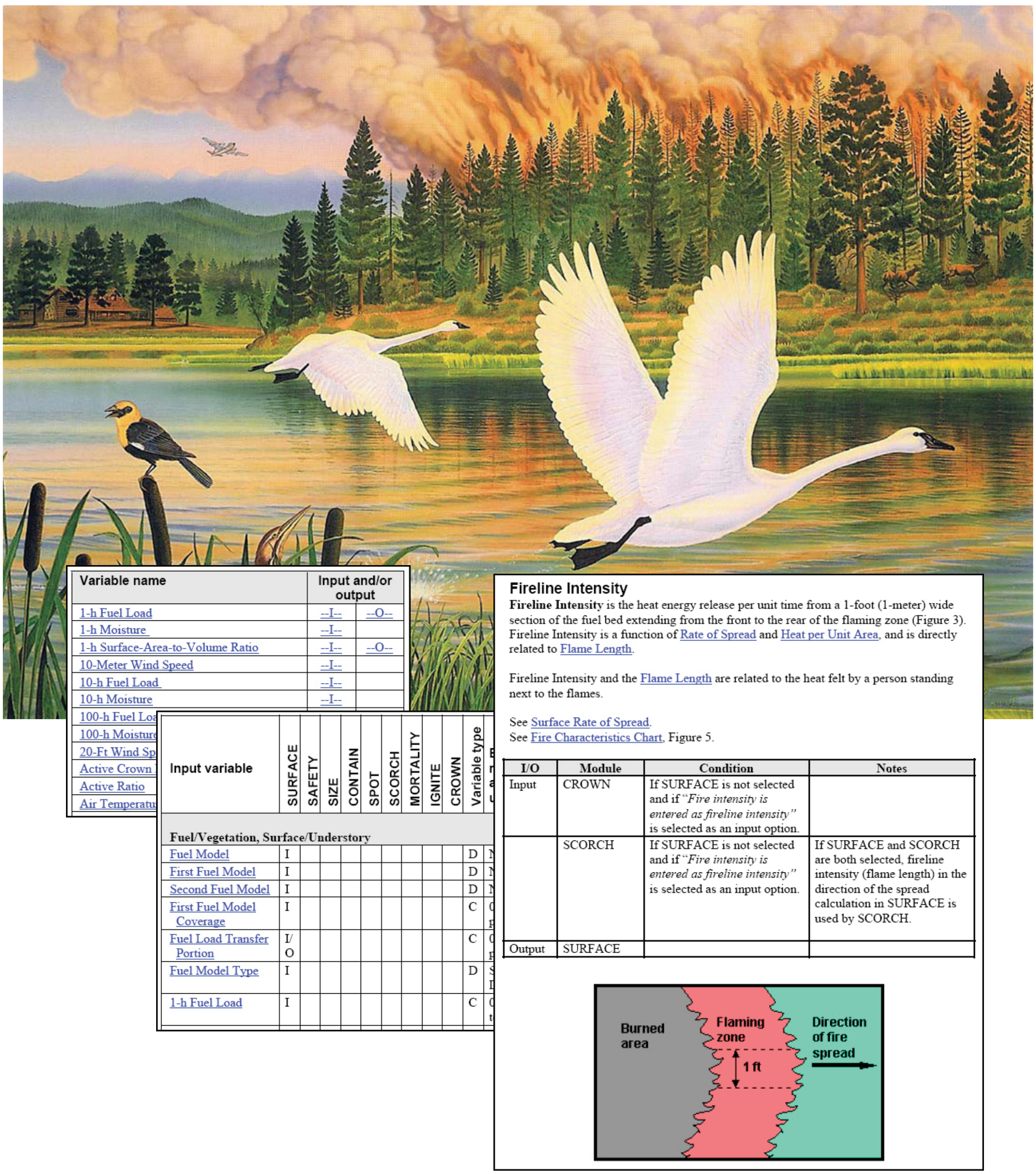
Rocky Mountain Research Station

General Technical Report RMRS-GTR-213WWW Revised

September 2009

BehavePlus fire modeling system, version 5.0: Variables

Patricia L. Andrews



Andrews, Patricia L. 2009. **BehavePlus fire modeling system, version 5.0: Variables**. Gen. Tech. Rep. RMRS-GTR-213WWW Revised. Fort Collins, CO: Department of Agriculture, Forest Service, Rocky Mountain Research Station. 111 p. http://www.fs.fed.us/rm/pubs/rmrs_gtr213.pdf

Abstract

This publication has been revised to reflect updates to version 4.0 of the BehavePlus software. It was originally published as the BehavePlus fire modeling system, version 4.0: Variables in July, 2008.

The BehavePlus fire modeling system is a computer program based on mathematical models that describe wildland fire behavior and effects and the fire environment. It is a flexible system that produces tables, graphs, and simple diagrams. It can be used for a host of fire management applications including projecting the behavior of an ongoing fire, planning prescribed fire, fuel hazard assessment, and training. The BehavePlus program automatically creates a worksheet that requests the required input variables based on the modules, output variables, and options selected by the user. This is a reference paper that describes the 189 variables in BehavePlus, with information on input and output relationships. A User's Guide describes operation of the program and can be accessed at http://www.fs.fed.us/rm/pubs/rmrs_gtr106.html.

Keywords: Fire behavior, fire modeling, fire spread, fire intensity, computer program

Author Profile

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Acknowledgments

We acknowledge funding from the Joint Fire Science Program under Project JFSP 05-4-1-23 for development of BehavePlus training material, including this document.

The Help system was developed through contracts with Systems for Environmental Management. Version 4.0 Help system was updated based on material in this document by Faith Ann Heinsch. Earlier Help system material was developed by Don Carlton, Joe Scott, and Collin Bevins.

Preface

This Variables paper describes the many input and output variables used in the BehavePlus fire modeling system. A User's Guide covers operation of the BehavePlus software. Because basic program operation did not change, the version 4.0 user's guide was not revised for version 5.0.

This publication is a revision to reflect changes in modeling capabilities from BehavePlus version 4.0 to version 5.0. A list of changes can be found on http://www.firemodels.org/.

The User's Guide and this Variables paper are RMRS online publications. They can be downloaded from the Rocky Mountain Research Station publications web page, http://www.fs.fed.us/rm/publications/titles/rmrs_gtr.html, or from the BehavePlus web page, http://www.firemodels.org/. They are updated as features and modeling capabilities are added to the program.

The Variables paper and the User's Guide are also an integral part of the BehavePlus system, serving as online help.

The BehavePlus system is supported by

US Forest Service
Fire and Aviation Management
800-253-5559 or 208-387-5290
E-mail at fire_help@fs.fed.us

Contents

Introduction

The BehavePlus fire modeling system is a computer program based on mathematical models that describe wildland fire and the fire environment. It is a flexible system that produces tables, graphs, and simple diagrams. It can be used for a host of fire management applications including projecting the behavior of an ongoing fire, planning prescribed fire, fuel hazard assessment, and training (Andrews 2007, Andrews and others 2008). Successful application of the system is dependent upon decisions made by the user. An educated fire behavior person understands the fire modeling foundation with the associated assumptions and limitations as well as the influence of various input variables on calculated values.

This document is a reference guide that describes the many input and output variables in BehavePlus. It is based on information that was previously available only in the help windows of the program. This document can be printed and kept in a notebook as a reference. It is, however, most useful when viewed on a computer utilizing the many links and bookmarks. This paper is also packaged with the BehavePlus program and can be opened through the help system. It can also be accessed at http://www.firemodels.org/ or http://www.fs.fed.us/rm/publications/titles/rmrs_gtr.html.

The many fire behavior, fire effects, and fire environment models in BehavePlus are grouped according to modules (Table 1). The CROWN module, for example, is based on models for crown fire spread rate (Rothermel 1991), transition from surface to crown fire (Van Wagner 1977), conditions for an active crown fire (Van Wagner 1993), crown fire flame length (Thomas 1963), and power of the fire and power of the wind (Byram 1959). A table of the mathematical models (complete with references) that form the basis for BehavePlus is found in Appendix A.

The BehavePlus program automatically creates a worksheet that requests the required input variables based on the modules, output variables, and options selected by the user. Using indentation, the module selection screen (Figure 1) indicates that some modules can be linked, with output from one being used as input to another. For example, Flame Length can be calculated in SURFACE and used in SCORCH. Or the user can enter the Flame Length directly into SCORCH. Notes on linkages are included in Table 1.

Information on the 189 variables in BehavePlus, version 5.0 is organized in several ways in this document to facilitate finding the needed information. The Contents section lists variables according to logical groupings used to order the description of each variable. Table 2 is an alphabetical list of the variables, with links to the variable description, input table, and/or output table. Table 3 lists the input variables sorted according to the categories used on the worksheet (Fuel/Vegetation, Fuel Moisture, Weather, and so forth.) with indication of the modules in which the variable is used and valid input ranges. Table 4 provides the output variables according to module. Some variables, such as Flame Length as discussed above, are in both the input and the output table.

The bulk of this document is a description of each variable. These are brief definitions and are not meant to be comprehensive. This is just one document that supports effective use of fire modeling for fire management applications.

Table 1—Modules in BehavePlus are groupings of related mathematical fire models.

Module	Calculations	Linkages
SURFACE	• Surface fire rate of spread • Fireline intensity and flame length • Reaction intensity and heat per unit area • Intermediate values: heat source, heat sink, characteristic dead fuel moisture, relative packing ratio, and so forth • Standard, custom, and special case fuel models • Wind adjustment factor	
CROWN	• Transition from surface to crown fire • Crown fire rate of spread • Crown fire area and perimeter • Fire type: surface, torching, conditional crown, crowning • Crown fire intensity and flame length • Power of the fire, Power of the wind	• Surface fireline intensity or flame length can come from SURFACE • Surface fire heat per unit area can come from SURFACE
SAFETY	• Safety zone size based on flame length • Area, perimeter, separation distance	• Head fire flame length can come from SURFACE
SIZE	• Elliptically shaped point source fire • Area, perimeter, shape	• Head fire rate of spread and effective wind speed can come from SURFACE
CONTAIN	• Fire containment success for single or multiple resources given line construction rate, arrival time, resource duration, head or rear attack, direct or parallel attack • Final area and perimeter, fire size at initial attack, fireline constructed	• Head fire rate of spread can come from SURFACE • Length-to-width ratio and fire size at report can come from SIZE
SPOT	• Maximum spotting distance from torching trees, burning piles, or wind-driven surface fire	• Head fire flame length can come from SURFACE for wind-driven surface fire
SCORCH	• Crown scorch height from surface fire flame length	• Surface fireline intensity or flame length can come from SURFACE
MORTALITY	• Probability of mortality from bark thickness and crown scorch	• Scorch height can come from SCORCH
IGNITE	• Probability of ignition by firebrands • Probability of ignition from lightning strikes	

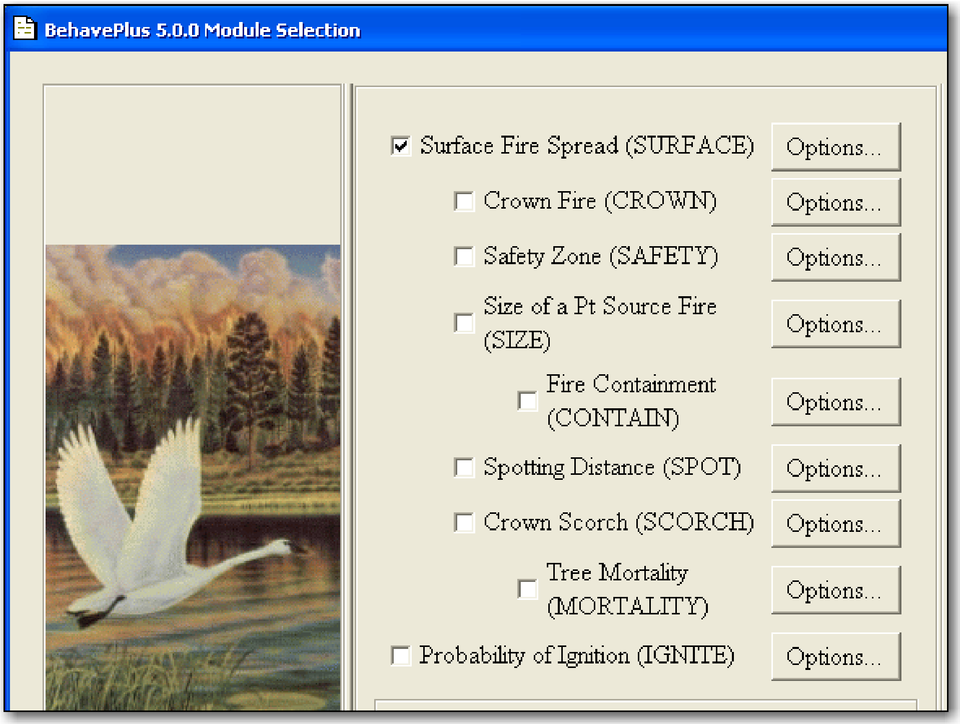


Figure 1—Module selection for BehavePlus. Indentation indicates that modules can be linked, with output from one being used as input to the other. For example, flame length calculated in SURFACE can be used to calculate scorch height in the SCORCH module. If SURFACE is not selected, the user enters values for flame length.

Alphabetical List of Variables

An alphabetical list of the 189 variables in BehavePlus version 5.0 is given in Table 2. Each variable name is linked to its description in the body of the document. The --I-- takes you to the input variable table, and the --O-- to the output variable table. Note that some variables can play the role of either input or output depending on the modules and run options selected.

Table 2—Alphabetical list of all input and output variables and an indication of whether each serves as input and/or output.

Variable name	Input and/or output	
1-h Fuel Load	--I--	--O--
1-h Moisture	--I--	
1-h Surface-Area-to-Volume Ratio	--I--	--O--
10-h Fuel Load	--I--	
10-h Moisture	--I--	
10-Meter Wind Speed	--I--	
100-h Fuel Load	--I--	
100-h Moisture	--I--	
20-Ft Wind Speed	--I--	
Active Crown Fire?		--O--
Active Ratio		--O--
Air Temperature	--I--	
Area (or Fire Size at Report)	--I--	--O--
Area per Heavy Equipment	--I--	
Area per Person	--I--	
Aspect	--I--	
Aspen Curing Level	--I--	
Aspen Fire Severity	--I--	
Aspen Fuel Model	--I--	
Backing Spread Distance		--O--
Bark Thickness		--O--
Bulk Density		--O--
Canopy Base Height	--I--	
Canopy Bulk Density	--I--	
Canopy Cover	--I--	
Canopy Heat per Unit Area		--O--

Variable name	Input and/or output	
Canopy Height	--I--	
Characteristic Dead Fuel Moisture		--O--
Characteristic Live Fuel Moisture		--O--
Characteristic Surface-Area-to-Volume Ratio		--O--
Contain Status		--O--
Contained Area		--O--
Containment Diagram		--O--
Contour Interval	--I--	
Cost of Resources Used		--O--
Cover Height Applied for Spotting Distance from a Burning Pile		--O--
Cover Height Applied for Spotting Distance from a Wind-Driven Surface Fire		--O--
Cover Height Applied for Spotting Distance from Torching Trees		--O--
Critical Crown ROS		--O--
Critical Surface Flame Length		--O--
Critical Surface Intensity		--O--
Crown Fill Portion		--O--
Crown Fire Area		--O--
Crown Fire Heat per Unit Area		--O--
Crown Fire Length-to-Width Ratio		--O--
Crown Fire Perimeter		--O--
Crown Fireline Intensity		--O--
Crown Flame Length		--O--
Crown Load		--O--
Crown Ratio	--I--	--O--
Crown ROS		--O--
Crown Spread Distance		--O--
D.B.H.	--I--	
Dead Fuel Heat Content	--I--	
Dead Fuel Load Portion		--O--
Dead Fuel Moisture	--I--	
Dead Fuel Moisture of Extinction	--I--	
Dead Fuel Reaction Intensity		--O--
Dead Herbaceous Fuel Load		--O--

Variable name	Input and/or output	
Direction of Maximum Spread		--O--
Direction of Wind Vector (from Upslope)	--I--	
Downwind Canopy Height	--I--	
Effective Wind Speed	--I--	--O--
Effective Wind Speed Limit		--O--
Elapsed Time	--I--	
Fire Area at Initial Attack		--O--
Fire Characteristics Chart		--O--
Fire Length		--O--
Fire Shape Diagram		--O--
Fire Size at Report (or Area)	--I--	--O--
Fire Type		--O--
Firebrand Drift Distance from a Wind-Driven Surface Fire		--O--
Firebrand Height from a Burning Pile		--O--
Firebrand Height from a Wind-Driven Surface Fire		--O--
Firebrand Height from Torching Trees		--O--
Fireline Constructed		--O--
Fireline Intensity	--I--	--O--
First Fuel Model	--I--	
First Fuel Model Coverage	--I--	
Flame Height from a Burning Pile	--I--	
Flame Length	--I--	--O--
Flame Residence Time		--O--
Flat Terrain Spotting Distance from a Burning Pile		--O--
Flat Terrain Spotting Distance from a Surface Fire		--O--
Flat Terrain Spotting Distance from Torching Trees		--O--
Foliar Moisture	--I--	
Forward Spread Distance		--O--
Fuel Bed Depth	--I--	--O--
Fuel Load Transfer Portion	--I--	--O--
Fuel Model	--I--	
Fuel Model Type	--I--	
Fuel Shading from the Sun	--I--	

Variable name	Input and/or output	
Heat per Unit Area	--I--	--O--
Heat Sink		--O--
Heat Source		--O--
Length-to-Width Ratio	--I--	--O--
Lightning Duff and Litter Depth	--I--	
Lightning Ignition Fuel Type	--I--	
Lightning Strike Type	--I--	
Line Construction Offset	--I--	
Live Fuel Heat Content	--I--	
Live Fuel Load Portion		--O--
Live Fuel Moisture	--I--	
Live Fuel Moisture of Extinction		--O--
Live Fuel Reaction Intensity		--O--
Live Herbaceous Surface-Area-to-Volume Ratio	--I--	
Live Herbaceous Fuel Load	--I--	--O--
Live Herbaceous Fuel Load Remainder		--O--
Live Herbaceous Moisture	--I--	
Live Woody Fuel Load	--I--	--O--
Live Woody Moisture	--I--	
Live Woody Surface-Area-to-Volume Ratio	--I--	--O--
Map Distance	--I--	
Map Representative Fraction	--I--	
Maximum Effective Wind Exceeded?		--O--
Maximum Fire Width		--O--
Midflame Wind Speed	--I--	--O--
Moisture Scenario	--I--	
Mortality Tree Species	--I--	
Number of Contour Intervals	--I--	
Number of Heavy Equipment	--I--	
Number of Personnel	--I--	
Number of Resources Used		--O--
Number of Torching Trees	--I--	
P-G Age of Rough	--I--	
P-G Dead Fine Fuel Load		--O--
P-G Dead Foliage Fuel Load		--O--
P-G Dead Medium Fuel Load		--O--

Variable name	Input and/or output	
P-G Height of Understory	--I--	
P-G Litter Fuel Load		--O--
P-G Live Fine Fuel Load		--O--
P-G Live Foliage Fuel Load		--O--
P-G Live Medium Fuel Load		--O--
P-G Overstory Basal Area	--I--	
P-G Palmetto Coverage	--I--	
Packing Ratio		--O--
Perimeter		--O--
Perimeter at Initial Attack		--O--
Power of the Fire		--O--
Power of the Wind		--O--
Power Ratio		--O--
Probability of Aspen Mortality		--O--
Probability of Ignition from a Firebrand		--O--
Probability of Ignition from Lightning		--O--
Probability of Mortality		--O--
Reaction Intensity		--O--
Relative Packing Ratio		--O--
Resource Arrival Time	--I--	
Resource Base Cost	--I--	
Resource Duration	--I--	
Resource Hourly Cost	--I--	
Resource Line Production Rate	--I--	
Resource Name	--I--	
Ridge-to-Valley Elevation Difference	--I--	
Ridge-to-Valley Horizontal Distance	--I--	
Safety Zone Radius		--O--
Safety Zone Separation Distance		--O--
Safety Zone Size		--O--
Scorch Height	--I--	--O--
Second Fuel Model	--I--	
Slope Elevation Change		--O--
Slope Factor		--O--
Slope Horizontal Distance		--O--
Slope Steepness	--I--	--O--
Spot Tree Species	--I--	

Variable name	Input and/or output	
Spotting Distance from a Burning Pile		--O--
Spotting Distance from a Wind-Driven Surface Fire		--O--
Spotting Distance from Torching Trees		--O--
Spotting Source Location	--I--	
Spread Direction	--I--	
Steady State Flame Duration from Torching Trees		--O--
Steady State Flame Height from Torching Trees		--O--
Suppression Tactic	--I--	
Surface Rate of Spread	--I--	--O--
Surface Spread Distance		--O--
Time from Report		--O--
Torching Tree Height	--I--	
Total Dead Fuel Load		--O--
Total Live Fuel Load		--O--
Transition Ratio		--O--
Transition to Crown Fire?		--O--
Tree Crown Length Scorched		--O--
Tree Crown Volume Scorched		--O--
Tree Height / Flame Height Ratio for Torching Trees		--O--
WAF Calculation		--O--
Wind Adjustment Factor	--I--	--O--
Wind Direction (from North)	--I--	
Wind-Driven Fire?		--O--
Wind Factor		--O--
Wind/Slope/Spread Direction Diagram		--O--

Input Variable Table

Input variables sorted according to the categories used on the worksheet are given in Table 3. Some serve as input for more than one module. I/O indicates input variables that can be output variables when modules are linked, with output from one module serving as input to another (for example, flame length). In addition, some run options allow variables to be either input by the user or calculated by BehavePlus (for example, bark thickness). The valid range for input values is given for English and metric units. Variable type of Continuous (C) indicates that a range of numerical values is meaningful (for example, 1-h fuel load). Discrete variables (D) have specific valid inputs (for example, fuel model). The variable name is linked to a description of the variable.

Table 3—Input variables for BehavePlus version 5.0. (I=Input; O=Output; I/O=Input or Output depending on the selected modules and options; C=Continuous; D= Discrete)

Input variable	SURFACE	SAFETY	SIZE	CONTAIN	SPOT	SCORCH	MORTALITY	IGNITE	CROWN	Variable type	English range and units	Metric range and units
Fuel/Vegetation, Surface/Understory												
Fuel Model	I									D	N/A	N/A
First Fuel Model	I									D	N/A	N/A
Second Fuel Model	I									D	N/A	N/A
First Fuel Model Coverage	I									C	0 to 100 percent	0 to 100 percent
Fuel Load Transfer Portion	I/O									C	0 to 100 percent	0 to 100 percent
Fuel Model Type	I									D	Static, Dynamic	Static, Dynamic
1-h Fuel Load	I/O									C	0.0 to 31 ton/ac	0.0 to 69.5 tonne/ha
10-h Fuel Load	I									C	0.0 to 31 ton/ac	0.0 to 69.5 tonne/ha
100-h Fuel Load	I									C	0.0 to 31 ton/ac	0.0 to 69.5 tonne/ha
Live Herbaceous Fuel Load	I/O									C	0.0 to 31 ton/ac	0.0 to 69.5 tonne/ha
Live Woody Fuel Load	I/O									C	0.0 to 31 ton/ac	0.0 to 69.5 tonne/ha

Input variable	SURFACE	SAFETY	SIZE	CONTAIN	SPOT	SCORCH	MORTALITY	IGNITE	CROWN	Variable type	English range and units	Metric range and units
1-h Surface-Area-to-Volume Ratio	I/O									C	109 to 4,000 ft^2/ft^3	358 to 13,123 m^2/m^3
Live Herb Surface-Area-to-Volume Ratio	I									C	109 to 4,000 ft^2/ft^3	358 to 13,123 m^2/m^3
Live Woody Surface-Area-to-Volume Ratio	I/O									C	109 to 4,000 ft^2/ft^3	358 to 13,123 m^2/m^3
Fuel Bed Depth	I/O									C	0.05 to 10.0 ft	0.02 to 3.05 m
Dead Fuel Moisture of Extinction	I									C	5 to 100 percent	5 to 100 percent
Dead Fuel Heat Content	I									C	6,000 to 12,000 Btu/lb	13,967 to 27,934 kJ/kg
Live Fuel Heat Content	I									C	6,000 to 12,000 Btu/lb	13,967 to 27,934 kJ/kg
P-G Age of Rough	I									C	1 to 25 years	1 to 25 years
P-G Height of Understory	I									C	1 to 6 ft	0 to 2 m
P-G Palmetto Coverage	I									C	15 to 85 percent	15 to 85 percent
P-G Overstory Basal Area	I									C	30 to 110 ft^2/ac	7 to 25 m^2/ha
Aspen Curing Level	I									C	0 to 90 percent	0 to 90 percent
Aspen Fuel Model	I									D	[5 types]	[5 types]
Lightning Ignition Fuel Type								I		D	[8 types]	[8 types]
Lightning Duff and Litter Depth								I		C	0 to 12 in	0 to 30 cm

Input variable	SURFACE	SAFETY	SIZE	CONTAIN	SPOT	SCORCH	MORTALITY	IGNITE	CROWN	Variable type	English range and units	Metric range and units
Fuel / Vegetation, Overstory												
Canopy Cover	I									C	0 to 100 percent	0 to 100 percent
Canopy Height	I						I		I	C	0 to 300 ft	0 to 91 m
Downwind Canopy Height					I					C	0 to 300 ft	0 to 91 m
Torching Tree Height					I					C	10 to 300 ft	3 to 91 m
Crown Ratio	I/O						I			C	0.1 to 1.0	0.1 to 1.0
Canopy Base Height									I	C	0 to 100 ft	0 to 30.5 m
Canopy Bulk Density									I	C	0.001 to 0.062 lb/ft^3	0.016 to 1.001 kg/m^3
Mortality Tree Species							I			D	[206 species]	[206 species]
Spot Tree Species					I					D	[14 species]	[14 species]
D.B.H.	I				I		I			C	2 to 40 in	5 to 102 cm
Fuel Moisture												
Moisture Scenario	I									D	N/A	N/A
1-h Moisture	I							I	I	C	1 to 60 percent	1 to 60 percent
10-h Moisture	I								I	C	1 to 60 percent	1 to 60 percent
100-h Moisture	I							I	I	C	1 to 60 percent	1 to 60 percent
Live Herbaceous Moisture	I									C	30 to 300 percent	30 to 300 percent
Live Woody Moisture	I								I	C	30 to 300 percent	30 to 300 percent

Input variable	SURFACE	SAFETY	SIZE	CONTAIN	SPOT	SCORCH	MORTALITY	IGNITE	CROWN	Variable type	English range and units	Metric range and units
Dead Fuel Moisture	I									C	1 to 60 percent	1 to 60 percent
Live Fuel Moisture	I									C	30 to 300 percent	30 to 300 percent
Foliar Moisture									I	C	30 to 300 percent	30 to 300 percent
Weather												
Midflame Wind Speed	I/O					I				C	0 to 40 mi/h	0.0 to 64.4 km/h
20-ft Wind Speed	I				I	I			I	C	0 to 80 mi/h	0 to 128 km/h
10-m Wind Speed	I				I	I			I	C	0 to 80 mi/h	0 to 128 km/h
Wind Adjustment Factor	I/O									C	0.1 to 1.0	0.1 to 1.0
Effective Wind Speed	O		I							C	0 to 80 mi/h	0.0 to 128 km/h
Direction of Wind Vector (from Upslope)	I									C	0 to 360 deg	0 to 360 deg
Wind Direction (from North)	I									C	0 to 360 deg	0 to 360 deg
Air Temperature						I		I		C	-40 to 120 deg F	-40 to 49 deg C
Fuel Shading from the Sun								I		C	0 to 100 percent	0 to 100 percent
Lightning Strike Type								I		D	-, +, ?	-, +, ?
Terrain												
Slope Steepness	I/O									C	0 to 604 percent 0 to 81 deg	0 to 604 percent 0 to 81 deg
Aspect	I									C	0 to 360 deg	0 to 360 deg

Input variable	SURFACE	SAFETY	SIZE	CONTAIN	SPOT	SCORCH	MORTALITY	IGNITE	CROWN	Variable type	English range and units	Metric range and units
Ridge-to-Valley Elevation Difference					I					C	0 to 4,000 ft	0 to 1,219 m
Ridge-to-Valley Horizontal Distance					I					C	0 to 4.0 mi	0 to 6.4 km
Spotting Source Location					I					D	RT, MW, VB, ML	RT, MW, VB, ML
Fire												
Surface Rate of Spread (Maximum)	O		I	I						C	0 to 500 ch/h	0.0 to 167.6 m/min
Heat per Unit Area	O								I	C	0 to 5000 Btu/ft^2	0 to 56,826 kJ/m^2
Flame Length	O	I			I	I			I	C	0 to 200 ft	0 to 61 m
Fireline Intensity	O					I			I	C	0 to 10,000 Btu/ft/s	0 to 34,641 kW/m
Spread Direction	I									C	0 to 360 deg	0 to 360 deg
Aspen Fire Severity	I									D	Low, Moderate+	Low, Moderate+
Flame Height from a Burning Pile					I					C	0 to 100 ft	0 to 30.5 m
Number of Torching Trees					I					C	0 to 30	0 to 30
Scorch Height						O	I			C	0 to 200 ft	0 to 61 m
Elapsed Time	I		I						I	C	0.1 to 8.0 h	0.1 to 8.0 h
Fire Size at Report			O	I						C	0.1 to 100 ac	0.0 to 40.5 ha
Length-to-Width Ratio			O	I						C	1 to 7	1 to 7

Input variable	SURFACE	SAFETY	SIZE	CONTAIN	SPOT	SCORCH	MORTALITY	IGNITE	CROWN	Variable type	English range and units	Metric range and units
Map												
Map Representative Fraction	I		I		I				I	C	1,980 to 1,013,760	1,980 to 1,013,760
Contour Interval	I									C	1 to 1000 ft	0.3 to 304.8 m
Map Distance	I									C	0.1 to 100 in	0.3 to 254 cm
Number of Contour Intervals	I									C	1 to 100	1 to 100
Suppression												
Suppression Tactic				I						D	Head, Rear	Head, Rear
Line Construction Offset				I						C	0 to 100 ch	0 to 2012 m
Resource Name				I						D	N/A	N/A
Resource Line Production Rate				I						C	1 to 250 ch/h	20 to 5029 m/h
Resource Arrival Time				I						C	0 to 8 h	0 to 8 h
Resource Duration				I						C	0.0 to 20 h	0.0 to 20 h
Resource Base Cost				I						C	0 to 500,000	0 to 500,000
Resource Hourly Cost				I						C	0 to 500,000	0 to 500,000
Number of Personnel		I								C	1 to 200	1 to 200
Area per Person		I								C	10 to 100 ft^2	1 to 9 m^2
Number of Heavy Equipment		I								C	0 to 10	0 to 10
Area per Heavy Equipment		I								C	100 to 500 ft^2	9 to 46 m^2

Output Variable Table

Output variables sorted according to the module that produces them are given in Table 4. The English and metric units of each variable are given. (BehavePlus also gives you the option of developing, saving, and using a custom units set.) Default output variables are indicated. Variables that are available as shading variables for the option "Table shading for acceptable fire conditions" are identified. And the variables that are affected by the option "Display output distances in map units" on the module selection window are indicated. Variable names are linked to a description of the variable.

Table 4—Output variables for BehavePlus version 5.0.

Output variable	Default output variable	Table shading variable	Available as map distance	English units	Metric units
SURFACE					
Basic Outputs					
Surface Rate of Spread	X	X		ch/h	m/min
Heat per Unit Area		X		Btu/ft^2	kJ/m^2
Fireline Intensity		X		Btu/ft/s	kW/m
Flame Length	X	X		ft	m
Reaction Intensity				Btu/ft^2/min	kW/m^2
Direction of Maximum Spread				degrees	degrees
Surface Spread Distance			X	ch	m
Wind/Slope/Spread Direction Diagram				N/A	N/A
Fire Characteristics Chart				N/A	N/A
Wind Outputs					
Midflame Wind Speed				mi/h	km/h
Wind Adjustment Factor				fraction	fraction
Crown Ratio				ratio	ratio
Crown Fill Portion				percent	percent

Output variable	Default output variable	Table shading variable	Available as map distance	English units	Metric units
WAF Calculation				Sheltered, Unsheltered, Input	Sheltered, Unsheltered, Input
Effective Wind Speed				mi/h	km/h
Effective Wind Speed Limit				mi/h	km/h
Max Effective Wind Exceeded?				Yes, No	Yes, No
Slope Outputs					
Slope Steepness				percent	percent
Slope Elevation Change				ft	m
Slope Horizontal Distance				ft	m
Intermediate Outputs					
Characteristic Dead Fuel Moisture				percent	percent
Characteristic Live Fuel Moisture				percent	percent
Live Fuel Moisture of Extinction				percent	percent
Characteristic Surface-Area-to-Volume-Ratio				ft^2/ft^3	m^2/m^3
Bulk Density				lbs/ft^3	kg/m^3
Packing Ratio				ratio	ratio
Relative Packing Ratio				ratio	ratio
Dead Fuel Reaction Intensity				$Btu/ft^2/min$	kW/m^2
Live Fuel Reaction Intensity				$Btu/ft^2/min$	kW/m^2
Wind Factor				no units	no units
Slope Factor				no units	no units
Heat Source				$Btu/ft^2/min$	kW/m^2
Heat Sink				Btu/ft^3	kJ/m^3

Output variable	Default output variable	Table shading variable	Available as map distance	English units	Metric units
Flame Residence Time				min	min
Fuel Outputs					
Fuel Load Transfer Portion				percent	percent
Dead Herbaceous Fuel Load				ton/ac	tonne/ha
Live Herbaceous Fuel Load Remainder				ton/ac	tonne/ha
Total Dead Fuel Load				ton/ac	tonne/ha
Total Live Fuel Load				ton/ac	tonne/ha
Dead Fuel Load Portion				percent	percent
Live Fuel Load Portion				percent	percent
Aspen Outputs					
1-h Fuel Load				ton/ac	tonne/ha
Live Herbaceous Fuel Load				ton/ac	tonne/ha
Live Woody Fuel Load				ton/ac	tonne/ha
1-h Surface-Area-to-Volume Ratio				ft^2/ft^3	m^2/m^3
Live Woody Surface-Area-to-Volume Ratio				ft^2/ft^3	m^2/m^3
Probability of Aspen Mortality				percent	percent
P-G Fuel Outputs					
P-G Dead Fine Fuel Load				ton/ac	tonne/ha
P-G Dead Medium Fuel Load				ton/ac	tonne/ha
P-G Dead Foliage Fuel Load				ton/ac	tonne/ha

Output variable	Default output variable	Table shading variable	Available as map distance	English units	Metric units
P-G Live Fine Fuel Load				ton/ac	tonne/ha
P-G Live Medium Fuel Load				ton/ac	tonne/ha
P-G Live Foliage Fuel Load				ton/ac	tonne/ha
P-G Litter Fuel Load				ton/ac	tonne/ha
Fuel Bed Depth				ft	m
CROWN					
Spread Outputs					
Critical Surface Intensity	X			Btu/ft/s	kW/m
Critical Surface Flame Length				ft	m
Transition Ratio	X			ratio	ratio
Transition to Crown Fire?	X	X		Yes, No	Yes, No
Crown ROS	X	X		ch/h	m/min
Critical Crown ROS	X			ch/h	m/min
Active Ratio	X			ratio	ratio
Active Crown Fire?	X	X		Yes, No	Yes, No
Fire Type	X	X		Surface, Torching, Conditional crown, Crowning	Surface, Torching, Conditional crown, Crowning
Crown Spread Distance			X	ch	m
Crown Fire Area				ac	ha
Crown Fire Perimeter				ch	m
Crown Fire Length-to-Width Ratio				ratio	ratio
Intensity Outputs					
Crown Fireline Intensity				Btu/ft/s	kW/m
Crown Flame Length				ft	m

Output variable	Default output variable	Table shading variable	Available as map distance	English units	Metric units
Power of the Fire				ft-lb/s/ft^2	kg-m/s/m^2
Power of the Wind				ft-lb/s/ft^2	kg-m/s/m^2
Power Ratio				ratio	ratio
Wind-Driven Fire?				Yes, No	Yes, No
Crown Load				ton/ac	tonne/ha
Canopy Heat per Unit Area				Btu/ft^2	kJ/ m^2
Crown Fire Heat per Unit Area				Btu/ft^2	kJ/ m^2
SAFETY					
Safety Zone Separation Distance	X	X		ft	m
Safety Zone Size	X	X		ac	ha
Safety Zone Radius		X		ft	m
SIZE					
Area	X	X		ac	ha
Perimeter	X			ch	m
Length-to-Width Ratio				ratio	ratio
Forward Spread Distance			X	ch	m
Backing Spread Distance			X	ch	m
Fire Length			X	ch	m
Maximum Fire Width			X	ch	m
Fire Shape Diagram				N/A	N/A
CONTAIN					
Fire Area at Initial Attack				ac	ha
Perimeter at Initial Attack				ch	m
Contain Status	X	X		Contained, Escaped, Withdrawn	Contained, Escaped, Withdrawn
Time from Report	X	X		h	h
Contained Area	X	X		ac	ha

Output variable	Default output variable	Table shading variable	Available as map distance	English units	Metric units
Fireline Constructed	X			ch	m
Number of Resources Used				integer	integer
Cost of Resources Used				no units	no units
Containment Diagram				N/A	N/A
SPOT					
Basic Output					
Spotting Distance from Torching Trees	X	X	X	mi	km
Spotting Distance from a Burning Pile		X	X	mi	km
Spotting Distance from a Wind-Driven Surface Fire		X	X	mi	km
Torching Tree Outputs					
Cover Height Applied for Spotting Distance from Torching Trees				ft	km
Steady State Flame Height from Torching Trees				ft	m
Tree Height / Flame Height Ratio for Torching Trees				ratio	ratio
Steady State Flame Duration from Torching Trees				no units	no units
Firebrand Height from Torching Trees				ft	m
Flat Terrain Spotting Distance from Torching Trees				mi	km

Burning Pile Outputs					
Cover Height Applied for Spotting Distance from a Burning Pile				ft	m
Firebrand Height from a Burning Pile				ft	m
Flat Terrain Spotting Distance from a Burning Pile				mi	km
Surface Fire Outputs					
Cover Height Applied for Spotting Distance from a Wind-Driven Surface Fire				ft	m
Firebrand Height from a Wind-Driven Surface Fire				ft	m
Firebrand Drift Distance from a Wind-Driven Surface Fire				mi	km
Flat Terrain Spotting Distance from a Surface Fire				mi	km
SCORCH					
Scorch Height	X	X		ft	m
MORTALITY					
Bark Thickness				in	cm
Tree Crown Length Scorched				ft	m
Tree Crown Volume Scorched		X		percent	percent
Probability of Mortality	X	X		percent	percent

IGNITE					
Probability of Ignition from a Firebrand	X	X		percent	percent
Probability of Ignition from Lightning				percent	percent

Variable Descriptions

A description is given for each of the 189 variables, which are ordered in this section by a grouping that differs from the organization on the Input and Output Variable Tables 3 and 4. For example, Canopy Cover is included in the Wind section, because in BehavePlus, it is used only to calculate Wind Adjustment Factor. In addition, variables are assigned to one section although some are applicable to more than one group. For example, Elapsed Time is described under the Fire Size and Shape section, although it is also used to calculate spread distance in the SURFACE and CROWN modules. Organization of information about the variables is presented in several ways and the links among them should help you find the information that you need.

There are links to these variable descriptions from:
- Contents section
- Table 2—Alphabetical List of Variables
- Table 3—Input Variable Table
- Table 4—Output Variable Table

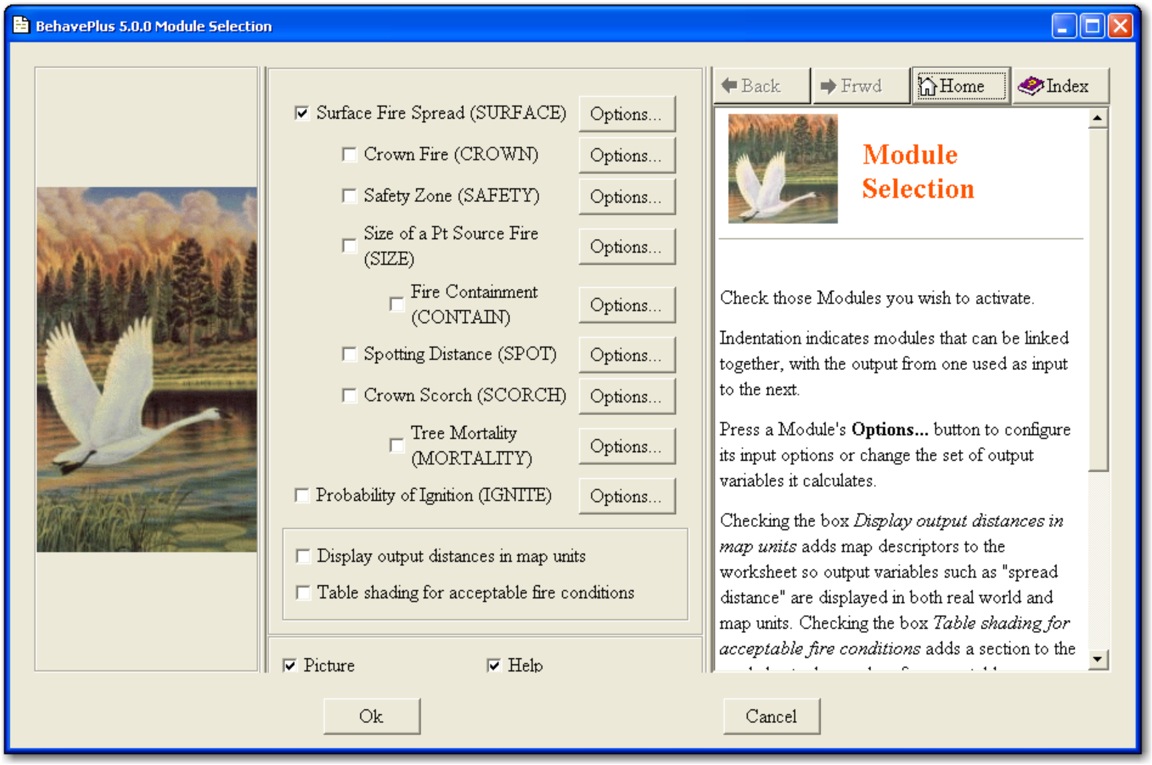
In this section, a table is included with each variable showing when it is used. When BehavePlus runs, it automatically produces worksheets based on user selection of modules, input options, and output variables. Only required input is requested. The tables describe relevant module and input option selection.

For example, the following is part of the Flame Length table.

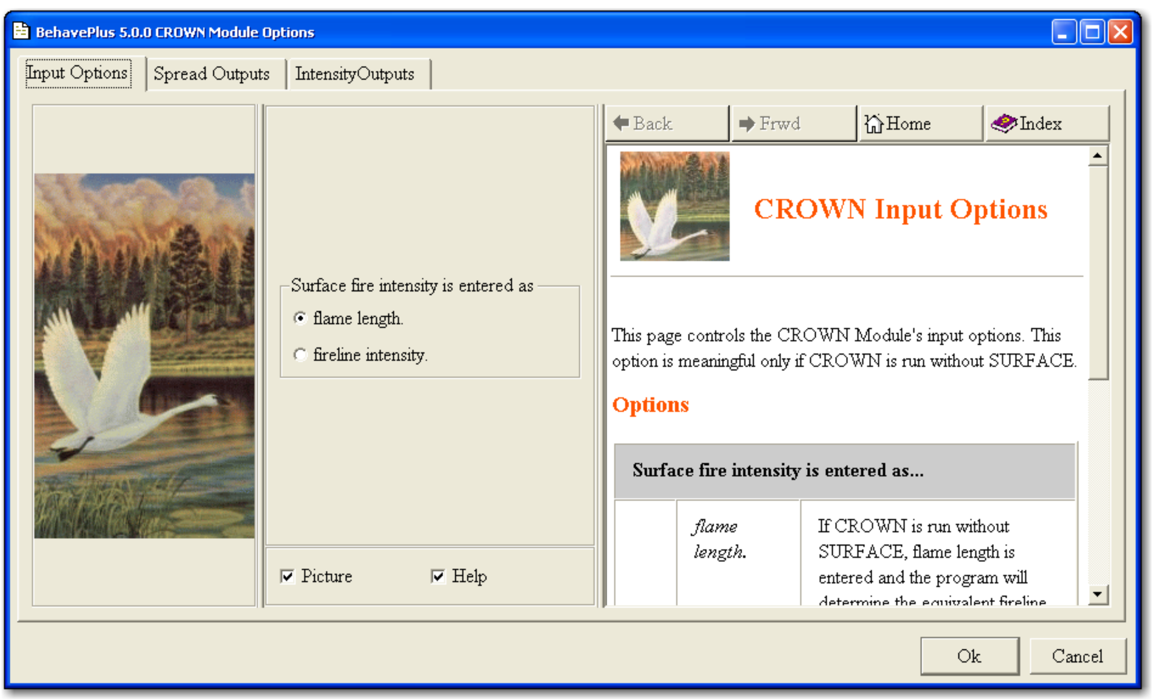
I/O	Module	Condition	Notes
Input	CROWN	If SURFACE is not selected and if “*Surface fire intensity is entered as flame length*” is selected as an input option.	

You can read it as “Flame Length is an input to the CROWN module if the SURFACE module is not selected and if ‘*Surface fire intensity is entered as flame length’* is selected as an input option.”

The following window shows the selection of the CROWN module, not SURFACE.



The following window shows the selection of the input option for CROWN. Italics in the “Condition” column of the table indicate specific wording of the input option, in this case, “*Surface fire intensity is entered as flame length.*”



Surface Fire Spread and Intensity

Surface Rate of Spread

Surface Rate of Spread is the "speed" the fire travels through the surface fuels. Surface fuels include the litter, grass, brush, and other dead and live vegetation within about 6 ft of the ground.

A SURFACE module input option determines whether rate of spread calculations are done for the heading fire spread or any other direction as specified on the worksheet.

The maximum rate of spread is the spread rate of the head fire. This value is used along with Elapsed Time to determine the size of an elliptically shaped fire in SIZE. The maximum spread rate is also used by CONTAIN to model fire growth as suppression action is occurring.

The surface rate of spread prediction uses the Rothermel (1972) surface fire spread model, which assumes that weather, topography, and fuel are constant and uniform for the elapsed time. The basic model is for a head fire spreading upslope with the wind. Adaptations have been made to allow calculations for other direction options.

Spread Distance = Surface Rate of Spread × Elapsed Time

See Fire Characteristics Chart, Figure 5.

I/O	Module	Condition	Notes
Input	SIZE	If SURFACE is not selected.	The maximum (head fire) spread rate is used in SIZE. If both SURFACE and SIZE are selected, the calculated maximum rate of spread is used in SIZE, even if it is not displayed as an output in SURFACE.
	CONTAIN	If SURFACE is not selected.	If both SURFACE and CONTAIN are selected, the calculated maximum (head fire) rate of spread is used in CONTAIN, even if it is not displayed as an output in SURFACE.
Output	SURFACE		

Flame Length

The **Flame Length** of a spreading surface fire within the flaming front is measured from midway in the active flaming combustion zone to the average tip of the flames (Figure 2).

"Flame length is an elusive parameter that exists in the eye of the beholder. It is a poor quantity to use in a scientific or engineering sense, but it is so readily apparent to fireline personnel and so readily conveys a sense of fire intensity that it is worth featuring as a primary fire variable" (Rothermel 1991).

Fireline Intensity and flame length are related to the heat felt by a person standing next to the flames. Flame length is calculated from Fireline Intensity, which is a function of Rate of Spread and Heat per Unit Area.

Flame Length is used as a worst-case estimation of flame height for Safety Zone Size calculations in SAFETY. The head fire flame length is always used.

See Fireline Intensity, Figure 3.
See Fire Characteristics Chart, Figure 5.

I/O	Module	Condition	Notes
Input	CROWN	If SURFACE is not selected and if *"Surface fire intensity is entered as flame length"* is selected as an input option.	
	SCORCH	If SURFACE is not selected and if *"Fire intensity is entered as flame length"* is selected as an input option.	If SURFACE and SCORCH are both selected, the flame length in the direction of fire spread is calculated in SURFACE and used by SCORCH.
	SAFETY	If SURFACE is not selected.	If SURFACE and SAFETY are both selected, the flame for the head fire is used to estimate safety zone size (even if another spread direction is specified on the worksheet).
	SPOT	If SURFACE is not selected and spotting distance from a wind-driven surface fire is calculated.	If SURFACE and SPOT are both selected, the flame length is for the head fire, in the direction of maximum spread.
Output	SURFACE		

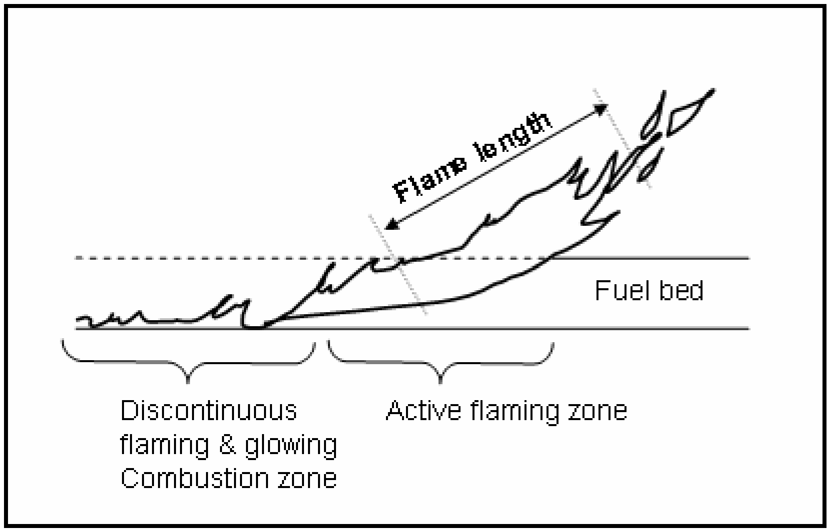


Figure 2—Flame length.

Fireline Intensity

Fireline Intensity is the heat energy release per unit time from a 1-foot (1-meter) wide section of the fuel bed extending from the front to the rear of the flaming zone (Figure 3). Fireline Intensity is a function of Rate of Spread and Heat per Unit Area, and is directly related to Flame Length.

Fireline Intensity and the Flame Length are related to the heat felt by a person standing next to the flames.

See Surface Rate of Spread.
See Fire Characteristics Chart, Figure 5.

I/O	Module	Condition	Notes
Input	CROWN	If SURFACE is not selected and if "*Fire intensity is entered as fireline intensity*" is selected as an input option.	
	SCORCH	If SURFACE is not selected and if "*Fire intensity is entered as fireline intensity*" is selected as an input option.	If SURFACE and SCORCH are both selected, fireline intensity (flame length) in the direction of the spread calculation in SURFACE is used by SCORCH.
Output	SURFACE		

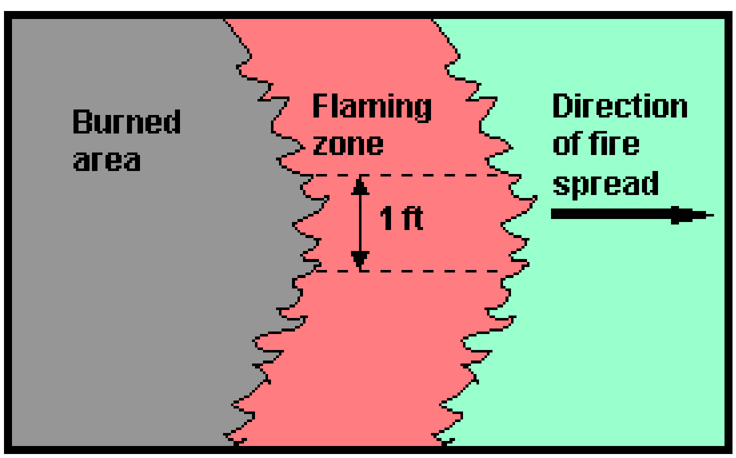


Figure 3—Fireline intensity.

Heat per Unit Area

Heat per Unit Area (HPUA) is the heat energy release per area (square foot or square meter) within the flaming front of the surface fuel. Heat per Unit Area is not affected by wind, slope, or direction of spread. HPUA is calculated in Rothermel's (1972) surface fire spread model and is based on only the fine fuels that affect fire spread. Additional energy is released in the burnout phase of combustion, so care should be exercised when using Heat per Unit Area to predict fire effects.

Surface fire Heat per Unit Area is used to calculate Crown Fireline Intensity and Crown Flame Length according to Rothermel (1991). An alternative to using the HPUA calculated in SURFACE is to enter it directly into CROWN. Rothermel (1991) prepared a table of calculated heat per unit area values using the Burnout model, which produces values higher than those calculated by the surface fire spread model. These HPUA values are available in the Choices list.

Surface HPUA Btu/ft^2	Fuel model plus 1000-h fuel
580	8
760	2
1050	9
1325	9 + 30 ton/ac
1325	10
1570	10 + 30 ton/ac
3430	12

See Fire Characteristics Chart, Figure 5.

I/O	Module	Condition	Notes
Input	CROWN	If SURFACE is not selected and if Crown Fireline Intensity is calculated.	
Output	SURFACE		

Reaction Intensity

Reaction Intensity is the rate of the energy release per area (square foot or square meter) within the flaming front. Reaction Intensity is not affected by wind, slope, or direction of spread.

Reaction Intensity is part of the Rothermel (1972) surface fire spread model.

I/O	Module	Condition	Notes
Input	None		
Output	SURFACE		

Dead Fuel Reaction Intensity

Dead Fuel Reaction Intensity is the rate of the energy release per area (square foot or square meter) within the flaming front generated by the dead fuel. Reaction Intensity is not affected by wind, slope, or direction of spread. Reaction Intensity is a sum of the Dead and the Live Fuel Reaction Intensity.

I/O	Module	Condition	Notes
Input	None		
Output	SURFACE		Intermediate value

Live Fuel Reaction Intensity

Live Fuel Reaction Intensity is the rate of the energy release per area (square foot or square meter) within the flaming front generated by the live fuel. Reaction Intensity is not affected by wind, slope, or direction of spread. Reaction Intensity is a sum of the Live and Dead Fuel Reaction Intensity.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Direction of Maximum Spread

The **Direction of Maximum Spread** is calculated based on the influence of slope and wind and their relative directions (Figure 4). When the wind is not blowing directly uphill, the calculated Direction of Maximum Spread will be between the uphill direction and the direction in which the wind is blowing (direction of the wind vector). The Direction of Maximum Spread is expressed as degrees from upslope or as degrees from north, depending on the input option that was selected.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		

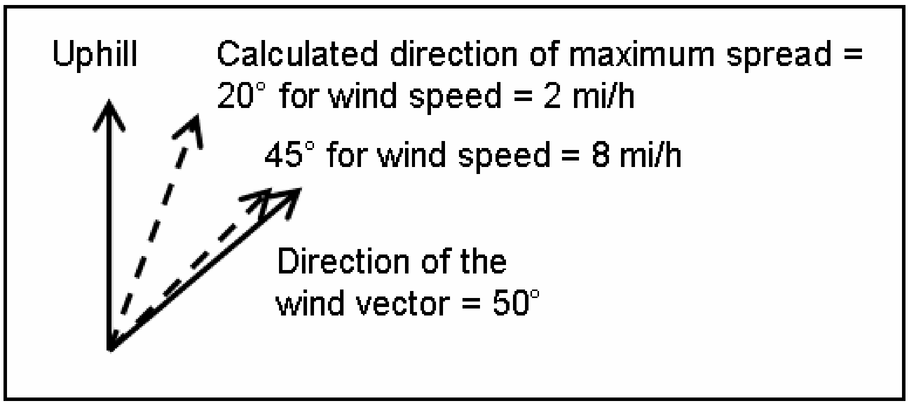


Figure 4—Direction of maximum spread is determined from directions of wind and slope.

Surface Spread Distance

Surface Spread Distance is the distance a surface fire travels during a specified elapsed time. It is the product of the Surface Rate of Spread in the specified direction and Elapsed Time.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Can also be output as a map distance if *"Display output distances in map units"* is selected.

Spread Direction

Spread Direction is the direction in which the Surface Rate of Spread is calculated. Spread Direction can be specified with respect to upslope or to north, depending on the selected input option.

I/O	Module	Condition	Notes
Input	SURFACE	If *"Surface fire spread direction is calculated in directions specified on the worksheet"* is selected as an input option.	
Output	none		

Wind/Slope/Spread Direction Diagram

Wind/Slope/Spread Direction Diagrams are diagrams of the relative directions of slope, wind, and fire spread. This illustrates the relative effect of wind and slope on head fire direction.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		

Fire Characteristics Chart

A **Fire Characteristics Chart** displays four basic fire characteristics—Surface Rate of Spread, Heat per Unit Area, Flame Length, and Fireline Intensity—as a single point on the chart (Figure 5) (Andrews and Rothermel 1982, Rothermel 1983). The chart is available for surface fire calculations.

Each of the calculated values in table output is plotted on a simple fire characteristics chart. Each calculation result produces a numbered point on the chart. A simple Run produces a single point labeled 1. A Run with one range variable of three values (for example, wind speed of 0, 5, and 10 mi/h) plots three points labeled 1, 2, and 3. If a second range variable exists (for example, for fuel models 1 and 2), six points are plotted. The labels follow the same row and column order as the output table. If the fuel models are the table row variables and the wind speeds are the table column variables, points 1, 2, and 3 are for the first row (fuel model 1) columns 1 through 3 (0, 5, and 10 mi/h wind), and points 4, 5, and 6 are for the second row (fuel model 2) columns 1 through 3.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Table output must be requested.

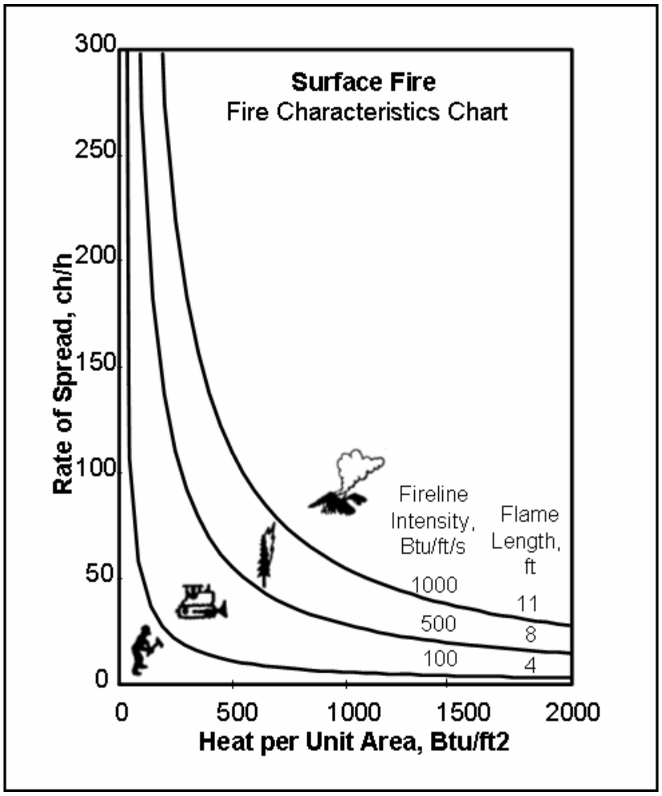


Figure 5—The surface fire characteristics chart shows the relationship among rate of spread, heat per unit area, fireline intensity, and flame length.

Fire characteristics		
Flame length (ft)	**Fireline intensity (Btu/ft/s)**	**Interpretations**
Under 4	Under 100	• Fires can generally be attacked at the head or flanks by persons using hand tools. • A hand line should hold the fire.
4 to 8	100 to 500	• Fires are too intense for direct attack on the head by persons using hand tools. • A hand line cannot be relied on to hold the fire. • Equipment such as dozers, pumpers, and retardant aircraft can be effective.
8 to 11	500 to 1000	• Fires may present serious control problems -- torching out, crowning, and spotting. • Control efforts at the fire head will probably be ineffective.
Over 11	Over 1000	• Crowning, spotting, and major fire runs are probable. • Control efforts at head of fire are ineffective.

Wind Factor

The **Wind Factor** is an intermediate value in Rothermel's (1972) surface fire spread model. Surface Rate of Spread is calculated for zero-wind and zero-slope (R_0) and then increased by the Wind Factor (Φ_w) and the Slope Factor (Φ_s).

$$ROS = R_0 \, (1 + \Phi_w + \Phi_s)$$

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Slope Factor

The **Slope Factor** is an intermediate value in Rothermel's (1972) surface fire spread model. Surface Rate of Spread is calculated for zero-wind and zero-slope (R_0) and then increased by the Wind Factor (Φ_w) and the Slope Factor (Φ_s).

$$ROS = R_0 \, (1 + \Phi_w + \Phi_s)$$

I/O	Module	Condition	Notes
Input	None		
Output	SURFACE		Intermediate value

Heat Source

The **Heat Source** is an intermediate value in Rothermel's surface fire spread model (Rothermel 1972, p. 6, eq. 9). The Surface Rate of Spread is calculated from the ratio of the heat flux received from the source (Heat Source, the numerator) and the heat required for ignition by the potential fuel (Heat Sink, the denominator). The propagating heat flux is increased by Wind and Slope Factors due to flame tilting over the potential fuel to get the total propagating heat flux or Heat Source.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Heat Sink

The **Heat Sink** is an intermediate value in Rothermel's (1972) surface fire spread model. The Surface Rate of Spread is calculated from the ratio of the heat flux received from the source (Heat Source, the numerator) and the heat required for ignition by the potential fuel (Heat Sink, the denominator). The heat required for ignition is dependent upon ignition temperature, moisture content of the fuel, and the amount of fuel involved in the ignition process.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Flame Residence Time

Flame Residence Time is a function of the Characteristic Surface-Area-to-Volume Ratio of the fuel bed as calculated by Rothermel's (1972) surface fire spread model. It is used to calculate flame depth and Heat per Unit Area. Fireline Intensity is calculated as the product of Reaction Intensity times flame depth or Heat per Unit Area times Surface Rate of Spread.

Flame Residence Time only applies to the fine fuels that carry fire spread. Flames are also a result of the burning of fuels behind the fire front. Care should be taken in interpreting and using Flame Residence Time.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Surface Fuel

Fuel Model

A **Fuel Model** is a set of numerical values that describe the fuel inputs for Rothermel's mathematical model that predicts surface fire spread.

There are 53 standard fire behavior fuel models including the original 13 described by Anderson (1982), plus the 40 defined by Scott and Burgan (2005). Custom fuel models can be developed and saved for later use. Standard and custom fuel models can be used with one of the three options for calculating a weighted Surface Rate of Spread through two fuel models. BehavePlus also offers two special case fuel models that require different input: palmetto-gallberry (Hough and Albini 1978) and western aspen (Brown and Simmerman 1986).

I/O	Module	Condition	Notes
Input	SURFACE	If *"Fuel is entered as fuel models* or *two fuel models"* is selected as an input option.	If *"Fuel is entered as fuel parameters"* is selected as the input option, the assigned parameters can be saved as a custom fuel model.
Output	none		

First Fuel Model

The **First Fuel Model** is specified for the two fuel model option. It does not have to be the model that covers the most area.

I/O	Module	Condition	Notes
Input	SURFACE	If *"Fuel is entered as two fuel models"* is selected as an input option.	
Output	none		

First Fuel Model Coverage

The **First Fuel Model Coverage** is the percent of the area represented by the *first* fuel model for the two fuel model option. The area represented by the Second Fuel Model is the remaining area.

I/O	Module	Condition	Notes
Input	SURFACE	If *"Fuel is entered as two fuel models"* is selected as an input option.	
Output	none		

Second Fuel Model

The **Second Fuel Model** is specified for the two fuel model option. It does not have to be the model that covers the least area.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as two fuel models*" is selected as an input option.	
Output	none		

Fuel Model Type

Fuel Model Type is *static* (S) or *dynamic* (D) for standard or custom fuel models. Dynamic fuel models have a live herbaceous fuel component, a portion of which is transferred into the Dead Herbaceous Fuel Load depending upon the Live Herbaceous Moisture—the lower the moisture content, the greater the load transfer. The Fuel Load Transfer Portion can also be entered directly.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" then the value stored for the standard or custom fuel model is used in the calculations.
Output	none		

Fuel Bed Depth

Fuel Bed Depth represents the depth of the surface fuel and is a Fuel Model parameter. Fuel Bed Depth is sometimes called fuel bed bulk depth. A single Fuel Bed Depth value must be used for a Fuel Model (Figure 6).

The Rothermel fire spread model calculations are highly sensitive to the Fuel Bed Depth. Fuel Bed Depth is assumed to be uniform for Rothermel's fire spread model. It is necessary to estimate a characteristic value for the area. The depth of the fuel bed determined as an output of the planar intercept method (Brown 1974) is called the "average high particle depth." Albini and Brown (1978) showed that for logging slash fuel beds, the Fuel Bed Depth is approximately 63.3 percent of the average high particle depth. For the special case fuel model, palmetto-gallberry (P-G), Fuel Bed Depth is calculated as 2/3 of the P-G Height of Understory variable entered on the worksheet. The option of using two fuel models to describe an area is also available.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or the "*special case fuel model, western aspen*" is selected as an input option, then the appropriate value is used.
Output	SURFACE	If "*Fuel is entered as special case fuel model, palmetto-gallberry*" is selected as an input option.	

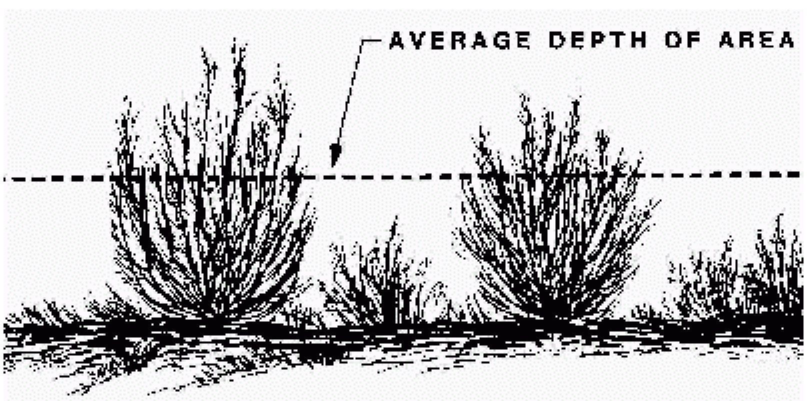


Figure 6—Fuel bed depth is the average for an area.

Dead Fuel Moisture of Extinction

Dead Fuel Moisture of Extinction is the Characteristic Dead Fuel Moisture above which a predictable steady state rate of fire spread is not attainable. Dead Fuel Moisture of Extinction is a Fuel Model parameter.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or a "*special case fuel model,*" then the appropriate stored value is used.
Output	none		

Live Fuel Moisture of Extinction

Live Fuel Moisture of Extinction is the Characteristic Live Fuel Moisture above which the live fuel is a Heat Sink. Below that value, the live fuel is a Heat Source and contributes to the surface fire spread. Live Fuel Moisture of Extinction is calculated from Dead Fuel Moisture, Live Fuel Moisture, load, size, and Dead Fuel Moisture of Extinction.

I/O	Module	Condition	Notes
Input	None		
Output	SURFACE		

Dead Fuel Heat Content

Dead Fuel Heat Content is the amount of heat energy contained in a unit of fuels, and is a Fuel Model parameter. The heat content for the standard fire behavior fuel models is 8,000 Btu/lb (18,622 kJ/kg).

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or a "*special case fuel model,*" then the appropriate stored value is used.
Output	none		

Live Fuel Heat Content

Live Fuel Heat Content is the amount of heat energy contained in a unit of fuels, and is a Fuel Model parameter. The heat content for the standard fire behavior fuel models is 8,000 Btu/lb (18,622 kJ/kg).

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or a "*special case fuel model,*" then the appropriate stored value is used.
Output	none		

1-h Fuel Load

The **1-h Fuel Load** is the weight of the 1-h dead fuel per unit area, and is a Fuel Model parameter. The one-hour (1-h) timelag dead fuel category includes dead fuel from 0 to 0.25 inches (0.64 cm) in diameter. This includes needles, leaves, cured herbaceous plants and fine dead stems of plants. This is an important fuel parameter for Rothermel's fire spread model.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or a "*special case fuel model,*" then the appropriate stored value is used.
Output	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	

10-h Fuel Load

The **10-h Fuel Load** is the weight of the 10-h dead fuel per unit area, and is a Fuel Model parameter. The ten-hour (10-h) timelag dead fuel category includes fuels from 0.25 to 1.0 inch (0.64 to 2.54 cm) in diameter.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or a "*special case fuel model aspen,*" then the appropriate stored value is used.
Output	none		

100-h Fuel Load

The **100-h Fuel Load** is the weight of the 100-h dead fuel per unit area, and is a Fuel Model parameter. The hundred-hour (100-h) timelag fuel category includes fuels from 1 to 3 inches (2.54 to 7.62 cm) in diameter. Fuels larger than this category (for example, 1000-h fuel) do not contribute to the Surface Rate of Spread as calculated by Rothermel's surface fire spread model.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or a "*special case fuel model,*" then the appropriate stored value is used.
Output	none		

Fuel Load Transfer Portion

Fuel Load Transfer Portion is the percent or fraction of Live Herbaceous Fuel Load that is transferred to the Dead Herbaceous Fuel Load. This variable is meaningful only for *dynamic* fuel models (standard or custom). The load transfer portion can be calculated from Live Fuel Moisture as described by Scott and Burgan (2005) or entered directly.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Dynamic curing load transfer is input directly*" is selected as an input option.	
Output	SURFACE	If "*Dynamic curing load transfer is calculated from live herbaceous fuel moisture*" is selected as an input option.	

Dead Herbaceous Fuel Load

Dead Herbaceous Fuel Load is the weight of that class of fuel per unit area and is a meaningful variable only for *dynamic* fuel models (standard and custom). The initial value is zero. A portion of the Live Herbaceous Fuel Load is transferred into the Dead Herbaceous Fuel Load category. The portion of the load transferred is either specified by the user or calculated from Live Herbaceous Moisture. The moisture content for this fuel category is the value assigned to the 1-h fuel. The surface-area-to-volume ratio is specified for the live herbaceous fuel.

I/O	Module	Condition	Notes
Input	None		
Output	SURFACE	If a fuel model is "*dynamic*."	

Live Herbaceous Fuel Load

Live Herbaceous Fuel Load is the weight of that class of fuel per area and is a fuel model parameter. Live herbaceous fuels are living grasses and forbs, either annual or perennial. If the Fuel Model is dynamic, the initial Live Herbaceous Fuel Load is stored with the fuel model. A portion of the Live Herbaceous Fuel Load is transferred to Dead Herbaceous Fuel Load. The portion of the load transferred is either specified by the user or calculated from Live Herbaceous Moisture.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or a "*special case fuel model*," then the appropriate stored value is used. If the fuel model is "*dynamic*," the stored value is the highest load.
Output	SURFACE	If the standard or custom fuel model is "*dynamic*." If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	If the fuel model is "*dynamic*," the value used in the calculations is the initial value reduced according to the *Fuel Load Transfer Portion*.

Live Herbaceous Fuel Load Remainder

Live Herbaceous Fuel Load is the weight of that class of fuel that remains after some of the load is transferred to the dead herbaceous fuel class. This is a meaningful variable only for *dynamic* models (standard and custom fuel).

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If a fuel model is "*dynamic*."	

Live Woody Fuel Load

Live Woody Fuel Load is the weight of that class of fuel per unit area. Live Woody Fuel Load is a fuel model parameter. Live woody fuels include the foliage and very fine stems of living shrubs.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" or a "*special case fuel model,*" then the appropriate stored value is used.
Output	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	

Total Dead Fuel Load

Total Dead Fuel Load is the sum of the load of all dead fuel classes. For standard and custom fuel models this includes 1-h, 10-h, 100-h, and Dead Herbaceous Fuel Load. The calculation is done after the load transfer is done for *dynamic* fuel models. This variable is most meaningful in an examination of *dynamic* fuel models.

I/O	Module	Condition	Notes
Input			
Output	SURFACE		Of primary interest for "*dynamic*" fuel models.

Total Live Fuel Load

Total Live Fuel Load is the sum of the load of all live fuel classes. For standard and custom fuel models this includes Live Woody and Live Herbaceous Fuel Load. The calculation is done after the load transfer is done for *dynamic* fuel models. This variable is most meaningful in an examination of *dynamic* fuel models.

I/O	Module	Condition	Notes
Input			
Output	SURFACE		Of primary interest for "*dynamic*" fuel models.

Dead Fuel Load Portion

Dead Fuel Load Portion is the percent or fraction of the total fuel load that is dead fuel. The calculation is done after the load transfer is done for *dynamic* fuel models. This variable is most meaningful in an examination of *dynamic* fuel models.

I/O	Module	Condition	Notes
Input			
Output	SURFACE		Of primary interest for "*dynamic*" fuel models.

Live Fuel Load Portion

Live Fuel Load Portion is the percent or fraction of the total fuel load that is live fuel. The calculation is done after the load transfer is done for *dynamic* fuel models. This variable is most meaningful in an examination of *dynamic* fuel models.

I/O	Module	Condition	Notes
Input			
Output	SURFACE		Of primary interest for "*dynamic*" fuel models.

1-h Surface-Area-to-Volume Ratio

1-h Surface-Area-to-Volume Ratio (SA/V) is the amount of area on the outside of the fuel (surface area) divided by the volume of the fuel. 1-h fuel is dead fuel 0 to 0.25 in diameter. The 1-h SA/V is a Fuel Model parameter.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*" then the value stored for the standard or custom fuel model is used.
Output	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	

Live Herbaceous Surface-Area-to-Volume Ratio

Live Herbaceous Surface-Area-to-Volume Ratio (SA/V) is the total surface area of an herbaceous plant leaf divided by the volume occupied by the plant leaf. Live Herbaceous Surface-Area-to-Volume Ratio is a Fuel Model parameter.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models*," then the value stored for the standard or custom fuel model is used.
Output	none		

Live Woody Surface-Area-to-Volume Ratio

Live Woody Surface-Area-to-Volume Ratio (SA/V) is the total surface area of a shrub plant leaf divided by the volume occupied by the plant leaf. Live Woody Surface-Area-to-Volume Ratio is a Fuel Model parameter.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as fuel parameters*" is selected as an input option.	If "*Fuel is entered as fuel models,*" then the value stored for the standard or custom fuel model is used.
Output	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	

Characteristic Surface-Area-to-Volume Ratio

The surface-area-to-volume ratio is the area on the outside of the fuel (surface area) divided by the volume of the fuel. The fuel bed ***Characteristic*** **Surface-Area-to-Volume Ratio** (σ, ft^3/ft^2) is a weighted value for all dead and live fuel classes. This is an intermediate value in Rothermel's (1972) surface fire spread model.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Relative Packing Ratio

Relative Packing Ratio is the ratio of the fuel bed Packing Ratio to the optimum packing ratio (β / β_{op}). This is an intermediate value in Rothermel's (1972) surface fire spread model. It is a factor in determining the optimum reaction velocity.

I/O	Module	Condition	Notes
Input	None		
Output	SURFACE		Intermediate value

Bulk Density

The surface fuel bed **Bulk Density** (lb/ft^3) is the total oven-dry fuel loading per cubic volume of fuel bed (fuel loading divided by Fuel Bed Depth). This is an intermediate value in Rothermel's (1972) surface fire spread model.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Packing Ratio

The **Packing Ratio** (β) is the ratio of the fuel bed Bulk Density (lb/ft^3) to the fuel particle density (lb/ft^3). This is an intermediate value in Rothermel's (1972) surface fire spread model.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Aspen Fuel Model

There are five special case **Aspen Fuel Models** (Brown and Simmerman 1986). Their use requires different user input than is required for standard or custom fuel models.

Aspen Fuel model	Fuel bed depth, ft	10-h Fuel Load, tons/ac
• Aspen/shrub	0.65	0.975
• Aspen/tall forb	0.30	0.475
• Aspen/low forb	0.18	1.035
• Mixed/shrub	0.50	1.340
• Mixed forb	0.18	1.115

For all aspen fuel models, the following are constants:

- Heat content = 8,000 Btu/lb
- Moisture of extinction = 25 percent
- 1-h Surface-Area-to-Volume Ratio = 109 ft^2/ft^3
- Live Herbaceous Surface-Area-to-Volume Ratio = 2,800 ft^2/ft^3

Aspen Curing Level is used to calculate 1-h Fuel Load, Live Herbaceous Fuel Load, Live Woody Fuel Load, 1-h SA/V, and Live Woody SA/V.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	
Output	none		

Aspen Curing Level

Aspen Curing Level is the percent (or fraction) of herbaceous biomass that is dead. This value is used only for the special case aspen fuel models (Brown and Simmerman 1986). It is used to calculate 1-h Fuel Load, Live Herbaceous Fuel Load, Live Woody Fuel Load, 1-h SA/V, and Live Woody SA/V. Aspen Curing Level is different from the Fuel Load Transfer Portion used to represent curing for dynamic fuel models (standard or custom) (Scott and Burgan 2005).

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	
Output	none		

Aspen Fire Severity

Aspen Fire Severity is used for predicting Probability of Aspen Mortality (Brown and Simmerman 1986, Brown and Debyle 1987).

- *Low* fire severity in this case refers to fires that char, but do not completely consume leaf litter, and have patches of unburned vegetation and litter.
- *Moderate+* severity fires consume litter and some duff.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	Required for Probability of Aspen Mortality.
Output	none		

P-G Age of Rough

Palmetto-Gallberry Age of Rough (understory vegetation) is applicable only for the special case Palmetto-Gallberry Fuel Model. Age of Rough is used in determining the load of all the fuel classes. The age of understory rough is usually the number of years since the last fire. It is an important factor in the calculation of fuel load.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as special case fuel model, palmetto-gallberry*" is selected.	
Output	none		

P-G Height of Understory

Height of the palmetto-gallberry understory vegetation (**P-G Height of Understory)** is used in determining the load of all the live fuel classes and the load of the dead 0.0- to 0.25-inch fuel class. Fuel Bed Depth is calculated as 2/3 P-G Height of Understory.

In a very dense understory, the average height is to the top of the foliage of the palmetto and gallberry plants. In a patchy or scattered palmetto stand, however, it is necessary to measure the heights of the low shrubs or grasses that occur in the openings as well as the palmetto and gallberry foliage. The average height is between these two measurements and should be weighted by the amount of coverage in each category.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Fuel is entered as special case fuel model, palmetto-gallberry*" is selected.	
Output	none		

P-G Palmetto Coverage

The **P-G Palmetto Coverage** is the percentage of the ground area covered by palmetto fronds. This variable is used to determine the load of the live and dead foliage and load of the dead 0.25- to 1.0-inch fuel class.

According to Hough and Albini (1978), "percent palmetto coverage can be estimated by eye." The simplest method is to locate a number of 100-ft transects at different places in the stand. The number of feet of transect covered by palmetto fronds equals the palmetto coverage. If transects are not 100 ft long, the percent coverage must be calculated by dividing the feet of palmetto frond coverage by the length of the transect.

I/O	Module	Condition	Notes
Input	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	
Output	none		

P-G Overstory Basal Area

Basal area of the overstory above the palmetto-gallberry rough (**P-G Overstory Basal Area**) is used to determine litter fuel load for the palmetto-gallberry special case fuel model. No other variables are affected by Overstory Basal Area.

Basal area is the cross-sectional area (at breast height; 4.5 ft above ground) of trees, per unit of horizontal ground area. In a fixed-radius plot, basal area is the sum of cross-sectional area of all trees at breast height (ft^2) divided by the plot area (acres).

I/O	Module	Condition	Notes
Input	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	
Output	none		

P-G Dead Fine Fuel Load

The **P-G Dead Fine Fuel Load** for the palmetto-gallberry Fuel Model is the fuel load of dead palmetto-gallberry stems with 0- to 0.25-inch diameters. It is calculated from P-G Age of Rough and P-G Height of Understory.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	

P-G Dead Medium Fuel Load

The **P-G Dead Medium Fuel Load** for the palmetto-gallberry Fuel Model is the fuel load of dead palmetto-gallberry stems with 0.25- to 1.0-inch diameters. This variable is calculated from P-G Age of Rough and P-G Palmetto Coverage.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	

P-G Dead Foliage Fuel Load

The **P-G Dead Foliage Fuel Load** for the palmetto-gallberry Fuel Model is the fuel load of dead palmetto-gallberry foliage that is still on the stem. This variable is calculated from P-G Age of Rough and P-G Palmetto Coverage.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	

P-G Live Fine Fuel Load

The **P-G Live Fine Fuel Load** for the palmetto-gallberry Fuel Model is the fuel load of live palmetto-gallberry stems with 0- to 0.25-inch diameters. This variable is calculated from P-G Age of Rough and P-G Height of Understory.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	

P-G Live Medium Fuel Load

The **P-G Live Medium Fuel Load** for the palmetto-gallberry Fuel Model is the load of live palmetto-gallberry stems with 0.25- to 1.0-inch diameters. This variable is calculated from P-G Age of Rough and P-G Height of Understory.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	

P-G Live Foliage Fuel Load

The **P-G Live Foliage Fuel Load** for the palmetto-gallberry Fuel Model is the load of live palmetto-gallberry foliage still on the stem. This variable is calculated from P-G Age of Rough, P-G Height of Understory, and P-G Palmetto Coverage .

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	

P-G Litter Fuel Load

The **P-G Litter Fuel Load** for the palmetto-gallberry Fuel Model is the load of the litter layer. This variable is calculated from P-G Age of Rough and P-G Overstory Basal Area.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected.	

Surface Fuel Moisture

1-h Moisture

1-h Fuel Moisture content is the portion (percent or fraction) of the 1-h timelag dead fuel that is water, calculated on a dry weight basis. This value is also used for dead herbaceous moisture content for dynamic fuel models.

I/O	Module	Condition	Notes
Input	SURFACE		
	IGNITE	If *"Probability of Ignition from a Firebrand"* is selected as output.	
	CROWN		
Output	None		

10-h Moisture

The **10-h Fuel Moisture** content is the portion of the 10-h timelag dead fuel that is water, calculated on a dry weight basis. The 10-hr Fuel Moisture has less influence on the fire spread calculations than does the 1-h Moisture. The fuel moisture obtained for the "fuel moisture sticks" at a National Fire Danger Rating System (NFDRS) weather station is an estimate of the 10-h Fuel Moisture.

I/O	Module	Condition	Notes
Input	SURFACE	If there is 10-h fuel in the fuel model.	
	CROWN		
Output	none		

100-h Moisture

The **100-h Fuel Moisture** content is the portion of the 100-h timelag dead fuel that is water, calculated on a dry weight basis. The 100-hr fuel moisture content has less influence on the fire spread calculations than does the 1-h or 10-h Moisture content.

I/O	Module	Condition	Notes
Input	SURFACE	If there is 100-h fuel in the fuel model.	
	IGNITE	If *"Probability of Ignition from Lightning"* is selected as output.	
	CROWN		
Output	None		

Dead Fuel Moisture

The **Dead Fuel Moisture** value is used for 1-h, 10-h, and 100-h fuels. In most cases this gives the same result as 10-h = 1-h + 1 percent and 100-h = 1-h + 2 percent.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Moisture is entered by dead and live category*" is selected as an input option.	
Output	none		

Live Herbaceous Moisture

Live Herbaceous Fuel Moisture content is the portion of the live grasses and forbs that is water, calculated on a dry weight basis. This can be a very important value for dynamic fuels if it is used to determine the amount of fuel that is transferred from the Live Herbaceous Fuel Load category to Dead Herbaceous Fuel Load. (Alternatively, the user can directly specify the portion of fuel load that is transferred, Fuel Load Transfer Portion.)

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I/O	Module	Condition	Notes
Input	SURFACE	If live herbaceous fuels are in the fuel model.	If the fuel model is "*dynamic*" and if "*Dynamic curing load transfer is calculated from live herbaceous fuel moisture*" is selected, the value is used to determine live and dead herbaceous load values. If "*Fuel is entered as special case fuel model, palmetto-gallberry*" is selected, the value is used for P-G live foliage moisture.
Output	none		

Live Woody Moisture

Live Woody Fuel Moisture content is the portion of the shrub foliage and very fine stems that is water, calculated on a dry weight basis.

I/O	Module	Condition	Notes
Input	SURFACE	If live woody fuels are in the fuel model.	If *"Fuel is entered as special case fuel model, palmetto-gallberry"* is selected, the value is used for P-G live stemwood moisture.
	CROWN		
Output	none		

Live Fuel Moisture

The **Live Fuel Moisture** value is used for live herbaceous and live woody fuels.

I/O	Module	Condition	Notes
Input	SURFACE	If *"Moisture is entered by dead and live category"* is selected as an input option.	
Output	none		

Moisture Scenario

A fuel **Moisture Scenario** is a set of fuel moisture values representing moisture condition of the surface fuel: 1-h, 10-h, 100-h, Live Herbaceous, and Live Woody Moisture. Fuel moisture scenarios are analogous to Fuel Models—they package a number of parameters into a labeled set. The user can define and save a Moisture Scenario for later use.

Fuel Moisture Scenarios are useful for testing custom Fuel Models or developing fire prescriptions. For example, a moisture Scenario might be developed to represent a location's 90th-, 95th-, and 97th-percentile fire weather conditions.

I/O	Module	Condition	Notes
Input	SURFACE	If *"Moisture is entered by moisture scenario"* is selected as an input option.	Values entered when *"Moisture is entered by individual size class"* is selected can be "*Saved as Moisture Scenario*."
Output	none		

Characteristic Dead Fuel Moisture

The **Characteristic Dead Fuel Moisture** is the calculated Dead Fuel Moisture for the whole fuel bed. The calculation involves weighting by dead fuel loading and surface-area-to-volume ratio for each dead class.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Characteristic Live Fuel Moisture

The **Characteristic Live Fuel Moisture** is the calculated live fuel moisture for the whole fuel bed. The calculation involves weighting by live fuel loading and surface-area-to-volume ratio for each live class.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		Intermediate value

Wind

20-Ft Wind Speed

20-Ft Wind Speed is the wind value at 20 ft above the vegetation. For fire spread and intensity calculations in SURFACE, the 20-Ft Wind Speed is reduced to the Midflame Wind Speed. In SPOT the 20-Ft Wind Speed is the wind that carries the embers.

If *Wind speed is entered as midflame height* is selected as an input option for SURFACE, and if either SPOT or CROWN is also selected, the initial version of the worksheet will request both Midflame Wind Speed and 20-ft Wind Speed. The program then offers a choice of how to resolve the conflict.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Wind speed is entered as 20-ft wind and input* or *calculated wind adjustment factor*" is selected as an input option.	
	CROWN		
	SPOT		
	SCORCH	If "*Wind speed is entered as 20-ft wind and input* or *calculated wind adjustment factor*" is selected as an input option in SURFACE.	
Output	None		

10-Meter Wind Speed

10-Meter Wind Speed is the wind 10 meters above the vegetation. The 10-m Wind Speed is reduced to 20-Ft Wind Speed by dividing by 1.15. For fire spread and intensity calculations in SURFACE, the 20-Ft Wind Speed is further reduced to Midflame Wind Speed according to the Wind Adjustment Factor.

I/O	Module	Condition	Notes
Input	SURFACE	If “*Wind speed is entered as 10-m wind and input* or *calculated wind adjustment factor*” is selected as an input option.	
	CROWN	If “*Wind speed is entered as 10-m wind and input* or *calculated wind adjustment factor*” is selected as an input option in SURFACE.	Otherwise, 20-ft wind speed is requested.
	SPOT	If “*Wind speed is entered as 10-m wind and input* or *calculated wind adjustment factor*” is selected as an input option in SURFACE.	Otherwise, 20-ft wind speed is requested.
	SCORCH	If “*Wind speed is entered as 10-m wind and input* or *calculated wind adjustment factor*” is selected as an input option in SURFACE.	
Output	None		

Midflame Wind Speed

Midflame Wind Speed is the wind speed that exists at midflame height above the fuel bed and affects surface fire spread. Midflame wind is often called eye-level wind.

Technically, Midflame Wind Speed is the average wind speed from the top of the fuel bed to the height of the flame above the fuel (Albini and Baughman 1979). Calculation of the height as a function of the flames is not feasible. The variability in the Fuel Bed Depth, the flames, and the wind overwhelm other considerations.

Wind speed affects Scorch Height in two ways: in the calculation of Flame Length in SURFACE and flame tilt in SCORCH.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Wind speed is entered as midflame height*" is selected as an input option.	
	SCORCH	If "*Wind speed is entered as midflame height*" is selected as an input option in SURFACE.	
Output	SURFACE	If "*Wind speed is entered as 20-ft wind* (or *10-m wind*) *and Input* (or *calculated*) *wind adjustment factor*" is selected as an input option.	

Effective Wind Speed

Effective Wind Speed is the combined effect of Midflame Wind Speed and Slope Steepness in the direction of maximum spread (head fire). Effective Wind Speed is used to determine the shape (length-to-width ratio) of a point source fire. Calculation of Effective Wind Speed is based on the Wind and Slope Factors that are part of Rothermel's fire spread model.

I/O	Module	Condition	Notes
Input	SIZE	If SURFACE is not also selected.	If both SURFACE and SIZE are selected, the effective wind speed value for the direction of maximum spread calculated in SURFACE is used in SIZE.
Output	SURFACE		

Maximum Effective Wind Exceeded?

Maximum Effective Wind Exceeded? has a value of "Yes" or "No" to indicate whether the Effective Wind Speed Limit, as calculated in the surface fire spread model, has been exceeded.

The user has the option of "*Impose maximum reliable effective wind speed?*" (Yes or No). If "Yes," the maximum reliable effective wind speed is used in the calculations. If "No," the input values are used. For the aspen special case fuel model, however, the wind limit is never applied.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		An output value, even if the wind limit is not imposed.

Effective Wind Speed Limit

The **Effective Wind Speed Limit** is a function of Reaction Intensity. At high wind speeds, fire spread rate can become difficult to predict. In fact, studies have shown that at high wind speeds, the spread rate may decrease when the wind speed increases. The data are being reanalyzed to assess the role of fuel moisture in that relationship. Other studies have not shown a wind limit. The user has the option of "*Impose maximum reliable effective wind speed?*" (Yes or No). If "Yes," the maximum reliable Effective Wind Speed from Rothermel (1972) is used in the calculations. If "No," the input wind and slope values are used. If the Effective Wind Speed Limit is not applied, it might be advisable to view the output variable *Maximum Effective Wind Exceeded?*

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE		

Canopy Cover

Canopy Cover is the percent of the ground covered by overstory canopy. It is used to calculate Wind Adjustment Factor.

I/O	Module	If	Notes
Input	SURFACE	If "*Wind speed is entered as 20-ft (or 10-m) wind and Calculated wind adjustment factor*" is selected as an input option.	
Output	none		

Canopy Height

Canopy Height describes the stand as it affects calculation of the Wind Adjustment Factor (WAF) in SURFACE. If canopy height is less than 6 ft, then the unsheltered WAF calculation is used.

In the CROWN module, **Canopy Height** is multiplied by Canopy Bulk Density to get Crown Load, which is used to calculate Crown Flame Length.

In the MORTALITY module, **Canopy Height** is used to find Tree Crown Length Scorched, which is used to calculate Probability of Mortality.

Canopy Height at the site of the fire may be different from Downwind Canopy Height in the direction firebrands are carried. Downwind Canopy Height is used to calculate maximum spotting distance in SPOT and is the mean cover height in the downwind direction as it affects the distance a firebrand is carried. If the forest cover is open, a value of half the tree height should be entered.

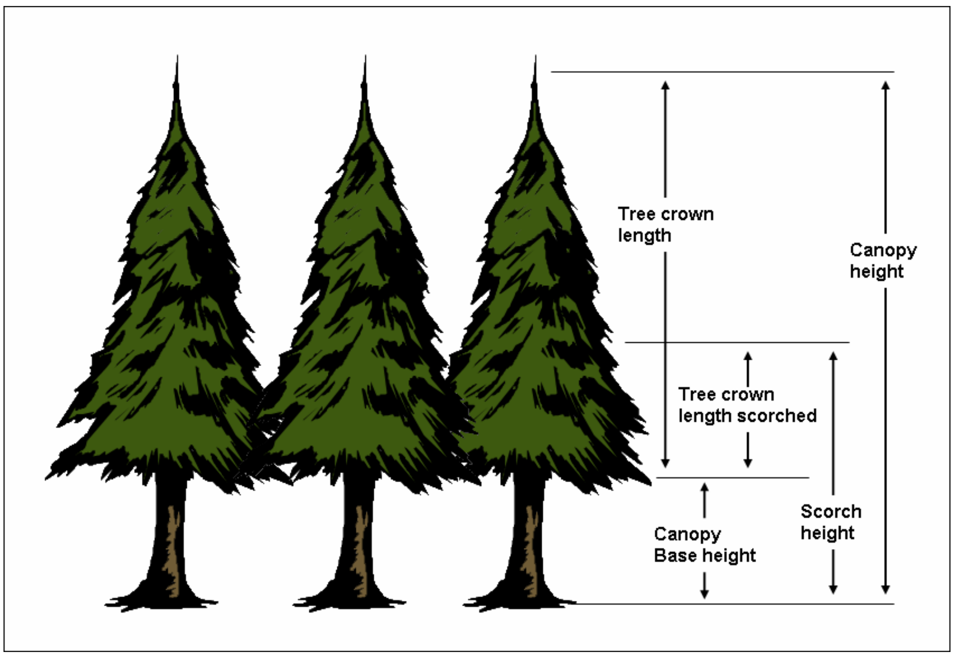

Figure 7—Tree crown length scorched is found from canopy height, tree crown length, and scorch height. Canopy height and canopy base height determine crown ratio.

I/O	Module	Condition	Notes
Input	SURFACE		If wind adjustment factor is calculated.
	CROWN		
	MORTALITY		
Output	none		

Wind Adjustment Factor

Wind Adjustment Factor (WAF) is a value between 0 and 1 used to adjust the wind speed at 20-ft above the vegetation to Midflame Wind Speed. 20-Ft Wind Speed * WAF = Midflame Wind Speed. Wind Adjustment Factor depends on sheltering of fuels from the wind. If fuels are not sheltered from the wind, WAF is a function of Fuel Bed Depth. If fuels are sheltered from the wind, WAF is not affected by the surface fuel model. Sheltering is determined by canopy cover and position on the slope. If WAF is calculated, then the user should be cautious of terrain and canopy features that are not input. In some cases, the preferred method might be to use human judgment to enter WAF directly.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Wind speed is entered as 20-ft* (or *10-m) wind and Input wind adjustment factor*" is selected as an input option.	
Output	SURFACE	If "*Wind speed is entered as 20-ft* (or *10-m) wind and Calculated wind adjustment factor"* is selected as an input option.	

Crown Fill Portion

Crown Fill Portion (percent or fraction) is an intermediate value in calculating Wind Adjustment Factor. It is calculated from Canopy Cover, Canopy Height, and Crown Ratio. If Crown Fill Portion is less than 5 percent, the calculation for unsheltered WAF is used; otherwise, the calculation is for sheltered WAF. If WAF is input, the value for Crown Fill Portion is not meaningful and is set to zero.

I/O	Module	Condition	Notes
Input	none	.	
Output	SURFACE	If "*Wind speed is entered as 20-ft* (or *10-m) wind and Calculated wind adjustment factor"* is selected as an input option.	

WAF Calculation

WAF (Wind Adjustment Factor) Calculation indicates the method of calculating Wind Adjustment Factor (WAF). If the Crown Fill Portion is less than 5 percent, the unsheltered model is used; otherwise, the sheltered model is used. If WAF is input rather than calculated, the variable is set to “Input.”

The variable WAF Calculation can have three values:

- Sheltered
- Unsheltered
- Input

I/O	Module	Condition	Notes
Input	none	.	
Output	SURFACE	If “*Wind speed is entered as 20-ft* (or *10-m) wind and Calculated wind adjustment factor”* is selected as an input option.	

Direction of Wind Vector (from Upslope)

Direction of the Wind Vector measured in degrees **from Upslope** is the direction that the wind is pushing the fire (Figure 8). This is useful in examining the vectoring approach to wind and slope influences.

Alternatively, the user can select the option to specify wind direction as the direction from which the wind is blowing. It is obviously critical that the user be certain of the method of specification of wind direction.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Wind is in specified directions*" and if "*Wind and spread directions are degrees clockwise from upslope (direction the wind is pushing the fire)*" are selected as input options.	
Output	none		

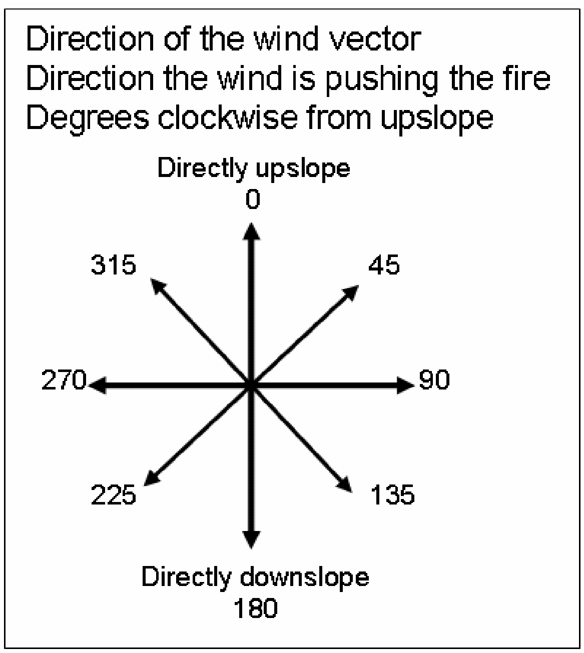

Figure 8—Direction of the wind vector is the direction the wind is pushing the fire.

Wind Direction (from North)

Wind Direction measured in degrees **from North** is the direction from which the wind is blowing (Figure 9). This is the usual way of specifying wind direction. This requires additional information on aspect to determine the direction of upslope in order to consider the combined effect of wind and slope on fire spread.

Alternatively the user can select the option to specify direction of the wind vector, the direction the wind is pushing the fire. It is obviously critical that the user be certain of the method of specification of wind direction.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Wind direction is specified on the worksheet*" and if "*Wind and spread directions are degrees clockwise from north (direction from which the wind is blowing)*" are selected as input options.	
Output	none		

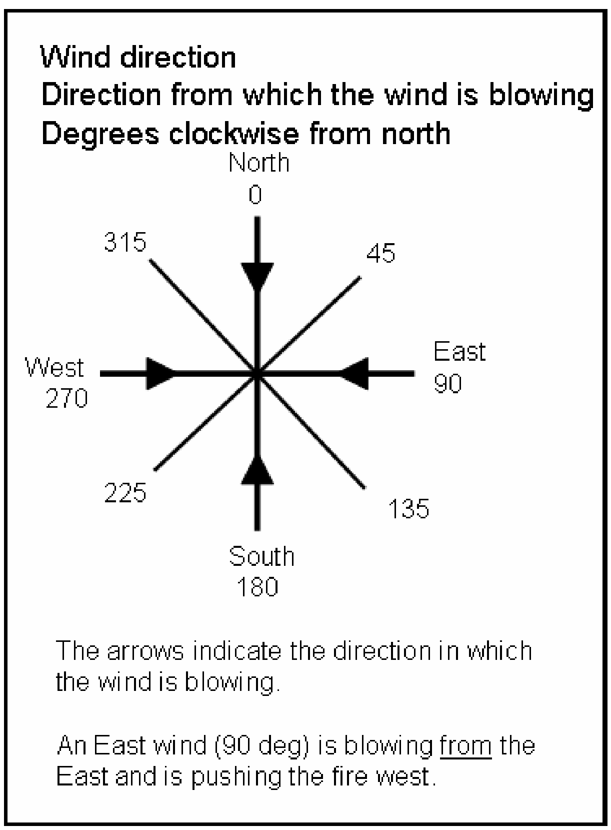

Figure 9—Wind direction is the direction from which the wind is blowing.

Slope

Aspect

Aspect is the direction a slope faces (Figure 10). It is used to determine the upslope direction in order to consider the combined effect of wind and slope on fire spread.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Wind and spread directions are degrees clockwise from north (direction from which the wind is blowing)*" are selected as an input option.	
Output	none		

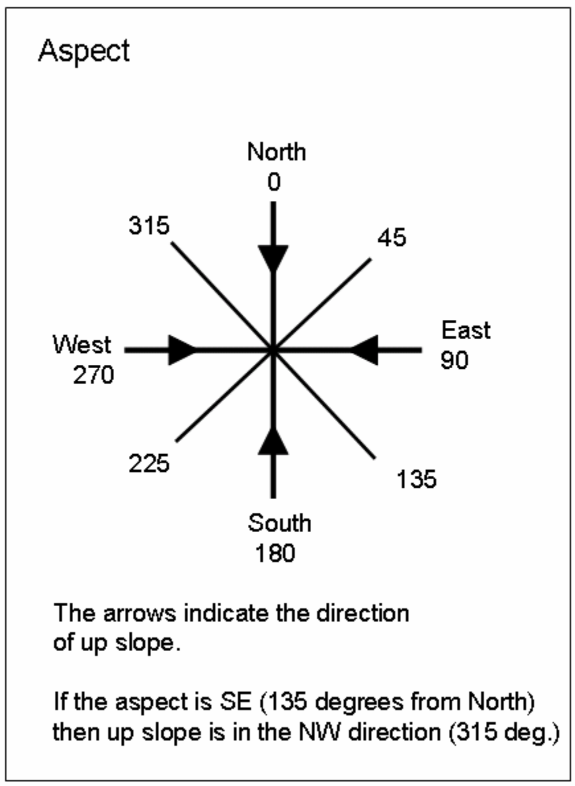

Figure 10—Aspect is the direction the slope is facing.

Number of Contour Intervals

The **Number of Contour Intervals** is a count of the number of contour intervals between two points on a map. It is used in the calculation of Slope Steepness.

When determining the Slope Steepness of a hillside, the user should select two points, one at the bottom of the slope and the other at the top. The line connecting these two points should be, as much as possible, perpendicular to the contour lines.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Slope steepness is calculated from map measurements*" is selected as an input option.	
Output	none		

Contour Interval

The **Contour Interval** is the difference in elevation between adjacent topographic contours on a topographic map. It is used in the calculation of Slope Steepness.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Slope steepness is calculated from map measurements*" is selected as an input option.	
Output	none		

Map Distance

The **Map Distance** is the distance between two points on a map generally expressed in inches or centimeters. It is used in the calculation of Slope Steepness.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Slope steepness is calculated from map measurements*" is selected as an input option.	
Output	none		

Map Representative Fraction

The **Map Representative Fraction** is the ratio of the number of units on the map between two points to the distance on the ground between these points. For example, if the Map Representative Fraction is 1:24,000, then each inch on the map represents 24,000 inches on the ground.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Display output distances in map units*" is checked on the module selection page and if distance variables are selected as output variables. If "*Slope steepness is calculated from map measurements*" is selected as an input option.	See the output variable table for the variables for which map distances are available.
	CROWN SIZE SPOT	If "*Display output distances in map units*" is checked on the module selection page and if distance variables are selected as output variables.	See the output variable table for the variables for which map distances are available.
Output	none		

Slope Horizontal Distance

The **Slope Horizontal Distance** is the ground distance between two locations on the ground. This is an intermediate value in the calculation of Slope Steepness from map measurements.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If "*Slope steepness is calculated from map measurements*" is selected as an input option.	

Slope Elevation Change

The **Slope Elevation Change** is the difference in elevation between the two points used to find the map distance. This is an intermediate value in the calculation of Slope Steepness from map measurements.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If "*Slope steepness is calculated from map measurements*" is selected as an input option.	

Slope Steepness

Slope Steepness is the maximum steepness of the slope. It is expressed as either percent or degrees depending on the input option that is selected. This is not necessarily the Slope Steepness in the direction of spread.

I/O	Module	Condition	Notes
Input	SURFACE	If "*Slope steepness is specified on the worksheet*" is selected as an input option.	
Output	SURFACE	If "*Slope steepness is calculated from map measurements*" is selected as an input option.	

Crown Fire

Foliar Moisture

Foliar Moisture content is the moisture content of the conifer overstory foliage (needles only). It is used along with surface fire intensity and crown base height to determine the threshold for transition to crown fire.

I/O	Module	Condition	Notes
Input	CROWN		
Output	none		

Canopy Base Height

The **Canopy Base Height** for an individual tree is the height at which sufficient fuel density exists for sustained canopy ignition. For a stand of trees, Canopy Base Height considers both the main canopy layer and ladder fuels in the understory. Canopy Base Height and Foliar Moisture content are used to calculate critical fireline intensity for transition to crown fire.

I/O	Module	Condition	Notes
Input	CROWN		
Output	None		

Canopy Bulk Density

Canopy Bulk Density is a stand description of weight of canopy fuels per unit of canopy volume (lb/ft^3 or kg/m^3). It is used to calculate Critical Crown Fire Rate of Spread to determine the threshold for achieving active crown fire (Van Wagner 1977).

I/O	Module	Condition	Notes
Input	CROWN		
Output	None		

Critical Surface Intensity

The **Critical Surface Intensity** is the Fireline Intensity of the surface fire that is required for a transition from a surface fire to a crown fire. It is calculated from Foliar Moisture content and Canopy Base Height.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Critical Surface Flame Length

The **Critical Surface Flame Length** is associated with the Critical Surface Intensity required for transition to crown fire.

I/O	Module	Condition	Notes
Input	None		
Output	CROWN		

Transition Ratio

The **Transition Ratio** is the surface Fireline Intensity divided by the Critical Surface Intensity. If the Transition Ratio is greater than or equal to 1, then the surface Fireline Intensity is sufficient for a transition to crown fire. Viewing Transition Ratio provides more information than the "Yes" or "No" for the Transition to Crown Fire? variable. It is instructive to know whether the Transition Ratio is close to 1 or significantly higher than or lower than 1.

I/O	Module	Condition	Notes
Input	None		
Output	CROWN		

Transition to Crown Fire?

Transition to Crown Fire? is either "Yes" or "No" to indicate whether conditions for transition from surface to crown fire are likely. Calculation depends on the Transition Ratio. If the Transition Ratio is greater than or equal to 1, then Transition to Crown Fire is "Yes." If the Transition Ratio is less than 1, then Transition to Crown Fire is "No."

I/O	Module	Condition	Notes
Input	None		
Output	CROWN		

Crown ROS

The **Crown Fire Rate of Spread (ROS)** is the forward spread rate of a crown fire estimated using Rothermel's (1991) crown fire spread model. It is the overall spread for a sustained run over several hours. The spread rate includes the effects of spotting. It is calculated from 20-Ft Wind Speed and surface fuel moisture values. The crown fire spread model does not include a description of the overstory.

I/O	Module	Condition	Notes
Input	None		
Output	CROWN		

Critical Crown ROS

The **Critical Crown Fire Rate of Spread (ROS)** is the rate at which a crown fire must spread to maintain itself as an active crown fire (Van Wagner 1977). It is calculated from the Canopy Bulk Density. Crown Fire Rate of Spread is compared to critical crown fire rate of spread to determine whether an Active Crown Fire is possible

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Active Ratio

The **Active Ratio** is Crown Fire Rate of Spread divided by the Critical Crown Fire Rate of Spread. If the Active Ratio is greater than or equal to 1, then the fire may be an active crown fire. Viewing Active Ratio provides more information than the “Yes” or “No” for the active crown fire variable. It is instructive to know whether the Active Ratio is close to 1 or significantly higher than or lower than 1.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Active Crown Fire?

Active Crown Fire? is either “Yes” or “No” to indicate whether conditions are such that a fire can maintain itself as an active crown fire. Calculation depends on the Active Ratio. If the Active Ratio is greater than or equal to 1, then Active Crown Fire is “Yes.” If the Active Ratio is less than 1, then Active Crown Fire is “No.”

I/O	Module	Condition	Notes
Input	None		
Output	CROWN		

Fire Type

Fire Type is one of the following four types:

- Surface (understory fire)
- Torching (passive crown fire, surface fire with occasional torching trees)
- Conditional crown (active crown fire possible if the fire transitions to the overstory)
- Crowning (active crown fire, fire spreading through the overstory crowns)

Assignment of Fire Type depends on the variables Transition to Crown Fire? and Active Crown Fire?.

Transition to Crown?	Active Crown Fire?	Fire Type
No	No	Surface
Yes	No	Torching
No	Yes	Conditional crown
Yes	Yes	Crowning

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Crown Spread Distance

The **Crown Fire Spread Distance** is the forward spread distance of a crown fire calculated from Crown Fire Rate of Spread and Elapsed Time. It is the overall spread distance for a sustained run over several hours. The Spread Distance includes the effects of spotting.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		Can also be output as a map distance if “*Display output distances in map units*” is selected.

Crown Fire Area

Crown Fire Area assumes an elliptically shaped fire. The model is in Rothermel (1991, p.16).

I/O	Module	Condition	Notes
Input	None		
Output	CROWN		

Crown Fire Perimeter

Crown Fire Perimeter assumes an elliptically shaped fire. The model is in Rothermel (1991, p.16).

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Crown Fire Length-to-Width Ratio

The **Crown Fire Length-to-Width Ratio** is based on 20-Ft Wind Speed as described by Rothermel (1991, p.16).

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Crown Load

Crown Load is used to calculate Crown Fireline Intensity (Rothermel 1991). Crown Load is Canopy Bulk Density times Canopy Height minus Canopy Base Height.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		Intermediate value

Canopy Heat per Unit Area

Canopy Heat per Unit Area is estimated from Crown Load as described by Rothermel (1991). It is added to the surface Heat per Unit Area to get Crown Fire Heat per Unit Area, which is used to calculate Crown Fireline Intensity.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		Intermediate value

Crown Fire Heat per Unit Area

Crown Fire Heat per Unit Area is the sum of surface fire Heat per Unit Area and Canopy Heat per Unit Area. It is used to calculate Crown Fireline Intensity.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		Intermediate value

Crown Fireline Intensity

Crown Fireline Intensity is calculated from Surface Heat per Unit Area, Crown Fire Heat per Unit Area, and Crown Rate of Spread as described by Rothermel (1991). Crown Fireline Intensity is used to calculate Crown Flame Length, and Power of the Fire.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Crown Flame Length

Crown Flame Length based on 20-Ft Wind Speed is calculated from Crown Fireline Intensity as described by Rothermel (1991). The flame length equation is from Thomas (1963) and differs from that used for surface fire (Byram 1959). Crown flame length is used to find Power of the Fire.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Power of the Fire

Power of the Fire is described by Rothermel (1991) based on work by Byram (1959). Power of the Fire is the rate at which energy is released, calculated on a unit area basis. This power is the source of energy that produces the convection column. If the Power of the Fire is greater than the Power of the Wind, then the fire-wind system is dominated by the energy of the fire. Such fires are plume-dominated and stand almost vertically. The expected spread rate of a plume-dominated fire is not yet predictable.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Power of the Wind

Power of the Wind is described by Rothermel (1991) based on work by Byram (1959). Power of the Wind is the rate of kinetic energy in the wind field and is expressed in the same units as Power of the Fire. If the Power of the Wind is greater than the Power of the Fire, then the fire-wind system is dominated by the energy of the wind. Such fires are Wind-Driven. Rothermel (1991) developed a method of estimating the spread rate of a wind-driven crown fire.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Power Ratio

Power Ratio is Power of the Fire divided by Power of the Wind. If Power Ratio is less than one (Power of the Wind is greater than Power of the Fire), the fire is estimated to be Wind-Driven.

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Wind-Driven Fire?

Wind-Driven Fire? is either “Yes” or “No.” “Yes” indicates wind-driven fire (Power of the Fire is greater than Power of the Wind). “No” indicates plume-dominated fire (Power of the Fire is greater than Power of the Wind).

I/O	Module	Condition	Notes
Input	none		
Output	CROWN		

Safety Zone

Number of Personnel

Number of Personnel to be located within the safety zone includes all firefighters, overhead team members, and any other personnel to be protected in the safety zone.

I/O	Module	Condition	Notes
Input	SAFETY		
Output	None		

Area per Person

The **Area per Person** is the average area occupied by each person to be located within the safety zone. A reasonable figure is 50 ft^2 per person, which is enough to allow shelter deployment in the event it becomes necessary.

I/O	Module	Condition	Notes
Input	SAFETY		
Output	None		

Number of Heavy Equipment

The **Number of Heavy Equipment** is the number of pieces of heavy equipment to be sheltered within the safety zone. Each piece is assumed to occupy the area specified by the Area per Heavy Equipment variable.

In the calculations, space is allocated in the safety zone for equipment brought in or already present. Equipment is a liability in a safety zone and often carries flammable liquids. In no other situation is heavy equipment allowed to operate in such close proximity to personnel. Heavy equipment or engines should not be brought to a safety zone if such equipment compromises the safety of personnel in the safety zone.

I/O	Module	Condition	Notes
Input	SAFETY		
Output	None		

Area per Heavy Equipment

The **Area per Heavy Equipment** is the average area needed for each piece of equipment to be located within the safety zone. For general planning, when the equipment types are not known, use a mean area of 300 ft^2.

I/O	Module	Condition	Notes
Input	SAFETY		
Output	None		

Safety Zone Separation Distance

The **Safety Zone Separation Distance** is the minimum distance a firefighter in protective clothing must be separated from flames to prevent radiant heat injury. Separation Distance is calculated as 4 x flame height. Flame Length is used as a worst case estimator of flame height. If SURFACE is used to calculate Flame Length, the maximum Flame Length is used for SAFETY even if SURFACE calculations are for a direction other than for the direction of maximum spread.

To estimate Separation Distance from a crown fire, the user must estimate flame height since there is not a Flame Length calculation in CROWN.

Separation Distance is calculated to prevent only radiant heat injury. Exposure to convective heat is not accounted for in this model.

I/O	Module	Condition	Notes
Input	none		
Output	SAFETY		

Safety Zone Radius

Safety Zone Radius is the radius of a circular safety zone just large enough to protect the specified number of personnel and heavy equipment from radiant burn injury. Calculation is based on Safety Zone Separation Distance plus the radius of a circle that fits all personnel and equipment. This core area represents the only safe area of the safety zone. Outside the core area persons may receive burns.

I/O	Module	Condition	Notes
Input	None		
Output	SAFETY		

Safety Zone Size

Safety Zone Size is the area of a circular safety zone just large enough to protect the specified number of personnel and heavy equipment from radiant burn injury. Calculation is based on the Safety Zone Radius, which is estimated from flame height. Flame Length can be calculated for a surface fire in SURFACE and used as a worst-case estimate of flame height. Flame height must be estimated by the user for a crown fire.

I/O	Module	Condition	Notes
Input	none		
Output	SAFETY		

Fire Size and Shape

Elapsed Time

Elapsed Time is the time for which the fire is spreading at an assumed constant rate. Rate of spread is multiplied by Elapsed Time to calculate the spread distance of a surface fire or a crown fire. In SIZE it is the time from when a fire begins spreading (which may be different from the time of ignition) until the time that the size calculation is done.

For surface fire, the fuel, fuel moisture, wind, and slope are assumed to be constant for the entire elapsed time. Because wildland fires burn under non-uniform conditions, the Elapsed Time and choice of input values must be considered carefully to achieve useful projections.

The crown fire model applies to spread times on the order of hours. During that time, conditions can vary considerably. Crown fire rate of spread includes the effect of spotting.

I/O	Module	Condition	Notes
Input	SURFACE		
	CROWN		
	SIZE		
Output	none		

Area or Fire Size at Report

The area of a fire started from a point source is based on the elliptical fire shape model (Figure 11). To avoid confusion, the variable is called **Area** when it is an output of the SIZE module. It is called **Fire Size at Report** when it is an input to the CONTAIN module. Calculation of Area is based on maximum rate of spread, Effective Wind Speed, and Elapsed Time. This variable applies to surface fire. Crown fire area can also be calculated.

I/O	Module	Condition	Notes
Input	CONTAIN	If SIZE is not also selected.	Labeled "*Fire Size at Report*."
Output	SIZE		Labeled "*Area*."

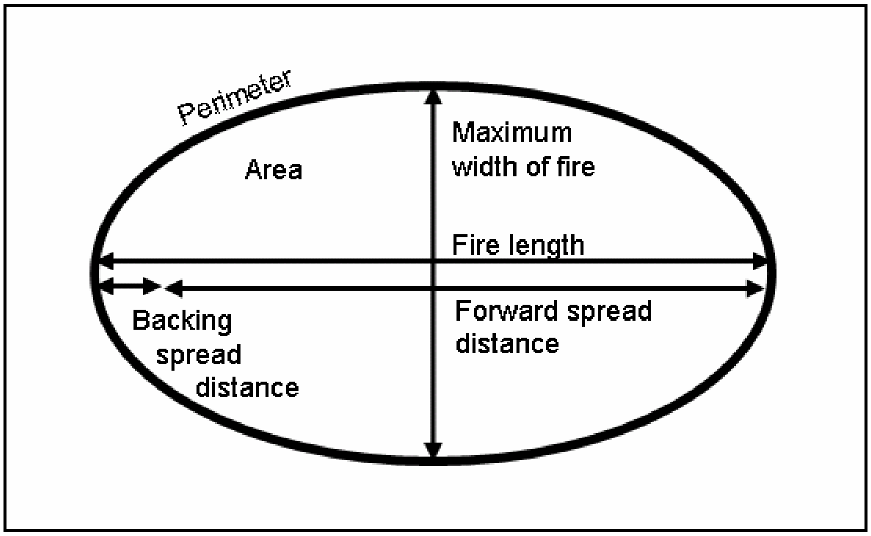

Figure 11—A point source fire shape and size is assumed to be elliptically shaped.

Perimeter

The **Perimeter** of a point source fire without suppression action is based on the elliptical fire shape model. Perimeter is the distance around the outside of the ellipse. This variable applies to surface fire. Crown fire perimeter can also be calculated.

See Area, Figure 11.

I/O	Module	Condition	Notes
Input	none		
Output	SIZE		

Length-to-Width Ratio

The **Length-to-Width Ratio** of an elliptically shaped fire is sometimes called length-to-breadth ratio. The Length-to-Width Ratio is a function of the Effective Wind Speed. Fire burning under a high wind speed will be long and narrow with a large Length-to-Width Ratio (Figure 12). This variable applies to surface fire. Crown fire Length-to-Width Ratio can also be calculated.

I/O	Module	Condition	Notes
Input	CONTAIN	If neither SURFACE nor SIZE is selected.	If SURFACE and CONTAIN are both selected, the length-to-width ratio is calculated in SURFACE and made available to CONTAIN even if SIZE is not selected.
Output	SIZE		

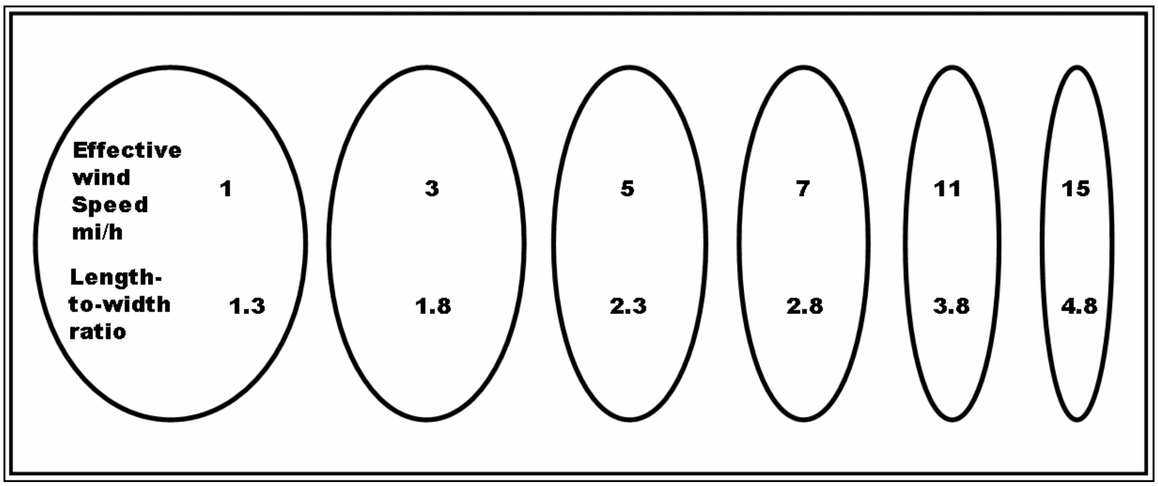

Figure 12—Fire shape depends on effective wind speed. Higher winds result in a higher length-to-width ratio.

Forward Spread Distance

The **Forward Spread Distance** is based on the elliptical fire shape model and is the distance the head fire travels in a specified period of time. This is the same as Surface Spread Distance for a heading fire.

See Area, Figure 11.

I/O	Module	Condition	Notes
Input	None		
Output	SIZE		Can also be output as a map distance if "*Display output distances in map units*" is checked.

Backing Spread Distance

The **Backing Spread Distance** is based on the elliptical fire shape model and is the distance the fire travels in a specified period of time in the direction of 180 degrees from the Direction of Maximum Spread.

See Area, Figure 11.

I/O	Module	Condition	Notes
Input	None		
Output	SIZE		Can also be output as a map distance if "*Display output distances in map units* is checked."

Fire Length

Fire Length is the distance from the head of a fire to the back end of the fire calculated for an elliptically shaped fire. Fire Length is the sum of the Forward Spread Distance and the Backing Spread Distance.

See Area, Figure 11.

I/O	Module	Condition	Notes
Input	none		
Output	SIZE		Can also be output as a map distance if "*Display output distances in map units* is checked."

Maximum Fire Width

The **Maximum Fire Width** is the maximum width of a fire and is based on the elliptical fire shape model and is maximum width of the ellipse.

See Area, Figure 11.

I/O	Module	Condition	Notes
Input	none		
Output	SIZE		Can also be output as a map distance if *"Display output distances in map units"* is checked.

Fire Shape Diagram

Fire Shape Diagrams of the elliptical shape of a point source surface fire with no suppression action are produced for each result in the table output. Surface Rate of Spread and Elapsed Time determine the Forward Spread Distance. Effective Wind Speed determines the Length-to-Width Ratio.

I/O	Module	Condition	Notes
Input	none		
Output	SIZE		A diagram is produced for each result in the table output.

Containment

Suppression Tactic

There are two possible **Suppression Tactics**:

- Head attack, where fireline is constructed starting at the head of the fire and proceeds at an equal rate down both flanks.
- Rear attack, where fireline is constructed starting at the rear of the fire and proceeds at an equal rate up both flanks.

Because the attack proceeds along both flanks, the Resource Line Production Rate along each flank is half of the specified rate for the resource. Head attack is more risky than rear attack, but head attack results in smaller fires and quicker containment.

I/O	Module	Condition	Notes
Input	CONTAIN		*Head* or *Rear* attack can be specified.
Output	none		

Line Construction Offset

Line Construction Offset is the distance from the fire at which the suppression line is constructed. Line Construction Offset distance of zero indicates a direct attack, while any other value indicates a parallel attack.

I/O	Module	Condition	Notes
Input	CROWN		
Output	none		

Resource Name

Resource Name is a simple, one-word identifier for a containment resource. The Resource Name is used to associate the resource with its Resource Arrival Time, Resource Line Production Rate, and Resource Duration. The Resource Name must be a single word with no embedded blanks or tabs. Examples include: Engine1, Type1Crew1, Type_2_Crew_2, and Bulldozer1.

The number of Resource Name entries on the worksheet must match the number of Resource Arrival Time, Resource Line Production Rate, and Resource Duration entries.

I/O	Module	Condition	Notes
Input	CONTAIN	If "*Suppression input entered for multiple resources*" is selected.	
Output	none		

Resource Line Production Rate

The **Resource Line Production Rate** is the average, sustained rate at which the resource can build and hold fire line. Enter the total rate for the resource, which is assumed to be split evenly between the two flanks. Thus, a crew (or single piece of equipment) that constructs fireline at 20 ch/h is assumed to be constructing 10 ch/h on the left flank and another 10 ch/h on the right flank. Guidelines are given in the Fireline Handbook.

If "*Suppression is entered for multiple resources*" is selected as an input option, there must be exactly one Resource Line Production Rate entry in the worksheet for every Resource Name entry.

I/O	Module	Condition	Notes
Input	CONTAIN		
Output	None		

Resource Arrival Time

The **Resource Arrival Time** is the elapsed time from the time the fire was reported until the containment resource arrives at the fire and begins line construction. All firefighting activities that occur before line construction begins should be accounted in the Resource Arrival Time (for example, travel time to fire, scouting and size up, safety zone construction, and so forth).

If "*Suppression input entered for multiple resources*" is selected as an input option, there must be exactly one Resource Arrival Time entry in the worksheet for every Resource Name entry. Each resource will be dispatched to the fire according to its Resource Arrival Time.

I/O	Module	Condition	Notes
Input	CONTAIN		
Output	None		

Resource Base Cost

Resource Base Cost is the fixed cost of mobilizing a resource on a fire. If "*Suppression input entered for multiple resources*" is selected as an input option, there must be exactly one Resource Base Cost entry in the worksheet for every Resource Name entry. If a resource is dispatched to a fire, its total cost is the Resource Base Cost plus its Resource Hourly Cost for the time spent on the fire until the fire is contained or the Resource Duration expires. If a resource is not dispatched to a fire, nothing is added to the total cost for that resource. Units for cost are not assigned. Costs can be calculated as, for example, euros, dollars, or hundreds of dollars.

I/O	Module	Condition	Notes
Input	CONTAIN		
Output	none		

Resource Hourly Cost

The **Resource Hourly Cost** is the cost per hour of using the resource on a fire. If "*Suppression input entered for multiple resources*" is selected as an input option, there must be exactly one Resource Base Cost entry in the worksheet for every Resource Name entry. If a resource is dispatched to a fire, its total cost is the Resource Base Cost plus its Resource Hourly Cost for the time spent on the fire until the fire is contained or the Resource Duration expires. If a resource is not dispatched to a fire, nothing is added to the total cost for that resource. Units for cost are not assigned. Costs can be calculated as, for example, euros, dollars, or hundreds of dollars.

I/O	Module	Condition	Notes
Input	CONTAIN		
Output	None		

Resource Duration

Resource Duration is the amount of time during which the containment resource is able to sustain its Resource Line Production Rate. The resource begins line construction at its designated Resource Arrival Time, performs line construction at its specified Resource Line Production Rate, and stops line construction after its Resource Duration has expired. If "*Suppression input entered for multiple resources*" is selected as an input option, there must be exactly one Resource Duration entry in the worksheet for every Resource Name entry. All resources will be dispatched to the fire according to their arrival times until the fire is either contained or escapes.

I/O	Module	Condition	Notes
Input	CONTAIN		
Output	none		

Fire Area at Initial Attack

Fire Area at Initial Attack is the fire size when the first resource begins suppression action on the fire. It is calculated from the Fire Size at Report and the Resource Arrival Time.

I/O	Module	Condition	Notes
Input	None		
Output	CONTAIN		

Perimeter at Initial Attack

Perimeter at Initial Attack is the perimeter of the elliptical shaped fire when the first resource begins suppression action. It is calculated from the Fire Size at Report and the Resource Arrival Time.

I/O	Module	Condition	Notes
Input	None		
Output	CONTAIN		

Contain Status

The **Contain Status** is the final status of the initial attack effort. This output variable has three possible values:

- **Contained**, which indicates that the fire was successfully contained using one or more of the specified resources.
- **Withdrawn**, which indicates that the fire escaped containment after resources arrived and constructed some containment line but were withdrawn because the specified resource duration was exceeded. (The resources are unable to work long enough to contain the fire even though they might have been gaining on it.)
- **Escaped**, which indicates that the specified available resources are insufficient to enclose the fire, so no containment line was constructed.

I/O	Module	Condition	Notes
Input	None		
Output	CONTAIN		

Time from Report

The **Time from Report** is the elapsed time from the fire report time until it was either successfully contained or it escaped the initial attack.

I/O	Module	Condition	Notes
Input	none		
Output	CONTAIN		

Contained Area

Contained Area is the size of the fire enclosed by the containment line. The Contained Area will be larger than the fire area at the time of containment when the Line Construction Offset is greater than zero. If the fire escapes because resource productivity is insufficient or all specified resources have arrived at the fire and their duration times have expired, the Contained Area is given as “-1.”

I/O	Module	Condition	Notes
Input	None		
Output	CONTAIN		

Fireline Constructed

Fireline Constructed is the total length of fireline constructed by all resources at the time the fire was contained or determined to have escaped. If the fire is not successfully contained, Fireline Constructed is the total length of fire line constructed by all resources at the time the last available resource duration expires. If the fire is successfully contained, Fireline Constructed is the total length of line constructed by all resources at the time of containment.

I/O	Module	Condition	Notes
Input	none		
Output	CONTAIN		

Number of Resources Used

The **Number of Resources Used** indicates those actually used to contain the fire. It may be less than the number of resources specified on the worksheet if the fire is contained before all resources arrive.

I/O	Module	Condition	Notes
Input	none		
Output	CONTAIN	If “*Suppression input entered for multiple resources*” is selected.	

Cost of Resources Used

Cost of Resources Used is the total cost of all resources dispatched to the fire. If a resource is dispatched to a fire, its cost is the Resource Base Cost plus its Resource Hourly Cost for the time spent on the fire until the fire is contained or its Resource Duration expires. Units for cost are not assigned. Costs can be calculated as, for example, euros, dollars, or hundreds of dollars.

I/O	Module	Condition	Notes
Input	None		
Output	CONTAIN		

Containment Diagram

The **Containment Diagram** is a diagram of the final fire shape, size, and constructed fireline at the time it was successfully contained or escaped initial attack.

I/O	Module	Condition	Notes
Input	None		
Output	CONTAIN		

Spotting Distance

Ridge-to-Valley Elevation Difference

The **Ridge-to-Valley Elevation Difference** is the vertical elevation difference in feet or meters between ridge top and valley bottom in the direction of terrain flow. A stylized terrain shape is used by the model to calculate spotting distance (Figure 13).

I/O	Module	Condition	Notes
Input	SPOT		
Output	none		

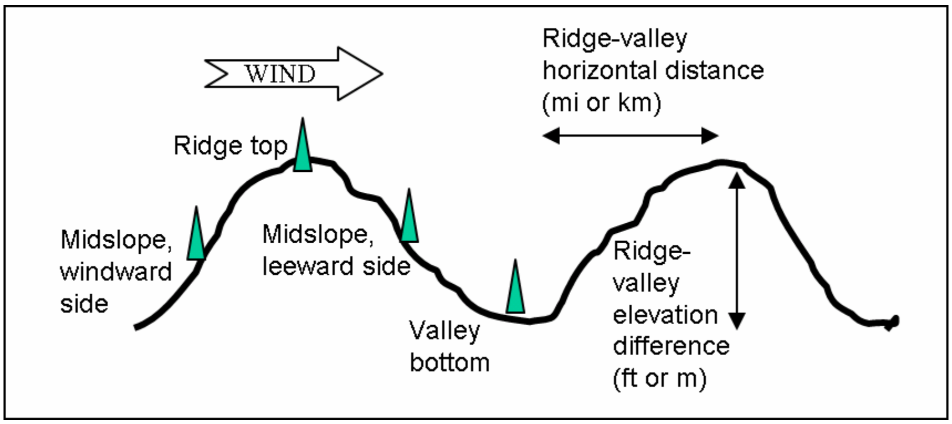

Figure 13—Terrain is described as a simplified sine shape for the spotting distance model.

Ridge-to-Valley Horizontal Distance

The **Ridge-to-Valley Horizontal Distance** is the horizontal distance in miles or kilometers between the ridge top and the valley bottom in the direction of the wind flow. A stylized terrain shape is used by the model to calculate spotting distance.

If winds are blowing directly up or down a valley, the Ridge-to-Valley Horizontal Distance will often be set to zero.

I/O	Module	Condition	Notes
Input	SPOT		The input value of Ridge-to-valley horizontal distance can also be output as a map distance if "*Display output distances in map units*" is checked.
Output	none		

Spotting Source Location

The **Spotting Source Location** refers to the origin of the firebrands that can result in spotting. The possible locations are:

- ridge top (RT)
- midslope, windward side (MW)
- valley bottom (VB)
- midslope, leeward side (ML)

I/O	Module	Condition	Notes
Input	SPOT		
Output	none		

Downwind Canopy Height

Downwind Canopy Height is used to calculate spotting distance in SPOT. It is the mean cover height in the downwind direction as it affects the distance a firebrand is carried. If the forest cover is open, a value of half the downwind canopy height should be entered.

Canopy Height may be different from Downwind Canopy Height. Canopy height represents the fire site for calculation of Wind Adjustment Factor, Crown Fireline Intensity, and Tree Mortality. For example, the canopy height at the site of the fire may be zero (no overstory) while the **downwind canopy height** (in the direction firebrands are carried) may be 75 feet.

I/O	Module	Condition	Notes
Input	SPOT		
Output	none		

Flame Height from a Burning Pile

Flame Height from a Burning Pile is the average height of the flames measured from the base of a burning pile (Figure 14). This is not the same as Flame Length from a spreading surface fire. There is not a model to calculate flame height from a burning pile, it is an input determined by expert opinion.

I/O	Module	Condition	Notes
Input	SPOT	If "*Spotting distance from a burning pile*" is selected as an output variable.	
Output	none		

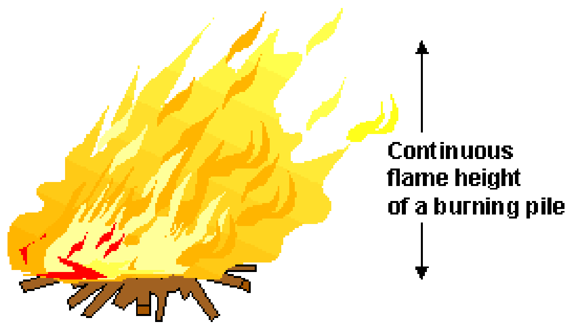

Figure 14—Continuous flame height is a user input for the model for spotting distance from a burning pile.

Torching Tree Height

Torching Tree Height is the distance from the ground to the top of a tree. It is the height of torching trees used to calculate maximum spotting distance in the SPOT module.

Torching Tree Height may be different from Canopy Height and Downwind Canopy Height. Canopy Height is used to calculate wind adjustment factor, crown fire intensity, and tree mortality. Downwind Canopy Height is used to calculate maximum spotting distance.

I/O	Module	Condition	Notes
Input	SPOT	If "*Spotting distance from torching trees*" is selected as an output variable.	
Output	none		

Number of Torching Trees

Number of Torching Trees is the number of trees that torch simultaneously. It is used to calculate the height to which firebrands are lofted.

I/O	Module	Condition	Notes
Input	SPOT	If "*Spotting distance from torching trees*" is selected as an output variable.	
Output	none		

Spot Tree Species

Spot Tree Species is used in estimating the maximum spotting distance from torching trees. Fourteen tree species are available for SPOT.

Tree species is also an input to MORTALITY. There are 206 species available for MORTALITY and 14 for SPOT. To avoid confusion, there are two tree species variables: Spot Tree Species and Mortality Tree Species. The same tree species codes are used for both variables.

I/O	Module	Condition	Notes
Input	SPOT		
Output	none		

Cover Height Applied for Spotting Distance from Torching Trees

Cover Height Applied for Spotting Distance from Torching Trees is the cover height actually used in the computation of spotting distance. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model. A critical cover height is first determined from the maximum firebrand height. The applied cover height is the greater of the critical cover height or the input canopy height.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Steady State Flame Height from Torching Trees

The **Steady State Flame Height from Torching Trees** is used to calculate the height to which a firebrand is lofted. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Tree Height/Flame Height Ratio for Torching Trees

The ratio of the torching tree height to the steady state flame height (**Tree Height/Flame Height Ratio for Torching Trees**) is used to determine the appropriate equation for firebrand height. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Steady State Flame Duration from Torching Trees

Steady State Flame Duration from Torching Trees is a dimensionless value (no units) used to calculate firebrand height. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Firebrand Height from Torching Trees

The **Firebrand Height from Torching Trees** is the maximum height to which a firebrand is lifted and is still viable for starting a fire when it lands. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Flat Terrain Spotting Distance from Torching Trees

The **Flat Terrain Spotting Distance from Torching Trees** is the maximum spotting distance over flat terrain. This value is then adjusted according to the terrain descriptors. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Cover Height Applied for Spotting Distance from a Burning Pile

Cover Height Applied for Spotting Distance from a Burning Pile is the cover height actually used in the computation of spotting distance. A critical cover height is first determined from the maximum firebrand height. The applied cover height is the greater of the critical cover height or the input canopy height. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	None		
Output	SPOT		Intermediate value

Firebrand Height from a Burning Pile

Firebrand Height from a Burning Pile is the maximum height to which a firebrand is lifted and is still viable for starting a fire when it lands. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Flat Terrain Spotting Distance from a Burning Pile

The **Flat Terrain Spotting Distance from a Burning Pile** is the maximum spotting distance over flat terrain. This value is then adjusted according to the terrain descriptors. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Cover Height Applied for Spotting Distance from a Wind-Driven Surface Fire

Cover Height Applied for Spotting Distance from a Wind-Driven Surface Fire is the cover height actually used in the computation of spotting distance. A critical cover height is first determined from the maximum firebrand height. The applied cover height is the greater of the critical cover height and the input canopy height. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Firebrand Height from a Wind-Driven Surface Fire

Firebrand Height from a Wind-Driven Surface Fire is the maximum height to which a firebrand is lifted and is still viable for starting a fire when it lands. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	None		
Output	SPOT		Intermediate value

Firebrand Drift Distance from a Wind-Driven Surface Fire

Firebrand Drift Distance from a Wind-Driven Surface Fire is the distance that the firebrand is carried as it is being lifted. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Flat Terrain Spotting Distance from a Surface Fire

The **Flat Terrain Spotting Distance from a Surface Fire** is the maximum spotting distance of a wind-driven surface fire over flat terrain. This value is then adjusted according to the terrain descriptors. This is an intermediate value in the calculations that might be of interest to someone examining the spotting distance model.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Intermediate value

Spotting Distance from Torching Trees

Spotting Distance from Torching Trees is the maximum distance that one can expect potential spot fires resulting from firebrands from torching trees (Figure 15).

The spotting model is applicable under conditions of intermediate fire severity in which spotting distance up to a mile or two might be expected. This model does not apply to those extreme situations where spotting may occur up to tens of miles from the fire front. The model is for spotting from torching trees, not from a spreading crown fire.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Spot distance can also be output as a map distance if "*Display output distances in map units*" is checked.

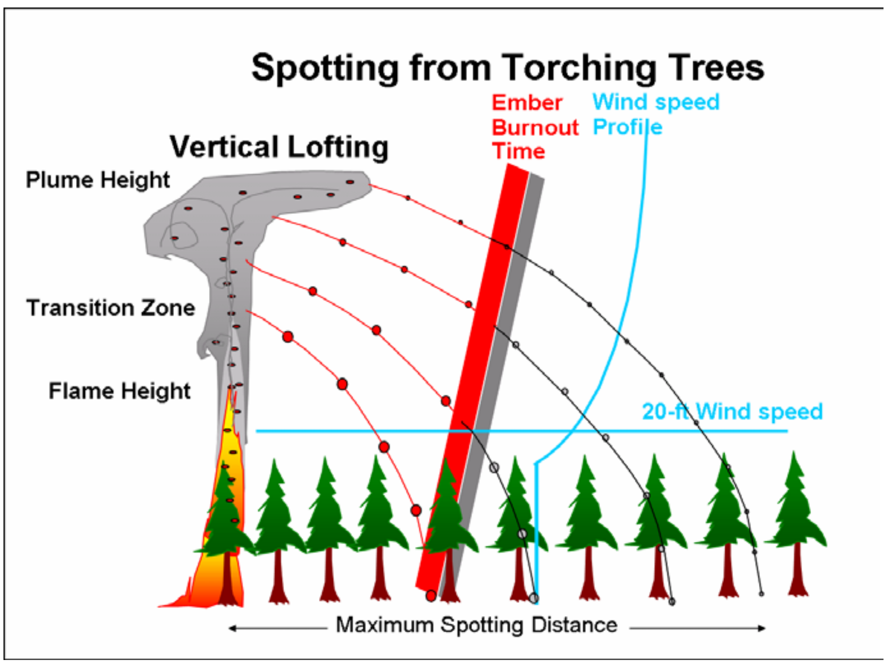

Figure 15—Maximum spotting distance from torching trees.

Spotting Distance from a Burning Pile

Spotting Distance from a Burning Pile is the maximum distance that one can expect potential spot fires resulting from firebrands from the burning pile. Flame height from a burning pile is an input, which is used to calculate the lofting strength from the burning pile.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Spot distance can also be output as a map distance if *"Display output distances in map units"* is checked.

Spotting Distance from a Wind-Driven Surface Fire

Spotting Distance from a Wind-Driven Surface Fire is the maximum distance that one can expect potential spot fires based on firebrands from a spreading wind-driven surface fire. The model is applicable only if the fire is truly wind-driven through surface fuels that are not sheltered from the wind by overstory.

If both SURFACE and SPOT are selected, calculated Flame Length in the direction of maximum spread is used in the spotting distance calculations. Because the spotting model is only valid for wind-driven head fires, the SURFACE calculation must be for the *direction of maximum spread*. The program provides guidance on resolving a conflict.

I/O	Module	Condition	Notes
Input	none		
Output	SPOT		Spot distance can also be output as a map distance if *"Display output distances in map units"* is checked.

Scorch Height

Air Temperature

Air Temperature is the ambient dry bulb temperature measured in the shade. It is used to calculate Scorch Height and Probability of Ignition from a Firebrand. Note that Air Temperature is not included in the SURFACE Surface Rate of Spread and Fireline Intensity calculations.

I/O	Module	Condition	Notes
Input	SCORCH		
	IGNITE	If *"Probability of ignition from a firebrand"* is calculated.	
Output	none		

Scorch Height

Scorch Height is the height above the ground that the temperature in the convection column reaches the lethal temperature to kill live crown foliage. This temperature is assumed to be 140° Fahrenheit (60° Celsius).

If both SURFACE and SCORCH modules are selected, Midflame Wind Speed and the Flame Length in the direction of the spread calculation are used as input to SCORCH.

See Canopy Height, Figure 7.

I/O	Module	Condition	Notes
Input	MORTALITY	If SCORCH is not selected.	If both MORTALITY and SCORCH are selected, then the scorch height calculated in SCORCH is used in MORTALITY.
Output	SCORCH		

Tree Mortality

Crown Ratio

Crown Ratio is the proportion of the total vertical tree height that is occupied by the vertical length of the tree crown (Figure 16). Crown Ratio and Canopy Height are used to find Canopy Base Height, which is used to calculate Tree Crown Length Scorched in the MORTALITY module. Crown Ratio is also used in the SURFACE module to calculate Wind Adjustment Factor.

See Canopy Height, Figure 7.

I/O	Module	Condition	Notes
Input	MORTALITY		If canopy base height is not entered for CROWN
	SURFACE		If wind adjustment factor is calculated and if canopy base height is not entered for CROWN
Output	SURFACE		If wind adjustment factor is calculated and canopy base height is entered for CROWN.

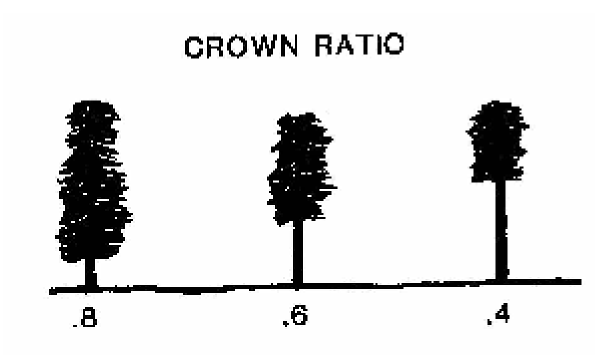

Figure 16—Crown ratio examples.

D.B.H.

D.B.H. is the abbreviation for diameter at breast high. It is the measurement of the diameter of a tree measured at about 4.5 ft (1.4 m) from the ground level. It is used to calculate Bark Thickness in MORTALITY and is part of the torching tree description in SPOT. D.B.H. is also an input for the western aspen special case fuel model.

I/O	Module	Condition	Notes
Input	MORTALITY		
	SPOT		
	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	
Output	none		

Bark Thickness

Bark Thickness is used to calculate tree mortality for some species. Bark Thickness is calculated from Mortality Tree Species and D.B.H.

I/O	Module	Condition	Notes
Input	none		
Output	MORTALITY		

Mortality Tree Species

Mortality Tree Species determines the model used to calculate tree mortality in the MORTALITY module. It is also used to estimate Bark Thickness for some species. Two hundred and six species are available for the MORTALITY module. There are 12 mortality equations and 39 bark thickness equations.

Tree species is also an input to SPOT. Because 14 species are used in the SPOT module, to avoid confusion, there are two tree species variables: Spot Tree Species and Mortality Tree Species. The same tree species codes are used for both variables.

I/O	Module	Condition	Notes
Input	MORTALITY		
Output	none		

Tree Crown Length Scorched

Tree Crown Length Scorched is calculated as Scorch Height - (Canopy Height - Live Crown Length). If Scorch Height is greater than Canopy Height then Tree Crown Length Scorched is set equal to the Tree Crown Length. Tree Crown Length Scorched is used to calculate percent Tree Crown Volume Scorched, which is used to calculate tree mortality for some species.

See Canopy Height, Figure 7.

I/O	Module	Condition	Notes
Input	None		
Output	MORTALITY		

Tree Crown Volume Scorched

Tree Crown Volume Scorched is the percentage (or fraction) of the tree crown volume that is scorched, and is used to calculate tree mortality for some species. It is calculated from the Tree Crown Length Scorched and the total crown length.

I/O	Module	Condition	Notes
Input	None		
Output	MORTALITY		

Probability of Mortality

Probability of Mortality is the likelihood that a tree will be killed by a fire. The equation used to calculate Probability of Mortality depends on the Mortality Tree Species. There are 12 mortality equations, which variously include Bark Thickness, Tree Crown Length Scorched, or Tree Crown Volume Scorched.

Probability of Mortality can be interpreted as the probability of an individual tree dying or it can be multiplied by the number of trees on a site to estimate the number of trees that will die.

Probability of Aspen Mortality is calculated by a different model and is available by selecting the western aspen special case fuel model in SURFACE.

I/O	Module	Condition	Notes
Input	None		
Output	MORTALITY		

Probability of Aspen Mortality

Probability of Aspen Mortality is the likelihood that a tree will be killed by a fire. It is based on Flame Length, D.B.H., and Aspen Fire Severity of either low or moderate+ (Brown and Debyle 1987). This calculation is done as part of the special case aspen fuel model that can be selected in SURFACE. It is not included as part of the MORTALITY module.

Probability of Aspen Mortality can be interpreted as the probability of an individual tree dying or it can be multiplied by the number of trees on a site to estimate the number of trees that will die.

I/O	Module	Condition	Notes
Input	none		
Output	SURFACE	If "*Fuel is entered as special case fuel model, western aspen*" is selected as an input option.	Aspen mortality is a special case and is not available in the MORTALITY module.

Probability of Ignition

Fuel Shading from the Sun

Fuel Shading from the Sun is the portion of the fuel that is not receiving direct sunlight due to cloud cover and overstory. It is used to calculate Probability of Ignition by a Firebrand.

Less than 50 percent shading is sometimes referred to as being in an *unshaded* condition; Fifty percent or more shading is referred to as *shaded* condition.

I/O	Module	Condition	Notes
Input	IGNITE		
Output	none		

Probability of Ignition from a Firebrand

Probability of Ignition from a Firebrand is an indication of the chance that a firebrand will cause an ignition. The number of firebrands, their size, and the fuel on which they land is generally unknown. Therefore, there is no specific interpretation of the probability of ignition of a fire.

The calculation of probability of ignition is based on Fuel Shading from the Sun, fine dead fuel moisture, and the Air Temperature.

I/O	Module	Condition	Notes
Input	None		
Output	IGNITE		

Lightning Ignition Fuel Type

Lightning Ignition Fuel Type is used to calculate probability of ignition from a lightning strike. There are eight fuel types, which are only used for this ignition model. Depending on fuel type, ignition from lightning is a function of either 100-h Moisture Content or Lightning Duff and Litter Depth.

I/O	Module	Condition	Notes
Input	IGNITE		For probability of ignition by lightning.
Output	none		

Lightning Duff and Litter Depth

Lightning Duff and Litter Depth is the average depth of the litter and duff layers at the point of the lightning strike. It is used to calculate the Probability of Ignition from Lightning. The word "lightning" is included in the variable name to emphasize that this duff and litter depth is not used in any other module.

I/O	Module	Condition	Notes
Input	IGNITE		For probability of ignition by lightning.
Output	none		

Lightning Strike Type

Lightning Strike Type is the type of lightning discharge (polarity). It can be
- negative (-)
- positive (+)
- unknown (?)

The characteristic of lightning responsible for ignition of ground fuel is the presence and duration of a continuing current, which varies by Lightning Strike Type. The presence or duration of a continuing current is not detected by the current operational lightning detection network.

I/O	Module	Condition	Notes
Input	IGNITE		For probability of ignition by lightning.
Output	none		

Probability of Ignition from Lightning

The **Probability of Ignition from Lightning** is the chance that a lightning strike will ignite *ground* fuel of the type specified. It is calculated from fuel type, duff and litter depth, fuel moisture, and Lightning Strike Type (negative, positive, or unknown).

This model predicts ignition of duff and similar ground fuels. No model is available to determine the probability of surface fire ignition from the ground fire. Not all ground fuel ignitions from lightning will result in a spreading surface fire.

I/O	Module	Condition	Notes
Input	none		
Output	IGNITE		

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Appendix A—Mathematical models in BehavePlus

Table A1—Models that are included in each of the BehavePlus modules with citations and notes.

BehavePlus Module	Model	Reference and notes
SURFACE	Surface head fire rate of spread, reaction intensity, heat per unit area, characteristic dead fuel moisture, live fuel moisture of extinction, etc.	(Rothermel 1972) (Albini 1976a) minor adjustments
	Fireline intensity Flame length	(Byram 1959) with adjustments to work with Rothermel's surface fire spread model by (Albini 1976b)
	Surface fire flame residence time (used to calculate fireline intensity)	(Anderson 1969)
	Direction of maximum spread	(Rothermel 1983) using manual vectoring (Rothermel 1983) (Finney 1998) calculations based on Rothermel's wind and slope factors
	Fire characteristics chart, relationship among rate of spread, heat per unit area, fireline intensity, and flame length	(Finney 1998)
	Spread in direction from ignition point from a point source fire	(Andrews 1986)
	Effective wind speed	(Albini 1976b)
	Wind adjustment factor	(Albini and Baughman 1979, Baughman and Albini 1980, Rothermel 1983)
	Wind speed at 10 m adjusted to 20 ft	(Turner and Lawson 1978)
	13 standard fire behavior fuel models	(Rothermel 1972) 11 fuel models (Albini 1976b) slight revision of the 11 plus two more fuel models (Anderson 1982) fuel model selection guide
	40 standard fire behavior fuel models	(Scott and Burgan 2005)
	Custom fire behavior fuel models	(Burgan and Rothermel 1984, Burgan 1987)
	Dynamic fuel load transfer	(Burgan 1979) (Burgan and Rothermel 1984, Andrews 1986) as used in BEHAVE (Scott and Burgan 2005) as used in the 2005 standard fire behavior fuel models
	Two fuel models, weighted rate of spread	(Rothermel 1983)
	Two fuel models, harmonic mean	(Fujioka 1985)
	Two fuel models, 2-dimensional expected spread	(Finney 2003)
	Palmetto gallberry special case fuel model	(Hough and Albini 1978)
	Western aspen special case fuel model	(Brown and Simmerman 1986) (Brown and DeByle 1987) for mortality

Table A1 (continued)

BehavePlus Module	Model	Reference and Notes
CROWN	Critical surface intensity needed for transition from surface to crown fire	(Van Wagner 1977)
	Transition to crown fire, relationship of surface fire intensity and critical surface fire intensity	(Finney 1998) (Scott and Reinhardt 2001)
	Crown fire rate of spread, area, and perimeter	(Rothermel 1991)
	Critical crown fire rate of spread, needed for an active crown fire	(Van Wagner 1993)
	Active crown fire, relationship of crown fire rate of spread and critical crown fire rate of spread	(Finney 1998) (Scott and Reinhardt 2001)
	Fire type: surface, torching, conditional crown, crowning	(Finney 1998) (Scott and Reinhardt 2001)
	Crown fire flame length	(Thomas 1963)
	Crown fire intensity	(Rothermel 1991)
	Power of the fire, power of the wind	(Byram 1959)
SAFETY	Safety zone size, separation distance, radius	(Butler and Cohen 1996; 1998b, a)
SIZE	Elliptical fire size and shape, area, perimeter, length-to-width ratio	(Anderson 1983) double ellipse (Andrews 1986) simplified to simple ellipse
CONTAIN	Fire containment	(Albini and others 1978) in the old BEHAVE (Fried and Fried 1996) in BehavePlus
SPOT	Spotting distance from torching trees	(Albini 1979, Chase 1981)
	Spotting distance from a burning pile	(Albini 1981)
	Spotting distance from a wind-driven surface fire	(Albini 1983a, Albini 1983b, Chase 1984)
SCORCH	Crown scorch height	(Van Wagner 1973)
MORTALITY	Tree mortality	(Ryan and Reinhardt 1988, Reinhardt and Crookston 2003) (Hood and others 2008) updates for version 5.0
	Bark thickness	(Ryan and Reinhardt 1988, Reinhardt and Crookston 2003)
IGNITE	Probability of ignition from firebrand	(Schroeder 1969)
	Probability of ignition from lightning	(Latham and Schlieter 1989)
Fine dead fuel moisture Tool	Fine dead fuel moisture tables	(Rothermel 1983)

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