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Spotting Distance from Wind-Driven Surface Fires — Extensions of Equations for Pocket Calculators

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Spotting Distance from Wind-Driven Surface Fires — Extensions of Equations for Pocket Calculators

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ABSTRACT

Extends equations for calculating the maximum spot fire distance to include wind-driven fires burning in surface fuels as a firebrand source. Predictions are based upon prevailing windspeed, vegetational cover, and local terrain. The equations can be used on a programmable pocket calculator. Previous methods of calculating spotting distance from torching trees and burning piles are also included. For copies of a program for the Texas Instruments TI-59, send eight blank TI-59 magnetic cards to the author. (Only two cards are required if the user has the previous version of the program.) Potential uses are in fire management planning and in predicting real-time fire behavior.

KEYWORDS: spot fire, spotting, firebrands, fire management

MODEL DESCRIPTION

Spot fires ignited by flying embers from wildfires and prescribed fires have long been a problem for fire managers. Spotting is difficult to prevent; therefore it is useful to be able to forecast when spotting is likely to occur and predict its maximum distance and direction.

Roussopoulos and Johnson (1975) and Rothermel (1983) provide guidelines based on fireline intensity that indicate when severe fire behavior such as torching, crown fires, and spot fires can be expected. Albini (1979, 1981) and Chase (1981) document calculation of the maximum distance firebrands can travel when the source of the firebrands is:

1. The transient flame produced by a torching tree (or group of trees burning with a single flame structure), and
2. A continuous steady flame as provided by burning piles of slash or "jackpots" of heavy fuel.

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Albini (1983) considers another source of firebrands:

3. A wind-driven fire burning in surface fuels (such as grass, shrubs, litter) without timber cover.

This note extends the equations for predicting maximum spotting distance to include the third case, and documents a revised program for the Texas Instruments TI-59[2] calculator that includes all three sources.

In all three instances an updraft lofts burning material vertically; then it is carried horizontally by the wind while also falling back to earth to land some distance downwind from the source. In the case of wind-driven fires burning in surface fuels, the firebrand drifts downwind as it is being lofted. When firebrands are produced by surface fires, significant overstory or timber cover may provide a barrier for the firebrands and interfere with the development of an updraft that lofts the firebrands vertically. Consequently, spotting distance in these situations is generally insignificant.

Albini's model covers intermediate range spotting (generally a few tenths of a mile to a mile). It does not address short-range spotting of a few tens of yards from fires of low intensity or very long-range spotting associated with severe fire behavior such as crown fires and firewhirls. The firebrand of interest is the one of optimum size. That is the particle whose dimensions, weight, and aerodynamics allow the wind to loft it a considerable distance and that is still burning when it lands. Particles smaller than optimum could travel farther, but would burn up before landing. Particles larger than optimum would often be burning when they land, but would not travel as far. The model does not consider the numbers of optimum firebrands produced by a fire. If particles of optimum size are not present, spot fire distance will be less than the maximum predicted. The model does not address whether the firebrand causes an ignition, or the number of spot fires caused.

Mountainous terrain is modeled as a washboard. If this simple representation does not describe your situation, perhaps the model will not give you a good approximation of spotting distance.

The surface-fire spotting model requires two fuel-model-dependent parameters used to relate thermal energy to windspeed. Albini (1983) derives these parameters for 12 of the 13 standard NFFL fuel models (Albini 1976; Anderson 1982) and they are presented in table1 as parameters A and B. A is used as a coefficient in the windspeed function and B is used as a power. Some models ordinarily have overstories, but are sometimes used to represent fuels without overstory cover. Model 9 (hardwood litter) can be used when the deciduous overstory is bare of leaves or the stand is sparse. Model 10 (timber litter and understory) is sometimes used to represent timber harvest debris overgrown with shrubs or other vegetation. Model 8 (closed timber litter) was omitted in Albini's analysis because it is seldom used to represent a model without cover.

The model-dependent parameters can also be derived for custom fuel models (Burgan and Rothermel 1984). Calculation speed and memory considerations preclude calculation of these parameters in the TI-59 program. Current plans are to include derivation of surface-spotting parameters for custom fuel models in the expected update of the BEHAVE system of interactive computer programs (Andrews 1983; Andrews, review draft; Burgan and Rothermel 1984).

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[2] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Table 1.—Corrected values of windspeed function parameters for 12 of the 13 NFFL fuel models (erratum notice, Albini 1983). Units of A are seconds; B is dimensionless.

Fuel model	Coefficient A	Power B
	Seconds	
Grass and litter		
1 Short grass	545	-1.21
2 Grassy understory	709	-1.32
3 Tall grass	429	-1.19
9 Hardwood litter	1121	-1.51
Shrub types		
4 Mature chaparral	301	-1.05
5 Young chaparral	235	- .92
6 Dormant brush	242	- .94
7 Southern rough	199	- .83
Logging slash		
10 Overgrown slash	224	- .89
11 Light conifer slash	179	- .81
12 Medium conifer slash	163	- .78
13 Heavy conifer slash	170	- .79

When available, these parameters can be entered in the TI-59 program according to the operating procedures described subsequently.

Users who desire to use NFFL model 8 (closed timber litter) as a surrogate for fuels without overstory should create a custom model with the BEHAVE system using parameters for model 8. The updated version of BEHAVE will then calculate the surface spotting parameters required.

The predictions provided by the program are only as good as the model on which they are based. Confidence in predictions can be improved by field verification. Personal communication (Catchpole 1983) indicates that the model may underpredict maximum spotting distance in eucalyptus forests due to the aerodynamical nature of the tree bark. The author invites submission of any validation data obtained.

Equations are given for English and metric units of measure. The TI-59 program uses English units, so only English units appear in the text. The transformation of the 20-foot reference windspeed to windspeed at heights required for input to Albini's (1983) model has been incorporated in the equations. The logarithmic windspeed profile and the power law profile both yield similar results when referenced near the surface and projected upwards; therefore the power law profile was used because it is simpler.

Table 3 of Albini (1983) presents values necessary for the derivation of the spotting parameters. The table was later found to contain inaccuracies. Corrected table entries are presented in the Appendix (table A). Also presented in the Appendix are the corrected values for the numerical examples appearing in Albini (1983).

SUMMARY OF EQUATIONS

Symbol	English units	Metric units	Description
Torching tree option			
d	inches	cm	Diameter at breast height (d.b.h.) of tree(s) torching out
h	ft	m	Height of burning tree(s)
n	none	none	Number of trees burning simultaneously to produce a single merged flame and buoyant plume structure
h_F	ft	m	Adjusted steady flame height (perpendicular measurement from base of flame to tip of flame)
d_F	none	none	Adjusted steady flame duration
Pile burning option			
H_F	ft	m	Continuous flame height for pile burning
Wind-driven surface fire option			
A	s	s	Fuel model-dependent parameter used as coefficient in windspeed function (see table 1)
B	none	none	Fuel model-dependent parameter used as power in windspeed function (see table 1)
f(U)	s	s	Windspeed function
E	Btu/ft	kJ/m	Strength of a thermal updraft generated by a wind-driven line fire
I	Btu/ft/s	kW/m	Fireline intensity
Common to all options			
$\bar{h}$	ft	n	Mean vegetation cover height downwind of source (see "Operating instructions")
$\bar{h}_c$	ft	m	Minimum value of $\bar{h}$ used to calculate spotting distance using the logarithmic windspeed variation with height (Albini 1981)
$\bar{h}^*$	ft	m	The greater of $\bar{h}$ and $\bar{h}_c$
U	mi/h	km/h	Windspeed 20 feet (6 m) above vegetation
D	mi	km	Ridge-to-valley horizontal distance (map)
H	1000's of ft	mult. of 300 m	Ridge-to-valley elevational difference
M	none	none	Code number for location of firebrand source 0 = midslope, windward side 1 = valley bottom 2 = midslope, leeward side 3 = ridgetop
z(0)	ft	m	Initial firebrand height above ground
F	mi	km	Flat-terrain spotting distance
S	mi	km	Mountainous-terrain spotting distance (map)

Equations Using English Units

$$z(0) = \begin{cases} \left.\begin{array}{ll} 4.24{d_F}^{0.332}(h_F) + h/2, & h/h_F \geq 1 \\ 3.64{d_F}^{0.391}(h_F) + h/2; & 0.5 \leq h/h_F < 1 \\ 2.78{d_F}^{0.418}(h_F) + h/2, & h/h_F < 0.5,\ d_F < 3.5 \\ 4.70(h_F) + h/2 & h/h_F < 0.5,\ d_F \geq 3.5 \end{array}\right\} & \text{torching tree option} \\ 1.055E^{1/2}, & \text{wind-driven surface fire option} \\ 12.2H_F, & \text{pile burning option} \end{cases}$$

where

$$h_F = \begin{cases} 16.5d^{0.515}n^{0.4}, & \text{grand fir, balsam fir} \\ 15.7d^{0.451}n^{0.4}, & \text{Engelmann spruce, subalpine fir, Douglas-fir, western hemlock} \\ 12.9d^{0.453}n^{0.4}, & \text{ponderosa pine, lodgepole pine, white pine} \end{cases}$$

$$d_F = \begin{cases} 12.6d^{-0.256}n^{-0.2}, & \text{ponderosa pine, lodgepole pine, Engelmann spruce} \\ 10.7d^{-0.278}n^{-0.2}, & \text{subalpine fir, Douglas-fir, balsam fir, grand fir, white pine} \\ 6.3d^{-0.249}n^{-0.2}, & \text{western hemlock} \end{cases}$$

$f(U) = A\ (0.474\ U)^B$, where A and B are fuel model-dependent parameters (see table 1)

$E = I \cdot f(U)$

$$F = \begin{cases} 7.18 \times 10^{-4}U\bar{h}^{*1/2}\left\{0.362 + \left(\frac{z(0)}{\bar{h}^*}\right)^{1/2} (½) \ln\left(\frac{z(0)}{\bar{h}^*}\right)\right\}, & \text{torching tree, pile burning options} \\ 7.18 \times 10^{-4}U\bar{h}^{*1/2}\left\{0.362 + \left(\frac{z(0)}{\bar{h}^*}\right)^{1/2} (½) \ln\left(\frac{z(0)}{\bar{h}^*}\right)\right\} + 2.78 \times 10^{-4}Uz(0)^{0.643}, & \text{wind-driven surface fire option} \end{cases}$$

where

$\bar{h}_c = 2.2z(0)^{0.337} - 4.0$

$\bar{h}^* = \max(\bar{h}, \bar{h}_c)$

$S = D \cdot X_6$,

where X_6 is from the iteration:

$X_o = A$

$X_{n+1} = A - B(\cos(\pi X_n - M\pi/2) - \cos(M\pi/2))$

$A = F/D$

$B = H/(10\pi)$

Equations Using Metric Units

$$z(0) = \begin{cases} \left.\begin{array}{ll} 4.24d_F^{0.332}(h_F) + h/2, & h/h_F \geq 1 \\ 3.64d_F^{0.391}(h_F) + h/2, & 0.5 \leq h/h_F < 1 \\ 2.78d_F^{0.418}(h_F) + h/2, & h/h_F < 0.5,\ d_F < 3.5 \\ 4.70(h_F) + h/2 & h/h_F < 0.5,\ d_F \geq 3.5 \end{array}\right\} & \text{torching tree option} \\ 0.173E^{1/2}, & \text{wind-driven surface fire option} \\ 12.2H_F, & \text{pile burning option} \end{cases}$$

where

$$h_F = \begin{cases} 3.11d^{0.515}n^{0.4}, & \text{grand fir, balsam fir} \\ 3.14d^{0.451}n^{0.4}, & \text{Engelmann spruce, subalpine fir, Douglas-fir, western hemlock} \\ 2.58d^{0.453}n^{0.4}, & \text{ponderosa pine, lodgepole pine, white pine} \end{cases}$$

$$d_F = \begin{cases} 16.0d^{-0.256}n^{-0.2}, & \text{ponderosa pine, lodgepole pine, Engelmann spruce} \\ 13.9d^{-0.278}n^{-0.2}, & \text{subalpine fir, Douglas-fir, balsam fir, grand fir, white pine} \\ 7.95d^{-0.249}n^{-0.2}, & \text{western hemlock} \end{cases}$$

$f(U) = A\ (0.295\ U)^B$, where A and B are fuel model-dependent parameters (see table 1)

$$E = I \cdot f(U)$$

$$F = \begin{cases} 1.30 \times 10^{-3}U\bar{h}^{*1/2}\left\{0.362 + \left(\frac{z(0)}{\bar{h}^*}\right)^{1/2}(1/2)\ln\left(\frac{z(0)}{\bar{h}^*}\right)\right\}, & \text{torching tree, pile burning options} \\ 1.30 \times 10^{-3}U\bar{h}^{*1/2}\left\{0.362 + \left(\frac{z(0)}{\bar{h}^*}\right)^{1/2}(1/2)\ln\left(\frac{z(0)}{\bar{h}^*}\right)\right\} + 5.03 \times 10^{-4}Uz(0)^{0.643}, & \text{wind-driven surface fire option} \end{cases}$$

where

$\bar{h}_c = z(0)^{0.337} - 1.22$

$\bar{h}^* = \max\ (\bar{h}, \bar{h}_c)$

$S = D \cdot X_6$,

where X_6 is from the iteration:

$X_o = A$

$X_{n+1} = A - B\ (\cos(\pi X_n - M\pi/2) - \cos(M\pi/2))$

$A = F/D$

$B = H/(10\pi)$

THE TI-59 PROGRAM

The program for predicting maximum spot fire distance (Chase 1981) had to be extended to include spotting from wind-driven surface fires. Some user convenience in program operation was given up to obtain the advantage of having a single set of program cards, one set of operating instructions, and a single worksheet covering all options. In this revised version, the user may have to reenter up to three unchanged inputs to revise a single value. The user must also be careful to select reasonable data and enter those data without error since there are no checks on the validity of input data.

Maximum spot fire distance is predicted from three sources of firebrands: torching trees, burning piles, and wind-driven surface fires. Figure 1 is a chart showing program flow. Species data cards for the torching tree option from the original program (Chase 1981) contain data that are still valid, but the cards must be rerecorded under a new memory partition before being used with the revised version. Directions for rerecording these cards are given in the section entitled "Program Duplication."

The program is recorded on two cards (magnetic strips). A listing is in the appendix. A prerecorded copy of the program may be obtained by sending two blank magnetic cards for the TI-59 (eight cards if species data cards are also desired) to the author at the Northern Forest Fire Laboratory.

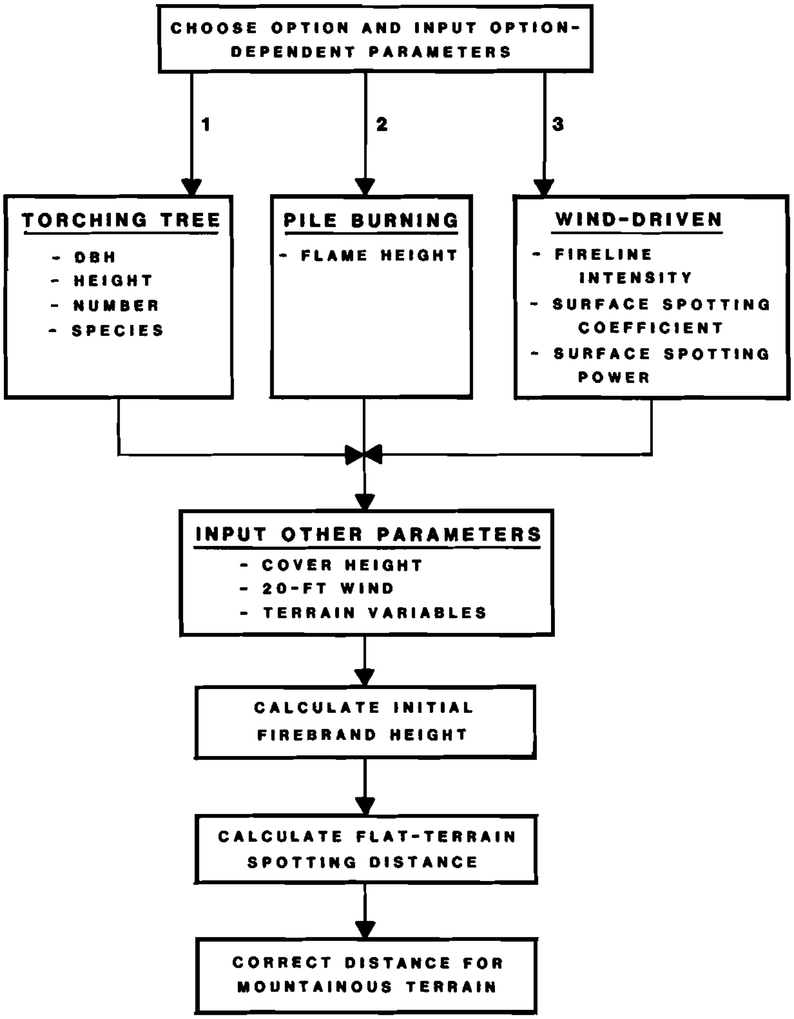


Figure 1.—This chart shows the general organization of the program to predict maximum spotting distance.

OPERATING INSTRUCTIONS

The program for calculating spot fire distance may be run on the TI-59 with any solid-state module in the calculator (such as NFDR/fire behavior module, library module, statistics module) or with no module in place.

Preliminaries

1. Turn on the calculator. (If it is already on, turn it off momentarily to clear program and memory registers.)
2. Partition memory before reading in the program. Press $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$. The display should read 639.39.
3. Press $\boxed{1}$. Feed side 1 of the program cards into the lower slot on the right side of the calculator. The motor will start and stop automatically. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 3.
4. Press $\boxed{2}$. Feed side 2 of the program into the slot. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 4.
5. Press $\boxed{3}$. Feed side 3 of the program into the slot. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 5.

Inputs

Record the necessary inputs on the worksheet (exhibit 1). Enter **one** of the following **three** groups of option-dependent inputs. The inputs in the selected group must be entered in the order given. The group number represents the option selected:

1. **Torching tree option:** Input of this group of values indicates choice of the torching tree option
   - —Enter diameter at breast height (d.b.h.) in inches of tree(s) torching out — Press $\boxed{\text{A}}$
   - —Enter height in feet of tree(s) torching out — Press $\boxed{\text{R/S}}$
   - —Enter the number of identical tree(s) burning at once to produce a single flame — Press $\boxed{\text{R/S}}$
   - —A $\boxed{4}$ will appear in the display; feed in the tree species data card for the species desired
2. **Pile burning option:** Input of this value indicates choice of the pile burning option.
   - —Enter estimated flame height in feet from observation of continuous flame — Press $\boxed{\text{B}}$
3. **Wind-driven surface fire option:** Input of this group of values indicates choice of the wind-driven surface fire option
   - —Enter the fireline intensity in Btu/ft/s (for assistance in obtaining this input, see section entitled "Estimating Fireline Intensities") — Press $\boxed{\text{C}}$
   - —Enter the surface spotting coefficient (A) for the fuel model which represents your fuel complex (see table 1 for models 1-7, 9-13; 1985 BEHAVE for custom fuel models) — Press $\boxed{\text{R/S}}$
   - —Enter surface spotting power (B) for your fuel model (see table 1 for models 1-7, 9-13; 1985 BEHAVE for custom models) — Press $\boxed{\text{R/S}}$

Enter all of the following groups of inputs. Groups may be entered in any order, but inputs within a group must be entered in the order specified.

Name____________________ Date____________ Sheet______ of ______

Purpose____

([4] [2nd] [OP] [1] [7])

INPUTS

	Reg. no.		Option			Option			
Option-dependent parameters		Tree 1	Pile 2	Surface 3	Tree 1	Pile 2	Surface 3	Before entry	After entry
Torching tree d.b.h., inches	39	____			____				A
Torching tree height, ft	38	____			____				R/S
Number of trees torching together	37	____			____				R/S
Species	(read card)	____			____			4	
Continuous flame height, ft	31		____			____			B
Fireline intensity, Btu/ft/s	30			____			____		C
Surface spotting coefficient (A)	29			____			____		R/S
Surface spotting power (B)	28			____			____		R/S
Other parameters									
Mean cover height, ft	35	____	____	____	____	____	____		D
20-foot windspeed, mi/h	36	____	____	____	____	____	____		E
Ridge/valley elevational difference, ft	34	____	____	____	____	____	____		2nd A
Ridge/valley horizontal distance, mi	33	____	____	____	____	____	____		R/S
Spotting source location code	32	____	____	____	____	____	____		R/S

0=midslope, windward side
1=valley bottom
2=midslope, leeward side
3=ridgetop

OUTPUT

Maximum spotting distance corrected for mountainous terrain, mi	21	____	____		____	____	____	SBR =	

Exhibit 1.—Maximum Spotting Distance Worksheet

4. **Cover**

—Enter the mean cover height, in feet, of the area downwind of the firebrand source. Where timber or shrub cover exists, enter the height. If there is broken forest cover, enter one-half the treetop height of the forest-covered portion. If there is little or no forest cover (as is the case for option 3), enter vegetation height. This value is used to characterize the general forest cover as it influences the wind. Press $\boxed{\text{D}}$

5. **Wind**

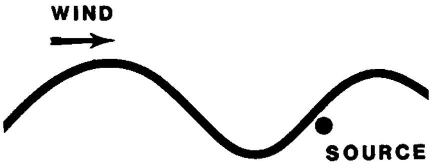
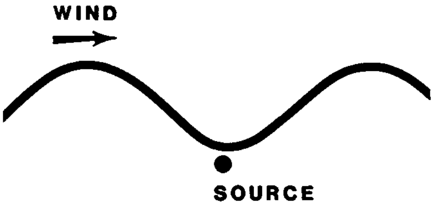
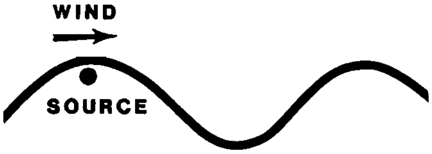
—Enter the average windspeed, in miles per hour, 20 feet above the vegetation Press $\boxed{\text{E}}$

6. **Terrain variables**

—If terrain is flat, enter zero here (do not skip this step—an incorrect nonzero value may be carried over from a previous run), then proceed to "Recall and Correction of Input". If terrain is not flat, enter average elevational difference in feet from ridge-top to valley bottom as would be shown on a map. (The model is not very sensitive to this input; rounding to nearest thousand is probably adequate.) The entry is in feet even though the equations use multiples of 1,000 feet. Press $\boxed{\text{2nd}}$ $\boxed{\text{A}}$

—Enter the ridgetop-to-valley bottom horizontal distance in miles as would be shown on a map. Press $\boxed{\text{R/S}}$

—Enter the firebrand source location code from the following list. Press $\boxed{\text{R/S}}$

Enter	for	
0	Midslope, windward side	
1	Valley bottom	
2	Midslope, leeward side	
3	Ridgetop	

Recall and Correction of Input

1. Recall flashing display of option number chosen by pressing SBR RCL. If flashing 9's appear in the display, no option has been chosen. If a flashing 6 appears, more than one option has been chosen. Press CLR to halt the flashing display. Press SBR CLR to clear option flags. Enter the group of option-dependent inputs desired and repeat this step.
2. Follow with a series of R/S to view successive inputs for the selected option in the order listed on the worksheet. Items appearing in parentheses are not recalled (i.e., tree species in torching tree option is not recalled). The number of R/S required for each option is:

Torching tree	8
Pile burning	6
Surface spotting	8

   If an additional R/S is pushed, flashing 9's will appear in the display to signal the end of the recalled values. Press CLR to halt the flashing display.
3. To change any item of input, reenter the group of inputs down through the correction for the wrong value as described in the input section.

Performing Calculations

1. Press SBR =. When calculations are completed, the mountainous terrain spotting distance in miles will appear in the display. A flashing display at this point indicates an invalid calculation in the computation sequence. A list of conditions known to cause a flashing display here follows. There may be other causes.

Cause	Option	Flashing display
Windspeed = 0	1, 2, 3	0.00
Windspeed less than 0	1, 2, 3	Nonzero
Fireline intensity = 0	3	0.00
Custom model spotting coefficient = 0	3	0.00
Number of trees torching = 0	1	Nonzero
No option selected	1, 2, 3	9's
More than one option selected	1, 2, 3	6.00

Press CLR to halt a flashing display and check your inputs.

Making Successive Runs

1. If changing options, press SBR CLR to clear option flags. Reenter group of option-dependent variables desired (group 1, 2, or 3).

2. Change one or more other groups of inputs by entering the group as described in input section. Then check entire input list, using SBR RCL, R/S, R/S, ...

3. Perform calculations (SBR =).

Following are some tips for users who don't wish to reenter valid inputs needlessly, but are willing to remember extra procedures:

1. If not changing options, the user can input a changed value manually by entering value STO nn where nn is the register number where that value is stored (see exhibit 1).
2. Proceed to reinput the group of parameters, but stop after all changed values have been entered.
3. If changing options, but valid inputs from a prior run are still in place, input only the first value in the group of option-dependent parameters. This serves to set the option flag.

Name Sample Problems Date Sheet 1 of 2

Purpose

([4] [2nd] [OP] [1] [7])

INPUTS

Option-dependent parameters	Reg. no.	Option Tree [✓ 1]	Option Pile 2	Option Surface 3	Option Tree 1	Option Pile [✓ 2]	Option Surface 3	Before entry	After entry
Torching tree d.b.h., inches	39	20							A
Torching tree height, ft	38	137							R/S
Number of trees torching together	37	1							R/S
Species	(read card)	Grand fir						4	
Continuous flame height, ft	31					45			B
Fireline intensity, Btu/ft/s	30								C
Surface spotting coefficient (A)	29								R/S
Surface spotting power (B)	28								R/S
Other parameters									
Mean cover height, ft	35	130				100			D
20-foot windspeed, mi/h	36	20				15			E
Ridge/valley elevational difference, ft	34	4000				2000			2nd A
Ridge/valley horizontal distance, mi	33	.25				1			R/S
Spotting source location code	32	3				1			R/S

0=midslope, windward side
1=valley bottom
2=midslope, leeward side
3=ridgetop

OUTPUT

	Reg. no.			
Maximum spotting distance corrected for mountainous terrain, mi	21	.31	.21	SBR =

Exhibit 2a.—Maximum Spotting Distance Worksheet

Name Sample Problems Date ________ Sheet 2 of 2

Purpose ________

(4 2nd OP 1 7)

INPUTS

Option-dependent parameters	Reg. no.	Tree 1	Option Pile 2	Surface [✓ 3]	Tree 1	Option Pile 2	Surface [✓ 3]	Before entry	After entry
Torching tree d.b.h., inches	39								A
Torching tree height, ft	38								R/S
Number of trees torching together	37								R/S
Species	(read card)							4	
Continuous flame height, ft	31								B
Fireline intensity, Btu/ft/s	30	Fuel model 1		580	Fuel model 4		14 400		C
Surface spotting coefficient (A)	29			545			301		R/S
Surface spotting power (B)	28			-1.21			-1.05		R/S
Other parameters									
Mean cover height, ft	35			1			6		D
20-foot windspeed, mi/h	36			10			35		E
Ridge/valley elevational difference, ft	34			0			1000		2nd A
Ridge/valley horizontal distance, mi	33			-			.25		R/S
Spotting source location code	32			-			0		R/S

0=midslope, windward side
1=valley bottom
2=midslope, leeward side
3=ridgetop

OUTPUT

Maximum spotting distance corrected for mountainous terrain, mi	21	0.27	1.58	SBR =

Exhibit 2b.—Maximum Spotting Distance Worksheet

ESTIMATING FIRELINE INTENSITIES

You may wish to use fire behavior calculations (Burgan 1979) to produce realistic fireline intensity values for input to the spot fire program. In this case, the NFDR/fire behavior CROM (custom read only memory) must be in place.

Switching from calculator to module memory (from spot fire distance to fire behavior calculations) and vice versa causes memory problems due to partitioning. Overcoming the problems involves a cumbersome procedure. Therefore it is recommended that the user make all the runs he/she wishes using one program, momentarily turn the calculator off and then on again, then access the other program (by pressing $\boxed{\text{2nd}}$ $\boxed{\text{PGM}}$ $\boxed{2}$ $\boxed{\text{SBR}}$ $\boxed{\text{R/S}}$ [see Burgan 1979] or by reading the program cards) to make the desired runs.

Note that 20-foot windspeed is the input for the spot fire program, while midflame windspeed is used for fire behavior. Refer to Rothermel (1983) for guidelines in adjusting windspeeds.

Another method of estimating fireline intensity for real-time predictions is to use observed flame lengths in Byram's (1959) formula, which relates fireline intensity and flame length:

$$I = 5.66L^{2.17}$$

where

I = fireline intensity, Btu/ft/s

L = flame length, ft

SAMPLE PROBLEMS

Exhibits 2a and 2b contain the inputs and outputs for four examples — one for torching tree option, one for pile burning, and two for the surface spot fire option.

CONDENSED INSTRUCTIONS

Preliminaries

1. $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$
2. Press $\boxed{1}$, feed side 1 (flashing: $\boxed{\text{CLR}}$, try again).
3. Press $\boxed{2}$, feed side 2 (flashing: $\boxed{\text{CLR}}$, try again).
4. Press $\boxed{3}$, feed side 3 (flashing: $\boxed{\text{CLR}}$, try again).

Input

Enter		Press
	Torching tree d.b.h.	$\boxed{\text{A}}$
Group 1	Torching tree height	$\boxed{\text{R/S}}$
	No. trees torching together	$\boxed{\text{R/S}}$
	Read species card	
or		
Group 2	Observed flame height	$\boxed{\text{B}}$
or		
	Fireline intensity	$\boxed{\text{C}}$
Group 3	Surface spotting coefficient (A)	$\boxed{\text{R/S}}$
	Surface spotting power (B)	$\boxed{\text{R/S}}$
Group 4	Mean cover height	$\boxed{\text{D}}$
Group 5	20-foot windspeed	$\boxed{\text{E}}$
	Ridge/valley elevational difference	$\boxed{\text{2nd}}$ $\boxed{\text{A}}$
Group 6	Ridge/valley horizontal distance	$\boxed{\text{R/S}}$
	Firebrand source location code	$\boxed{\text{R/S}}$

Check Inputs $\boxed{\text{SBR}}$ $\boxed{\text{RCL}}$; follow by series of $\boxed{\text{R/S}}$

Calculations $\boxed{\text{SBR}}$ $\boxed{=}$

To Clear Option Flags $\boxed{\text{SBR}}$ $\boxed{\text{CLR}}$

REGISTER ASSIGNMENTS

For completeness, the following list gives memory locations assigned to the inputs, outputs, and selected intermediate values.

Register	Symbol	Contents
39	d	Torching tree d.b.h.
38	h	Torching tree height
37	n	Number of trees torching together
31	H_F	Continuous flame height
30	I	Fireline intensity
29	A	Surface spotting coefficient
28	B	Surface spotting power
35	$\bar{h}$	Mean cover height
36	U	20-foot windspeed
34	1000H	Ridge/valley elevation difference
33	D	Ridge/valley horizontal distance
32	M	Spotting source location code
17	$\bar{h}^*$	Cover height used in calculations
16	none	Downwind drift during lofting
25	z(0)	Initial firebrand height
26	d_F	Adjusted steady flame duration
27	h_F	Adjusted steady flame height
24	F	Flat terrain spotting distance
21	S	Corrected spotting distance

PROGRAM DUPLICATION

The program recorded on one set of magnetic cards can be duplicated on another blank set as follows:

Program Cards

1. Turn on your calculator. Enter the program into memory using the set of cards to be duplicated.

$\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$

$\boxed{1}$; feed side 1 (if flashing; press $\boxed{\text{CLR}}$, try again)

$\boxed{2}$; feed side 2 (if flashing; press $\boxed{\text{CLR}}$, try again)

$\boxed{3}$; feed side 3 (if flashing; press $\boxed{\text{CLR}}$, try again)

2. Press $\boxed{1}$ $\boxed{\text{2nd}}$ $\boxed{\text{R/S}}$ and feed in side 1 of the set of blank cards. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 2.

3. Press $\boxed{2}$ $\boxed{\text{2nd}}$ $\boxed{\text{R/S}}$ and feed in side 2 of the set of blank cards. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 3.

4. Press $\boxed{3}$ $\boxed{\text{2nd}}$ $\boxed{\text{R/S}}$ and feed in side 3 of the set of blank cards. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 4.

5. Label the cards appropriately, using a pen with permanent, fast-drying ink. A suggestion for labeling is shown in figure 2.

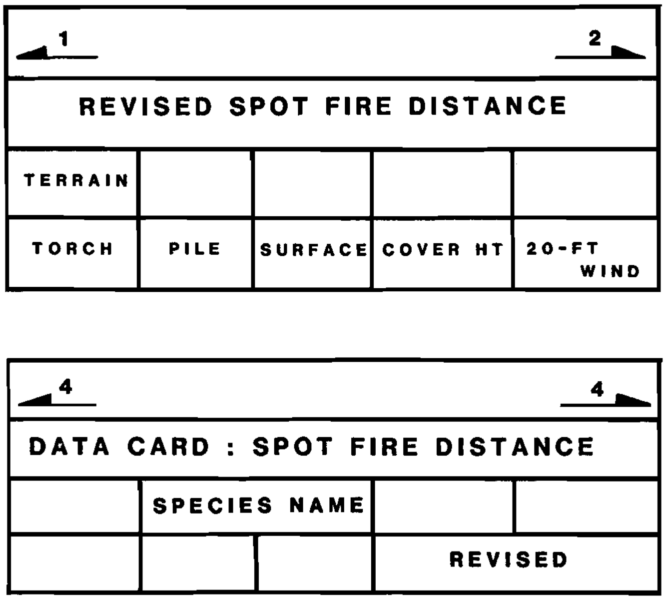


Figure 2.—Suggested labeling for spot fire program cards.

Data Cards

To re-record data cards for original program under new partition for revised program.

1. Turn on calculator.
2. Read card for original program:
   Press $\boxed{4}$; feed card (either side) (if flashing; press $\boxed{\text{CLR}}$, try again).
3. Repartition memory: $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$
4. Re-record:
   Press $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{WRITE}}$; feed card; (if flashing; press $\boxed{\text{CLR}}$, try again)
   Repeat step 4 for all sides of cards for this species.
5. Label the card appropriately (see fig. 2).
6. If there are data cards for another species to re-record:
   $\boxed{6}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$
   Repeat steps 2-5.

To duplicate valid data cards for the revised program:

1. Turn on calculator.
   Repartition memory: $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$
2. Press $\boxed{4}$ and feed in one side of the data card to be duplicated. If the display flashes, press $\boxed{\text{CLR}}$ and try again.
3. Press $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{RS}}$ and feed in one side of the blank card. If the display flashes, try again. Repeat step 3 for the other side of the blank card.
4. Label the card appropriately (see fig. 2).
   Repeat steps 2 through 4 for remaining data cards.

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APPENDIX
PROGRAM LISTING

```
000  25 CLR    057  32 X:T    114  71 SBR    171  22 INV    228  42 STO
001  91 R/S    058  09  9     115  34 √X     172  77  GE    229  24  24
002  76 LBL    059  42 STO    116  76 LBL    173  52 EE     230  92 RTN
003  22 INV    060  23  23    117  33 X²     174  42 STO    231  76 LBL
004  53  (     061  01  1     118  53  (     175  17  17    232  54  )
005  43 RCL    062  00  0     119  73 RC*    176  92 RTN    233  53  (
006  01  01    063  42 STO    120  23  23    177  76 LBL    234  53  (
007  65  ×     064  22  22    121  65  ×     178  52 EE     235  93  .
008  43 RCL    065  61 GTO    122  43 RCL    179  32 X:T    236  00  0
009  39  39    066  47 CMS    123  26  26    180  42 STO    237  00  0
010  45 Yˣ     067  76 LBL    124  45 Yˣ     181  17  17    238  00  0
011  43 RCL    068  24 CE     125  73 RC*    182  92 RTN    239  02  2
012  02  02    069  07  7     126  22  22    183  76 LBL    240  07  7
013  65  ×     070  42 STO    127  65  ×     184  53  (     241  08  8
014  43 RCL    071  23  23    128  43 RCL    185  53  (     242  65  ×
015  37  37    072  08  8     129  27  27    186  93  .     243  43 RCL
016  45 Yˣ     073  42 STO    130  85  +     187  00  0     244  36  36
017  93  .     074  22  22    131  43 RCL    188  00  0     245  65  ×
018  04  4     075  61 GTO    132  38  38    189  00  0     246  43 RCL
019  54  )     076  47 CMS    133  55  ÷     190  07  7     247  25  25
020  53  (     077  76 LBL    134  02  2     191  01  1     248  45 Yˣ
021  42 STO    078  23 LNX    135  54  )     192  08  8     249  93  .
022  27  27    079  05  5     136  61 GTO    193  65  ×     250  06  6
023  35 1/X    080  42 STO    137  42 STO    194  43 RCL    251  04  4
024  65  ×     081  23  23    138  76 LBL    195  36  36    252  03  3
025  43 RCL    082  06  6     139  44 SUM    196  65  ×     253  54  )
026  38  38    083  42 STO    140  53  (     197  43 RCL    254  42 STO
027  54  )     084  22  22    141  01  1     198  17  17    255  16  16
028  32 X:T    085  76 LBL    142  02  2     199  34 √X     256  85  +
029  01  1     086  47 CMS    143  93  .     200  65  ×     257  43 RCL
030  22 INV    087  92 RTN    144  02  2     201  53  (     258  24  24
031  77  GE    088  76 LBL    145  65  ×     202  93  .     259  54  )
032  23 LNX    089  34 √X     146  43 RCL    203  03  3     260  42 STO
033  93  .     090  53  (     147  31  31    204  06  6     261  24  24
034  05  5     091  43 RCL    148  54  )     205  02  2     262  61 GTO
035  22 INV    092  03  03    149  61 GTO    206  85  +     263  55  ÷
036  77  GE    093  65  ×     150  42 STO    207  53  (     264  76 LBL
037  24 CE     094  43 RCL    151  76 LBL    208  43 RCL    265  95  =
038  43 RCL    095  39  39    152  45 Yˣ     209  25  25    266  58 FIX
039  26  26    096  45 Yˣ     153  43 RCL    210  55  ÷     267  02  02
040  32 X:T    097  43 RCL    154  35  35    211  43 RCL    268  87 IFF
041  03  3     098  04  04    155  32 X:T    212  17  17    269  01  01
042  93  .     099  65  ×     156  53  (     213  54  )     270  65  ×
043  05  5     100  43 RCL    157  02  2     214  34 √X     271  87 IFF
044  77  GE    101  37  37    158  93  .     215  55  ÷     272  02  02
045  32 X:T    102  45 Yˣ     159  02  2     216  02  2     273  93  .
046  01  1     103  93  .     160  65  ×     217  65  ×     274  22 INV
047  01  1     104  02  2     161  43 RCL    218  53  (     275  87 IFF
048  42 STO    105  94 +/-    162  25  25    219  43 RCL    276  03  03
049  23  23    106  54  )     163  45 Yˣ     220  25  25    277  36 PGM
050  01  1     107  42 STO    164  93  .     221  55  ÷     278  61 GTO
051  02  2     108  26  26    165  03  3     222  43 RCL    279  75  -
052  42 STO    109  92 RTN    166  03  3     223  17  17    280  76 LBL
053  22  22    110  76 LBL    167  07  7     224  54  )     281  65  ×
054  61 GTO    111  35 1/X    168  75  -     225  23 LNX    282  87 IFF
055  47 CMS    112  71 SBR    169  04  4     226  54  )     283  02  02
056  76 LBL    113  22 INV    170  54  )     227  54  )     284  30 TAN
```

```
285  76 LBL
286  93  .
287  87 IFF
288  03  03
289  30 TAN
290  61 GTO
291  75  -
292  76 LBL
293  30 TAN
294  03  3
295  06  6
296  94 +/-
297  34 √X
298  91 R/S
299  76 LBL
300  36 PGM
301  00  0
302  35 1/X
303  91 R/S
304  76 LBL
305  75  -
306  87 IFF
307  01  01
308  35 1/X
309  87 IFF
310  02  02
311  44 SUM
312  53  (
313  53  (
314  53  (
315  43 RCL
316  29  29
317  65  ×
318  53  (
319  93  .
320  04  4
321  07  7
322  04  4
323  65  ×
324  43 RCL
325  36  36
326  54  )
327  45 Yˣ
328  43 RCL
329  28  28
330  54  )
331  65  ×
332  43 RCL
333  30  30
334  54  )
335  34 √X
336  65  ×
337  01  1
338  93  .
339  00  0
340  05  5
341  05  5
342  54  )
343  76 LBL
344  42 STO
345  42 STO
346  25  25
347  71 SBR
348  45 Yˣ
349  71 SBR
350  53  (
351  87 IFF
352  03  03
353  54  )
354  76 LBL
355  55  ÷
356  00  0
357  32 X⇌T
358  43 RCL
359  33  33
360  67  EQ
361  85  +
362  43 RCL
363  34  34
364  67  EQ
365  85  +
366  53  (
367  43 RCL
368  24  24
369  55  ÷
370  43 RCL
371  33  33
372  54  )
373  42 STO
374  20  20
375  42 STO
376  19  19
377  53  (
378  43 RCL
379  34  34
380  55  ÷
381  01  1
382  00  0
383  00  0
384  00  0
385  00  0
386  55  ÷
387  89  π
388  54  )
389  42 STO
390  18  18
391  06  6
392  42 STO
393  00  00
394  76 LBL
395  61 GTO
396  53  (
397  43 RCL
398  20  20
399  75  -
400  43 RCL
401  18  18
402  65  ×
403  53  (
404  53  (
405  01  1
406  08  8
407  00  0
408  65  ×
409  43 RCL
410  19  19
411  75  -
412  43 RCL
413  32  32
414  65  ×
415  09  9
416  00  0
417  54  )
418  39 COS
419  75  -
420  53  (
421  43 RCL
422  32  32
423  65  ×
424  09  9
425  00  0
426  54  )
427  39 COS
428  54  )
429  54  )
430  42 STO
431  19  19
432  97 DSZ
433  00  00
434  61 GTO
435  53  (
436  43 RCL
437  19  19
438  65  ×
439  43 RCL
440  33  33
441  54  )
442  42 STO
443  21  21
444  91 R/S
445  76 LBL
446  85  +
447  43 RCL
448  24  24
449  42 STO
450  21  21
451  91 R/S
452  76 LBL
453  43 RCL
454  87 IFF
455  01  01
456  71 SBR
457  87 IFF
458  02  02
459  37 P/R
460  22 INV
461  87 IFF
462  03  03
463  48 EXC
464  61 GTO
465  38 SIN
466  76 LBL
467  71 SBR
468  87 IFF
469  02  02
470  39 COS
471  76 LBL
472  37 P/R
473  87 IFF
474  03  03
475  39 COS
476  61 GTO
477  38 SIN
478  76 LBL
479  39 COS
480  03  3
481  06  6
482  94 +/-
483  34 √X
484  91 R/S
485  76 LBL
486  48 EXC
487  00  0
488  35 1/X
489  91 R/S
490  76 LBL
491  38 SIN
492  87 IFF
493  01  01
494  94 +/-
495  87 IFF
496  02  02
497  28 LOG
498  09  9
499  94 +/-
500  34 √X
501  91 R/S
502  43 RCL
503  30  30
504  91 R/S
505  43 RCL
506  29  29
507  91 R/S
508  43 RCL
509  28  28
510  91 R/S
511  76 LBL
512  29 CP
513  43 RCL
514  35  35
515  91 R/S
516  43 RCL
517  36  36
518  91 R/S
519  43 RCL
520  34  34
521  91 R/S
522  43 RCL
523  33  33
524  91 R/S
525  43 RCL
526  32  32
527  91 R/S
528  00  0
529  35 1/X
530  91 R/S
531  76 LBL
532  94 +/-
533  01  1
534  94 +/-
535  34 √X
536  91 R/S
537  43 RCL
538  39  39
539  91 R/S
540  43 RCL
541  38  38
542  91 R/S
543  43 RCL
544  37  37
545  91 R/S
546  61 GTO
547  29 CP
548  76 LBL
549  28 LOG
550  04  4
551  94 +/-
552  34 √X
553  91 R/S
554  43 RCL
555  31  31
556  91 R/S
557  61 GTO
558  29 CP
559  76 LBL
560  11  A
561  86 STF
562  01  01
563  42 STO
564  39  39
565  91 R/S
566  42 STO
567  38  38
568  91 R/S
569  42 STO
570  37  37
571  04  4
572  91 R/S
573  76 LBL
574  12  B
575  86 STF
576  02  02
577  42 STO
578  31  31
579  91 R/S
580  76 LBL
581  13  C
582  86 STF
583  03  03
584  42 STO
585  30  30
586  91 R/S
587  42 STO
588  29  29
589  91 R/S
590  42 STO
591  28  28
592  91 R/S
593  76 LBL
594  14  D
595  42 STO
596  35  35
597  91 R/S
598  76 LBL
599  15  E
600  42 STO
601  36  36
602  91 R/S
603  76 LBL
604  16  A'
605  42 STO
606  34  34
607  91 R/S
608  42 STO
609  33  33
610  91 R/S
611  42 STO
612  32  32
613  91 R/S
614  76 LBL
615  25 CLR
616  81 RST
```

CORRECTED VALUES

Table A.—Corrected values of the standard deviation of fire intensity, as a percentage of the mean intensity (coefficient of variation) for 12 fuel models that occur without timber cover (supersedes Albini, 1983, table 3).

	Mean horizontal windspeed at 10 m ht, m/s					
Fuel model	**5**	**10**	**15**	**20**	**25**	**30**
Grass and litter						
1 Short grass	37.5	27.9	22.0	18.0	15.0	12.8
2 Grassy understory	56.5	45.6	37.3	31.0	26.1	22.4
3 Tall grass	49.1	35.9	27.2	21.3	17.2	14.2
9 Hardwood litter	70.4	63.3	56.2	49.8	44.3	39.6
Shrub types						
4 Mature chaparral	40.0	24.9	17.3	13.0	10.3	8.42
5 Young chaparral	24.4	14.1	10.0	7.75	6.32	5.33
6 Dormant brush	48.9	33.1	24.2	18.8	15.3	12.8
7 Southern rough	43.4	27.6	19.9	15.4	12.5	10.5
Logging slash						
10 Overgrown slash	55.1	39.7	30.3	24.4	20.3	17.4
11 Light conifer slash	52.1	35.5	26.5	21.0	17.4	14.8
12 Medium conifer slash	50.1	33.4	24.6	19.3	15.9	13.4
13 Heavy conifer slash	49.6	32.5	23.8	18.7	15.4	13.0

Following are corrected example calculations (Albini 1983) using the author's equation numbers and nomenclature.

Example 1.

$$f(U) = AU^{B} = 545 \times (5)^{-1.21} = 77.7\ \mathrm{s} \tag{9}$$

$$E = I\ f(U) = (2000)(77.7) = 155\,400\ \mathrm{kJ/m} \tag{10}$$

$$H = 0.173\ E^{1/2} = (0.173)(155\,400)^{1/2} = 68.2\ \mathrm{m} \tag{11}$$

$$2.93\ \mathrm{m} = \text{effective cover height}$$

$$F = \text{flat terrain spotting distance} = 0.30\ \mathrm{km} \tag{13}$$

$$U(68) = U(10\mathrm{m}) \times \left(\frac{68}{10}\right)^{1/7} = (5)(1.32) = 6.6\ \mathrm{m/s} \tag{14}$$

$$X = (2.78)(6.6)(68.2)^{1/2} = 151\ \mathrm{m} = 0.151\ \mathrm{km} \tag{15}$$

$$\text{Spotting distance} = 0.30 + 0.15 = 0.45\ \mathrm{km}$$

Example 2.

$$f(U) = AU^{B} = 301\ (20)^{-1.05} = 13.0\ \mathrm{s} \tag{16}$$

$$E = I\ f(U) = (50\,000)(13.0) = 650\,000\ \mathrm{kJ/m} \tag{17}$$

$$H = 0.173\ E^{1/2} = (0.173)(806) = 139\ \mathrm{m} \tag{18}$$

$$F = 1.87\ \mathrm{km}$$

$$U(139) = U(10) \times \left(\frac{139}{10}\right)^{1/7} = 29.1\ \mathrm{m/s} \tag{19}$$

$$X = (2.78)(29.1)(139)^{1/2} = 954\ \mathrm{m} = 0.954\ \mathrm{km} \tag{20}$$

$$\text{Spotting distance} = 1.87 + 0.95 = 2.82\ \mathrm{km}$$

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)