

# BehavePlus fire modeling system, version 3.0

## Lesson 12 - Wind Adjustment Factor

## self-study

### Introduction

Wind is one of the most important influences on fire behavior. Determining an appropriate wind speed to use in modeling surface fire spread and intensity is not easy. There is significant temporal variation in wind speed and direction, on the order of hours, minutes, and even seconds. Wind varies spatially as it is affected by the terrain. There are also differences in wind speed in the vertical direction. The wind that affects the surface fire, called midflame wind, may be only 10% of the wind speed forecast by the National Weather Service at 20 feet above the vegetation (20-ft. wind). Midflame wind is obtained by multiplying 20-ft. wind by a Wind Adjustment Factor (WAF). Midflame wind speed is used in the calculation of surface fire flame length, which is used to estimate whether a surface will transition to a crown fire. The 20-ft. wind speed is used to estimate crown fire spread rate.

BehavePlus version 3 added the option of Calculating Wind Adjustment Factor to the previous options of inputting midflame wind speed directly or inputting a Wind Adjustment Factor.

### Objectives

1. Know the different methods of applying a Wind Adjustment Factor in a BehavePlus run.
2. Understand how Wind Adjustment Factors are calculated.
3. Know what inputs are required to calculate a Wind Adjustment Factor.

### Background

Rothermel's (1972) surface fire spread model requires input of an average wind speed at "midflame height". Midflame wind speed is equal to the 20-ft. wind speed multiplied by a wind adjustment factor (WAF). We use the term "wind adjustment factor" rather than "wind reduction factor" to avoid confusion in interpretation. A  $WAF = 0.40$  reduces the 20-ft. wind by 60%.

"Midflame" wind is poorly defined, and in practice is often taken to be "eye-level" wind speed as measured by a hand-held anemometer. The National Weather Service sometimes provides eye-level wind speed in spot weather forecasts. For many applications midflame wind speed is supplied directly to the surface fire spread model.

The actual variation in fuel bed depth, stand characteristics, flame length and height, and wind speed and direction can be more important than the wind adjustment factor. Nevertheless it is necessary to define a repeatable method of calculating WAF based on a description of the fuel and vegetation and not on the variable height of a flame.

Albini and Baughman (1979) presented mathematical models for wind above a vegetative cover that is a single-stratum fuel (grass, brush, etc.) and for wind under a forest canopy. Baughman and Albini (1980) produced a more practical tabular form based on fuel bed depth for the 13 fire behavior fuel models and on the degree of sheltering from the wind provided by the overstory. They gave guidance based on the effect of topography, e.g. "Fuels on high ridges where trees offer little shelter from wind." Rothermel (1983) presented a further simplification of that table. Finney

(1998) included calculation of WAF in FARSITE. (We will provide details of the various equations in a future paper.)

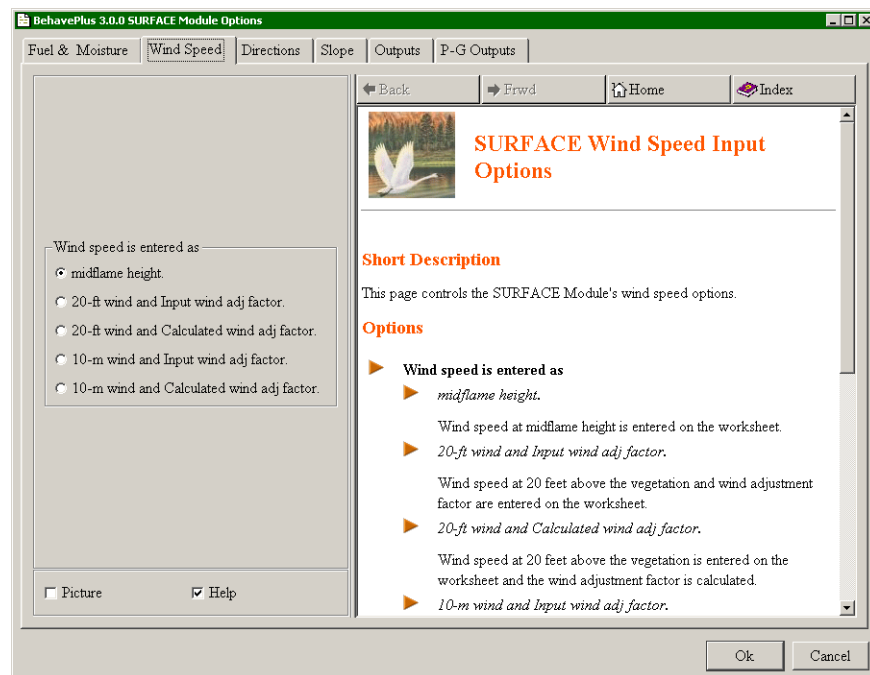
The WAF for fuels unsheltered from the wind is a function of fuel bed depth. We use the term "unsheltered from the wind" rather than "exposed to the wind" to avoid confusion with characterization of understory exposure to the sun in discussing fuel moisture.

Wind speed beneath the canopy does not depend on the surface fuel model, but rather on the fraction of the overstory filled with tree crowns. This is estimated from percent canopy cover, canopy height, and crown ratio. If less than 5% of the tree volume is filled, we use the model for unsheltered WAF.

## Wind Speed Options

Several options are available for entering wind speed in BehavePlus.

- Start with the default BasicStart.bpw Worksheet.
- Open the **Configure > Module selection > SURFACE > Options... > Wind Speed** tab.



Midflame wind speed can be entered directly on a Worksheet by selecting the **midflame height** radio button.

Wind speed can be entered for either 20 foot or 10 meter standard heights. If the 10-m option is selected, the wind speed is divided by 1.15 to get 20-ft. wind and the WAF values are applied to the 20-ft. wind.

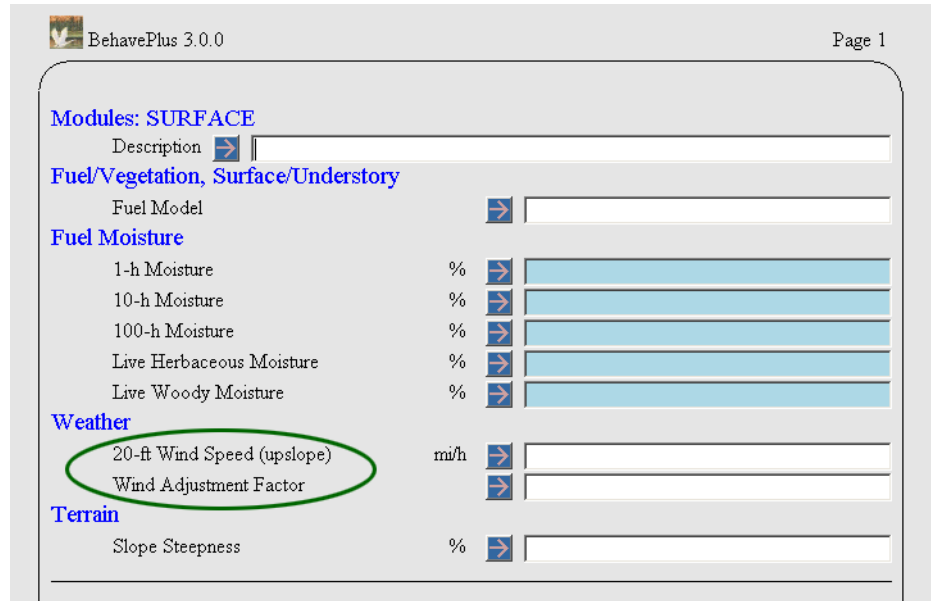
WAFs to convert 20-ft. wind speed can be directly entered on the Worksheet by selecting one of the radio buttons that specify **Input wind adj factor**.


The option of calculating a WAF is selected with either of two radio buttons that specify **Calculate wind adj factor**. Calculating a WAF will require overstory tree information be entered on the Worksheet. Calculation of WAF is based on two methods, one for fuels not sheltered from the wind and on for fuels sheltered by an overstory of trees.

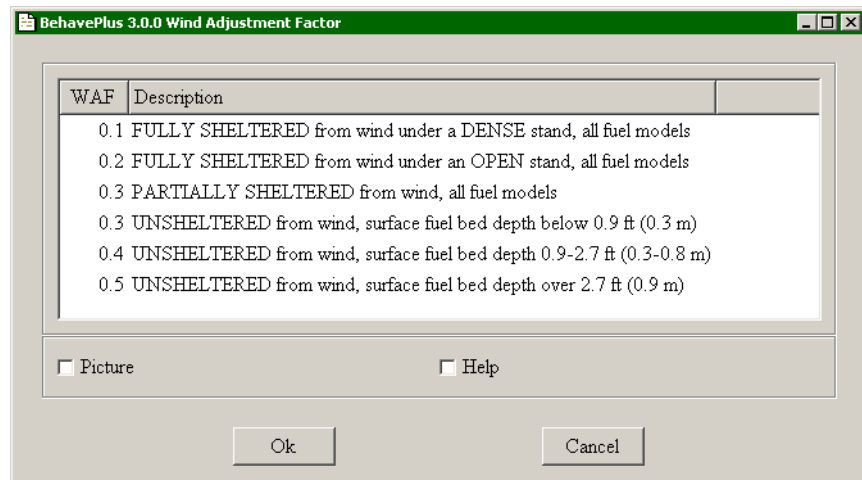
- Select the **20-ft wind and Input wind adj factor** radio button.
- Close the "SURFACE Module Options" dialog box by clicking the **Ok** button.

### Input a Wind Adjustment Factor

Selecting the **20-ft wind and Input wind adj factor** radio button adds to the worksheet lines for 20-ft wind and WAF.



Click the Guide  button for Wind Adjustment Factor and then click the **Choices** button on the "Input Guide" dialog box.



This gives choices for the WAF based on sheltering and, for unsheltered conditions, fuel bed depth. We reference fuel bed depth here because of the large number of standard fuel models and the option of using custom fuel models.

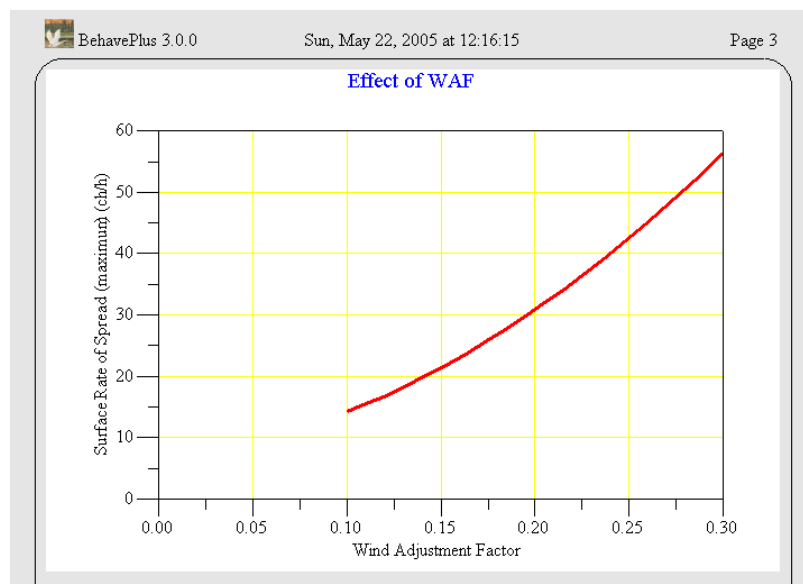
A table with Unsheltered WAF values for all 53 standard fuel models is found in the help pane of the “Wind Adjustment Factor” dialog box.

Wind Adjustment Factor and Fuel Bed Depth		
Fuel Bed Depth	Unsheltered WAF	Fuel Model
<0.9 ft (<0.3 m)	0.3	<ul style="list-style-type: none"> <li>• 8, 9</li> <li>• GR1</li> <li>• TU1, TU4</li> <li>• TL1, TL2, TL3, TL4, TL5, TL6, TL7, TL8, TL9</li> </ul>
0.9 - 2.7 ft (0.3 - 0.8 m)	0.4	<ul style="list-style-type: none"> <li>• 1, 2, 3, 5, 6, 7, 10, 11, 12</li> <li>• GR2, GR3, GR4, GR5, GR6</li> <li>• GS1, GS2, GS3, GS4</li> <li>• SH1, SH2, SH3, SH4, SH6</li> <li>• TU2, TU3, TU5</li> <li>• SB1, SB2, SB3, SB4</li> </ul>
>2.7 ft (>0.5 m)	0.5	<ul style="list-style-type: none"> <li>• 4, 13</li> <li>• GR7, GR8, GR9</li> <li>• SH5, SH7, SH8, SH9</li> </ul>

The help pane also has diagrams and tables for guidance on determining unsheltered, partially sheltered, or unsheltered conditions. As noted by Rothermel (1983) "Experience must play a large part in learning to choose the best wind adjustment factor." That continues to be the case.

### Effect of WAF on Fire Behavior

- Fill in the Worksheet with the following values;
  - fuel model 2,
  - 1-hr moisture = 5%,
  - 10-hr moisture = 6%,
  - 100-hr moisture = 7%,
  - live fuel moisture = 100%,
  - 20-ft wind of 20 mi/h,
  - slope = 30%.
- Enter a range for WAF from 0.1 to 0.3 to consider differences in the effect of sheltering by an overstory.



For the same 20-ft wind speed, surface rate of spread varies from 14 to 56 ch/h and flame length from 4 to 8 feet. Obviously the WAF value is an important consideration when you have only a 20 ft or 10 m wind value to rely on.

## Calculating a Unsheltered WAF

When the option to Calculate WAF is selected, additional lines are added to the worksheet to describe the overstory.

- Continue with the worksheet from the previous section.
- Change the Wind Speed input option to **20-ft wind and Calculated wind adj factor** (on the **Configure > Module selection > SURFACE > Options... > Wind Speed** tab).

Your Worksheet should now look like this.

Modules: SURFACE		
Description	➔	Effect of WAF
<b>Fuel/Vegetation, Surface/Understory</b>		
Fuel Model	➔	2
<b>Fuel/Vegetation, Overstory</b>		
Canopy Cover	% ➔	
Canopy Height	ft ➔	
Crown Ratio	➔	
<b>Fuel Moisture</b>		
1-h Moisture	% ➔	5
10-h Moisture	% ➔	6
100-h Moisture	% ➔	7
Live Herbaceous Moisture	% ➔	100
Live Woody Moisture	% ➔	
<b>Weather</b>		
20-ft Wind Speed (upslope)	mi/h ➔	20
<b>Terrain</b>		
Slope Steepness	% ➔	30

Note that a value must be entered for canopy cover. If zero is entered for canopy closure, entries are not required for canopy height or crown ratio.

Produce a plot that shows the Unsheltered WAF calculated as a function of fuel bed depth.

- On the **Configure > Module selection > SURFACE > Options... > Output** tab select only the **Wind Adjustment Factor** check box.
- On the **Configure > Module selection > SURFACE > Options... > Fuel & Moisture** tab select the **fuel parameters** radio button.
- Close the "Surface Module Options" and "Module Selection" dialog boxes by clicking the **Ok** buttons.

Your Worksheet should be similar to this.

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**Modules: SURFACE**

Description Effect of Fuel Bed Depth on WAF

Fuel/Vegetation, Surface/Understory Initialize from a Fuel Model

Fuel Bed Depth ft

Fuel/Vegetation, Overstory

Canopy Cover %

Canopy Height ft

Crown Ratio

**Run Option Notes**

Calculations are only for the direction of maximum spread [SURFACE].  
 Fireline intensity, flame length, and spread distance are always for the direction of the spread calculations [SURFACE].  
 Wind is blowing upslope [SURFACE].

**Output Variables**

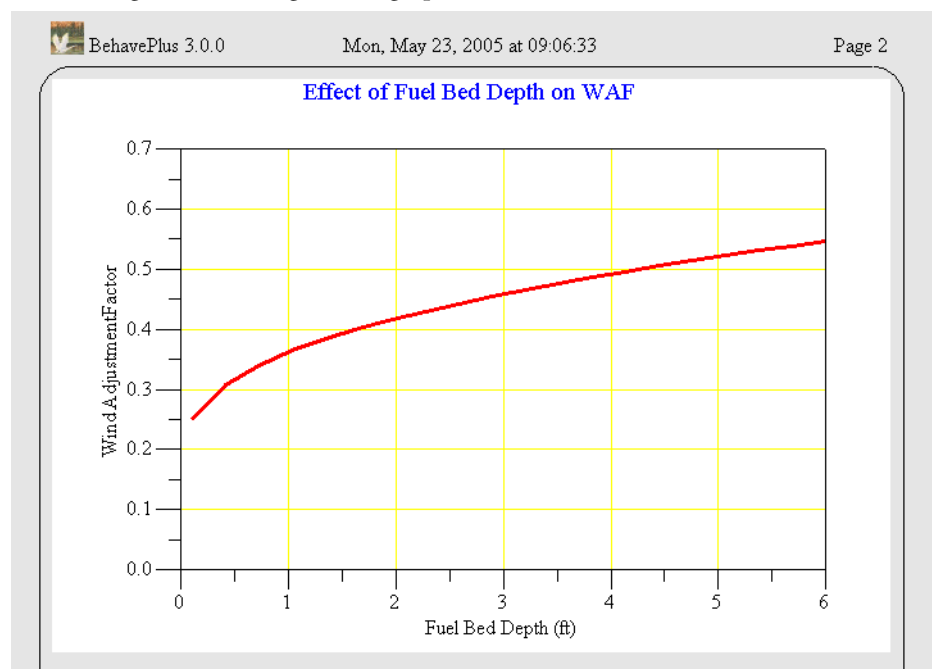
Wind Adjustment Factor [SURFACE]

Notice the simplicity of this worksheet, even though the fuels are described as fuel parameters, only one text box (**Fuel Bed Depth**) is shown. This is because fuel bed depth is the only parameter necessary to calculate the one output selected, **Wind Adjustment Factor**. This is an important feature of BehavePlus. Once you select your output variables, BehavePlus will only ask for the necessary inputs on the Worksheet.

To see the effect of fuel bed depth on WAF;

- Enter a range of 0.1, 6 ft for the **Fuel Bed Depth**.
- Enter 0 (zero) for the **Canopy Cover**.

Calculating the run will give this graph.



In summary, the WAF for exposed fuels (those without a tree overstory) depends solely on the fuel bed depth (one of the fuel model parameters). The WAF for fuels with a overstory is based on the stand characteristics of canopy cover, height, and crown ratio. Remember since shrubs are part of the surface fuels in fuel models 4, 5, 6, 7, and 10 they are not considered as part of the overstory.


## Calculate a sheltered WAF

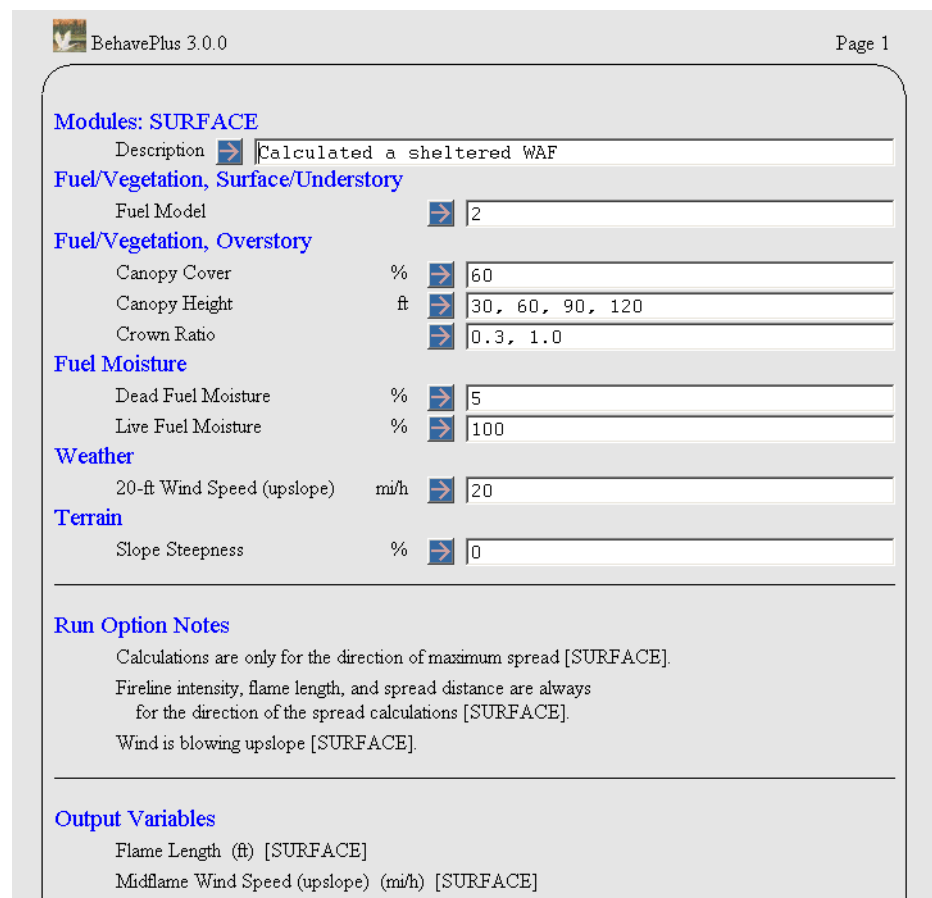
Wind adjustment factor can be calculated from a description of the overstory-canopy cover, canopy height, and crown ratio. The effect of terrain on WAF is not part of the calculations and is left to the user's knowledge of the situation being modeled. Depending on the application it might be more appropriate to input an estimated WAF rather than calculating it.

If you are unfamiliar with the silvicultural terms canopy cover, canopy height, and crown ratio a brief description can be found in the help pane of the Input Guide.

- Open a new Worksheet using the Example Worksheet

**SurfaceSimple.bpw.**

- Modify the Worksheet to look like this using the  toolbar button, note the output variables.



The screenshot shows the BehavePlus 3.0.0 software interface. The title bar indicates "BehavePlus 3.0.0" and "Page 1". The main window is titled "Modules: SURFACE" and contains the following configuration options:

- Description:** Calculated a sheltered WAF
- Fuel/Vegetation, Surface/Understory:** Fuel Model: 2
- Fuel/Vegetation, Overstory:**
  - Canopy Cover: 60%
  - Canopy Height: 30, 60, 90, 120 ft
  - Crown Ratio: 0.3, 1.0
- Fuel Moisture:**
  - Dead Fuel Moisture: 5%
  - Live Fuel Moisture: 100%
- Weather:** 20-ft Wind Speed (upslope): 20 mi/h
- Terrain:** Slope Steepness: 0%

Below the configuration options, there are sections for "Run Option Notes" and "Output Variables".

**Run Option Notes:**

- Calculations are only for the direction of maximum spread [SURFACE].
- Fireline intensity, flame length, and spread distance are always for the direction of the spread calculations [SURFACE].
- Wind is blowing upslope [SURFACE].

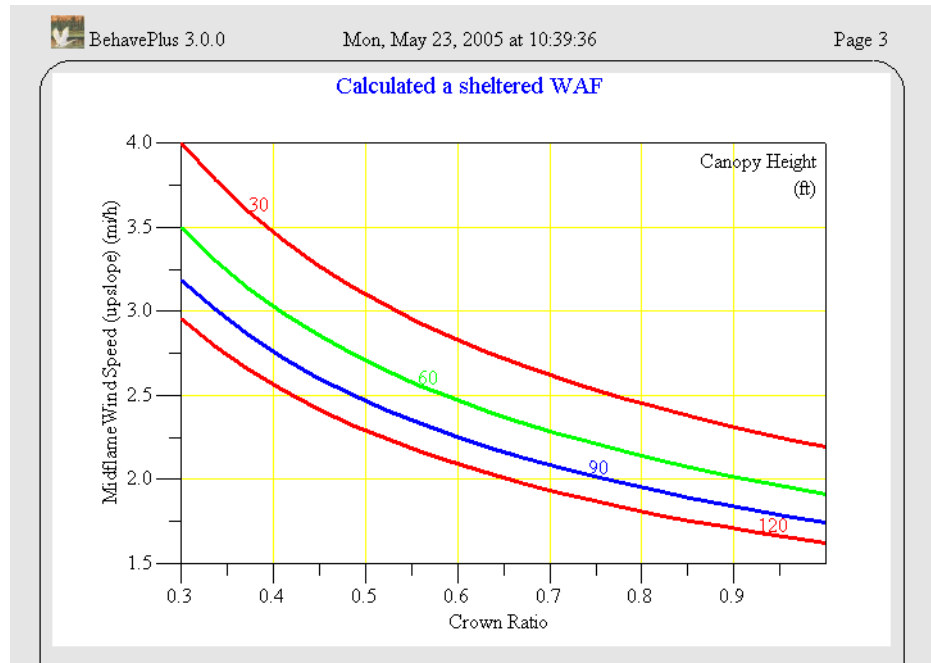
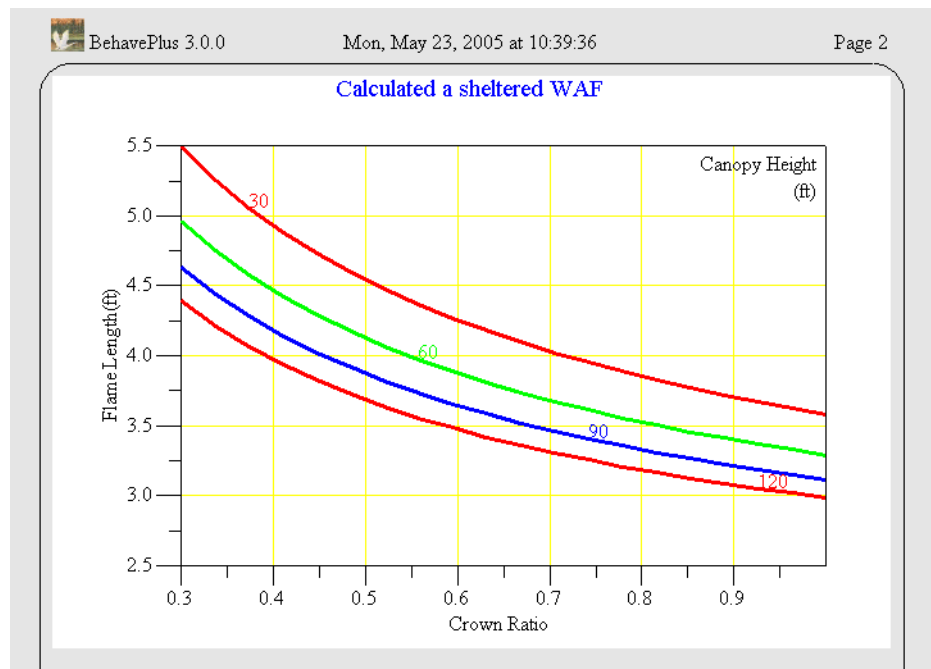
**Output Variables:**

- Flame Length (ft) [SURFACE]
- Midflame Wind Speed (upslope) (mi/h) [SURFACE]

The graphs below are produced, to get the same X and Y axis you will have to change a couple of things.

- On the **Configure > Appearance > Graph Size** tab select **Min Value** for the **X Axis Origin**.

- When calculating the run select the **Specify graph Y axis limits** check box on the "Calculate Results" dialog box.
- Finally, set the Y axis limits in the "Graph Limits" dialog box.



You can see the significant effect that crown ratio and canopy height have on midflame wind speed and the subsequent fire behavior.

Further explore this idea by seeing the effect of a range of canopy cover has on the WAF.

- Change the following inputs on the worksheet;



- Canopy Cover range 30 - 90% in increments of 10%,
  - Canopy Height of 90 ft,
  - Crown Ratio of 0.7.
- Add **Surface Rate of Spread** and **Wind Adjustment Factor** as output variables.

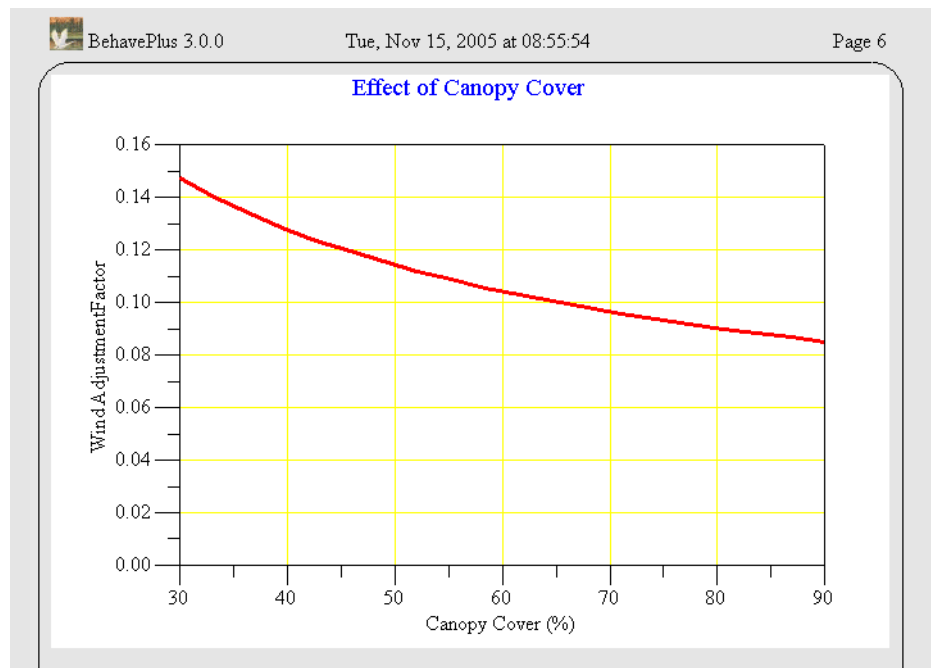
Look at the table that is calculated.

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### Effect of Canopy Cover

Canopy Cover %	ROS (max) ch/h	Flame Length ft	Midflame Wind Speed mi/h	Wind Adj Factor
30	15.7	4.4	2.9	0.1
40	12.6	4.0	2.6	0.1
50	10.7	3.7	2.3	0.1
60	9.4	3.5	2.1	0.1
70	8.5	3.3	1.9	0.1
80	7.8	3.2	1.8	0.1
90	7.2	3.1	1.7	0.1

Wow! - Why does the WAF remain 0.1 but the midflame wind varies from 2.9 to 1.7? Also look at the WAF graph to see what might be happening?



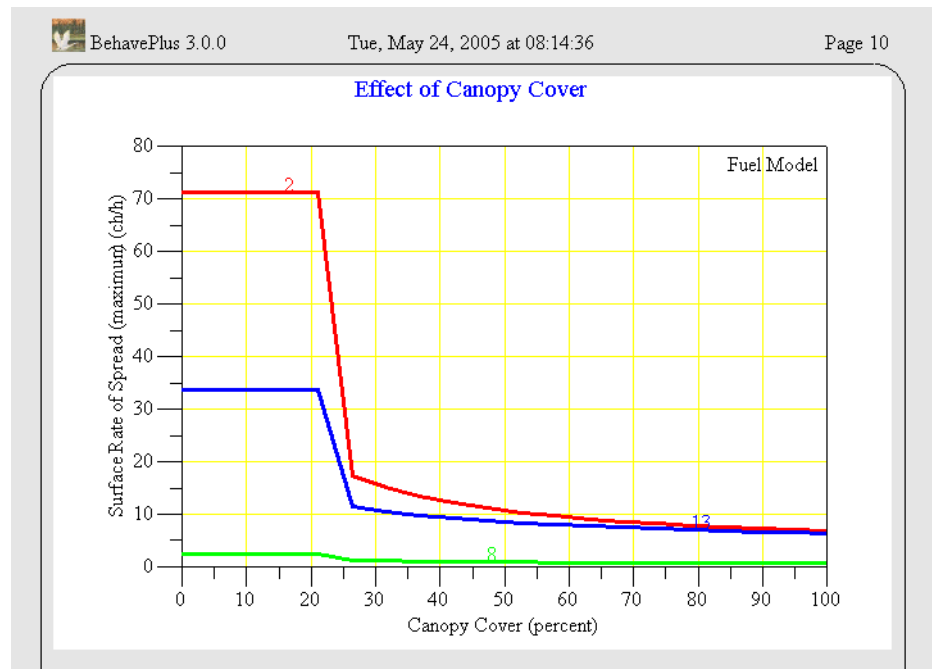
You can now see that the WAF does change over the range of Canopy Cover, its just that it varies between 0.08 and less than 0.15 so all the values round to 0.1 in the table.

## Unsheltered to Sheltered WAF Transition

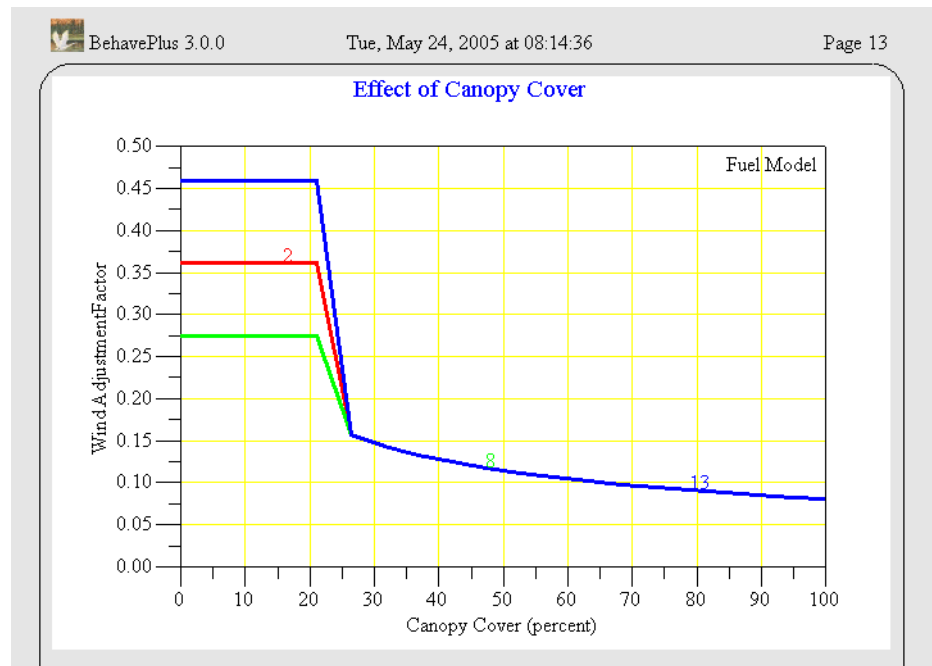
Now make the following changes to look at the entire ranges of canopy cover for three fuel models.

- Add fuel models 8 and 13 to the run.
- Change the Canopy Cover range to 0 - 100% in increments of 10%.

Look at the Surface Rate of Spread and Wind Adjustment Factor graphs.



There is a large step in the ROS for all three of the fuel models. This illustrates the transition from the calculation of an unsheltered WAF (a function of fuel bed depth) to a sheltered WAF (based on the overstory crown characteristics). This is also reflected in the calculated WAF graph.

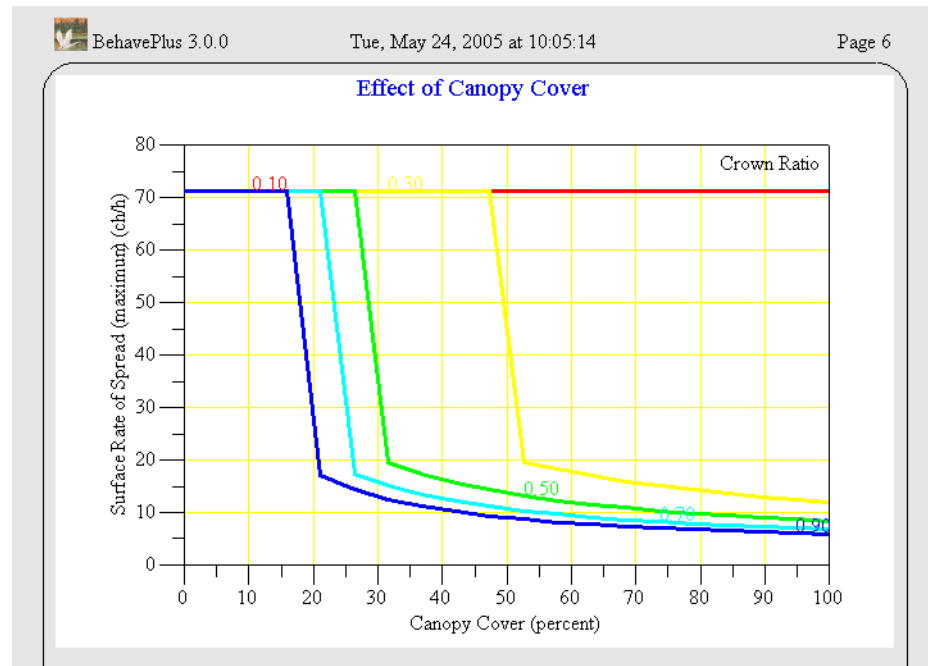


To further investigate this issue make these changes to your worksheet.

- Change the fuel model to just 2.

- Change Crown Ratio to a range of 0.1 - 1.0 in increments of 0.1.

Review the Surface ROS graph.



Note that the step occurs at different combinations of canopy cover and crown ratio. In this case a crown ratio of 0.10 always uses an unsheltered calculated WAF regardless of the canopy cover. A stand with a crown ratio of 0.90 transitions to a sheltered WAF for a canopy cover of 15%.

The step occurs when 5% of the stand volume is filled with tree crowns, this is called the filling fraction. The crown filling fraction is calculated from the crown ratio and canopy cover.

Realistically surface fire behavior isn't going to take a drastic jump when an additional tree or two is removed. This step phenomena is the result of using two different methods for calculating WAF and is limitation of the model. We again remind you that as a BehavePlus user, you are required to understand the relation between fire and fire models and think about what you are doing.

### Exercise 12-1

Compare the fire behavior (surface ROS and flame length) for the dry climate Grass and Grass-Shrub fuel models using a range of 1-h Moisture and a 20-ft Wind with a calculated Wind Adjustment Factor.

### Exercise 12-2

Compare for fuel model TU3 the fire behavior for a range of 1-h Moisture and a range of Canopy Cover.

Solutions for the above two exercises are labeled **SolutionEx12-1.bpr** and **SolutionEx12-2.bpr**. They are found in the **Solutions.zip** file which can be downloaded from the BehavePlus Training page at [www.fire.org](http://www.fire.org).

