Selecting a Grass Fuel Model for Prescribed Fire Planning

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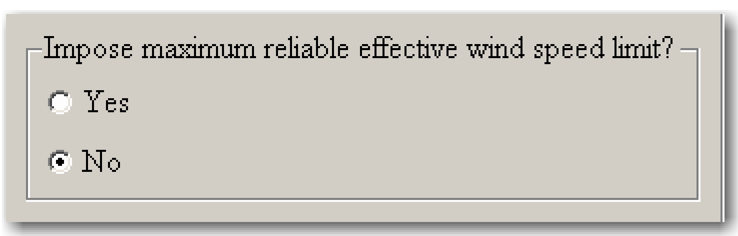
This example uses data from a National Park Service prescribed fire projects in North Dakota. We use predicted and observed data to select a standard fuel model, which will prove useful in future prescribed fire planning.

New options in BehavePlus version 4.0

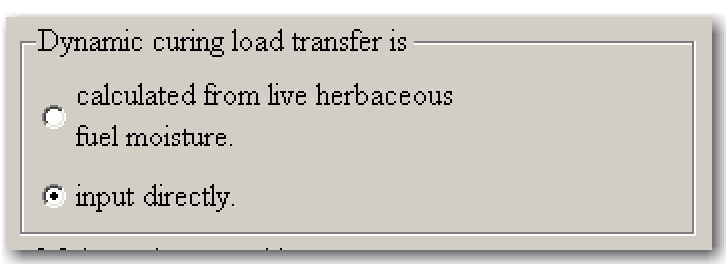
Two new options are available in BehavePlus 4.0 for enhanced fire modeling.

1. The maximum reliable wind speed can not be imposed
2. User entry of fuel load transfer for dynamic fuel models rather than calculation from live herbaceous fuel moisture

The first change discussed is the option to not impose the Maximum Reliable Wind speed. This option is found in the SURFACE module Options under the Wind tab. The 'Maximum reliable wind speed' value is calculated from the reaction intensity. When the wind limit is imposed (the default), rate of spread and flame length remain constant for winds above that value. The wind limit is reached for low intensity fuels, like grass. Dynamic grass fuel models have very low wind limits for high values of live fuel moisture. The user has the option of deciding whether that limit is appropriate.



The next new option discussed relates to dynamic curing load transfer found in SURFACE Options under the Fuel and Moisture tab. The default is to calculate the amount of fuel transferred from the live to the dead fuel from the live herbaceous fuel moisture content. The user now has the option of direct entry of curing (fuel load transfer portion) if that information is available.



Fire and Fuel Observations

We used data from two fires (April and September), each of which had two observations of head fire rate of spread and flame length. The monitoring data included wind speed, fuel loading, live and dead fuel moisture, and portion of live fuel. Table 1 is a summary of observed values.

Fuel Models

There are 3 grass fuel models in the original 13 (1, 2, and 3) and nine in the newer set of 40 fuel models (GR1 through GR9). Five of those nine are categorized as 'humid' types, which were eliminated from consideration. Table 2 gives the fuel parameters for the remaining seven grass fuel models. The fuel loading and the portion of live fuel is given for the two prescribed fires. A comparison gives us direction on which fuel models to consider.

Fuel model 1 load and depth are appropriate, but fuel model 1 includes no live fuel. The new 40 fuel models were developed in part because the original 13 represent dry conditions and don't cover the range of conditions experienced in prescribed fire, or times outside of the hot and dry portion of the fire season.

Fuel model 2 includes live fuel, as well as 10-h and 100-h, which is not appropriate for this grass type. Also, the total fuel load of 4 tons/acre is higher than the measured values.

Fuel model 3 includes only dead fuel. The fuel bed depth is 2.5 feet and the load is higher than measured in the burn units.

Fuel models GR1, GR2, GR4, and GR7 all have 1-h dead and live herbaceous fuel. The moisture of extinction for each is 15%. GR1 total load is low and GR7 is very high.

Fuel models GR2 and GR4 parameters most closely match the data collected for the prescribed fire units. Thus, these two fuel models will be used for further analysis.

Compare Calculations for Different Fuel Models

Following is a calculation for conditions on the Big Hidatsa Prescribed Fire, for fuel models 1, GR2, and GR4. (Fuel model 1 is included for demonstrating the difference in models.)

The initial run uses the SurfaceSimple.bpw worksheet with the default input options:

- The maximum reliable wind speed is imposed
- Dynamic curing load transfer is calculated from live herbaceous fuel moisture.

The output variables selected are

- Rate of Spread
- Flame Length
- Effective wind speed limit

The input values for dead and live fuel moisture and wind speed are taken from Table 1.

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Inputs: SURFACE

Description		Big Hidatsa Rx - Compare fuel models

Fuel/Vegetation, Surface/Understory

Fuel Model		1, gr2, gr4

Fuel Moisture

Dead Fuel Moisture	%	10
Live Fuel Moisture	%	220

Weather

Midflame Wind Speed (upslope)	mi/h	0 10 12 18

Terrain

Slope Steepness	%	0

Run Option Notes

Maximum reliable effective wind speed limit is imposed [SURFACE].

Notice that the Rate of spread and flame length values are the same for wind speed of 10, 12, and 18 mi/h

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Big Hidatsa Rx - Compare fuel models

Surface Rate of Spread (maximum) (ch/h)

Fuel Model	Midflame Wind Speed (upslope) mi/h 0.0	10.0	12.0	18.0
1	2.4	64.8	64.8	64.8
gr2	0.0	0.1	0.1	0.1
gr4	0.1	0.4	0.4	0.4

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Big Hidatsa Rx - Compare fuel models

Flame Length (ft)

Fuel Model	Midflame Wind Speed (upslope) mi/h			
	0.0	10.0	12.0	18.0
1	0.7	3.2	3.2	3.2
gr2	0.0	0.1	0.1	0.1
gr4	0.1	0.3	0.3	0.3

The reason that calculated fire behavior doesn't keep increasing with increasing wind is that the maximum effective wind limit has been imposed. For the moisture values in this run, the wind limit is 5.5 mi/h for fuel model 1, 0.9 mi/h for fuel model GR2, and 2.2 mi/h for fuel model GR4.

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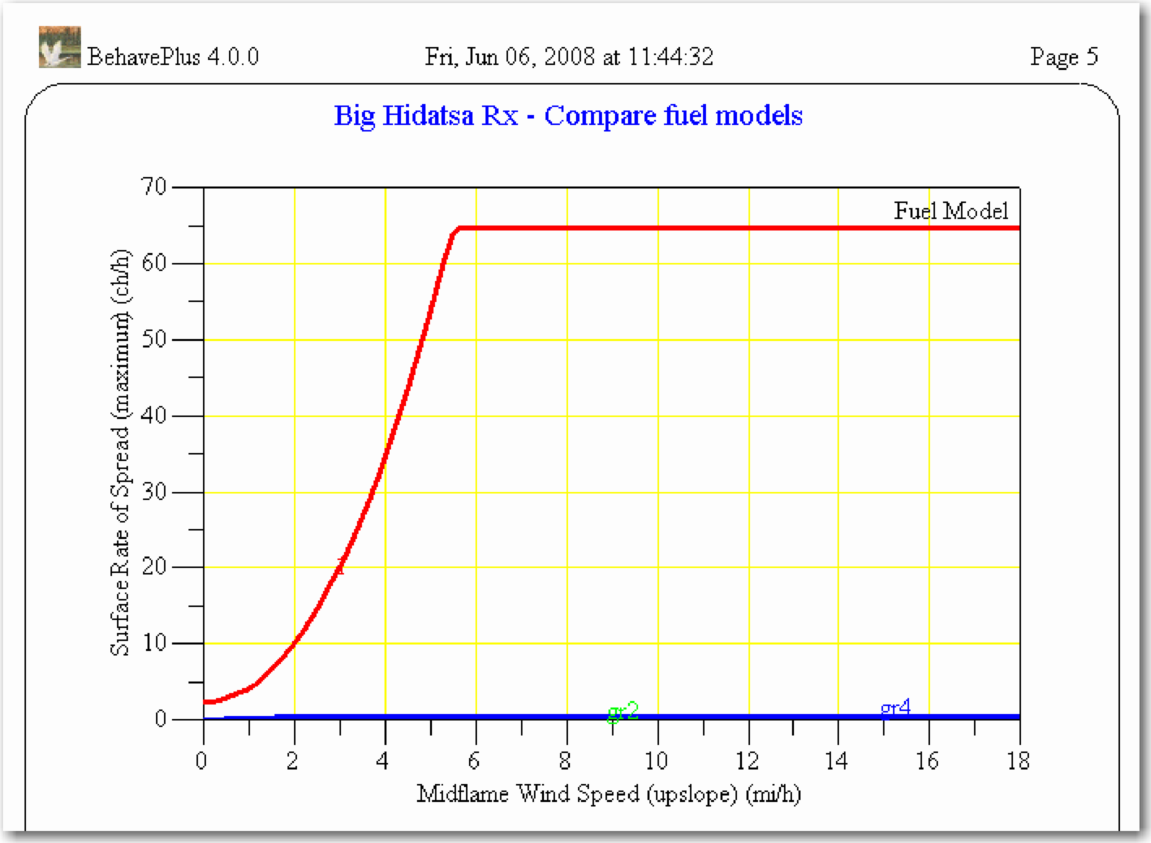
Big Hidatsa Rx - Compare fuel models

Effective Wind Speed Limit (mi/h)

Fuel Model	Midflame Wind Speed (upslope) mi/h			
	0.0	10.0	12.0	18.0
1	5.5	5.5	5.5	5.5
gr2	0.9	0.9	0.9	0.9
gr4	2.2	2.2	2.2	2.2

The plots clearly shows the effect of the wind limit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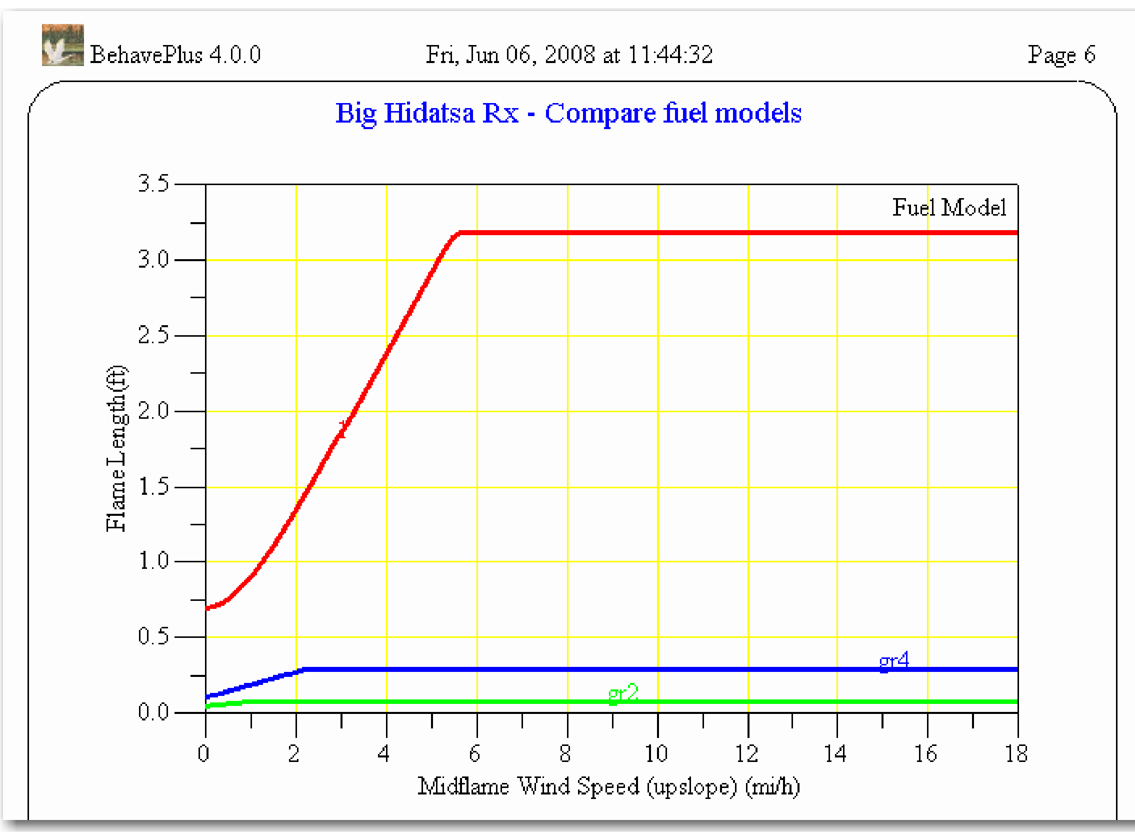
Big Hidatsa Rx - Compare fuel models
Fuel Model
gr2
gr4
Surface Rate of Spread (maximum) (ch/h)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
Midflame Wind Speed (upslope) (mi/h)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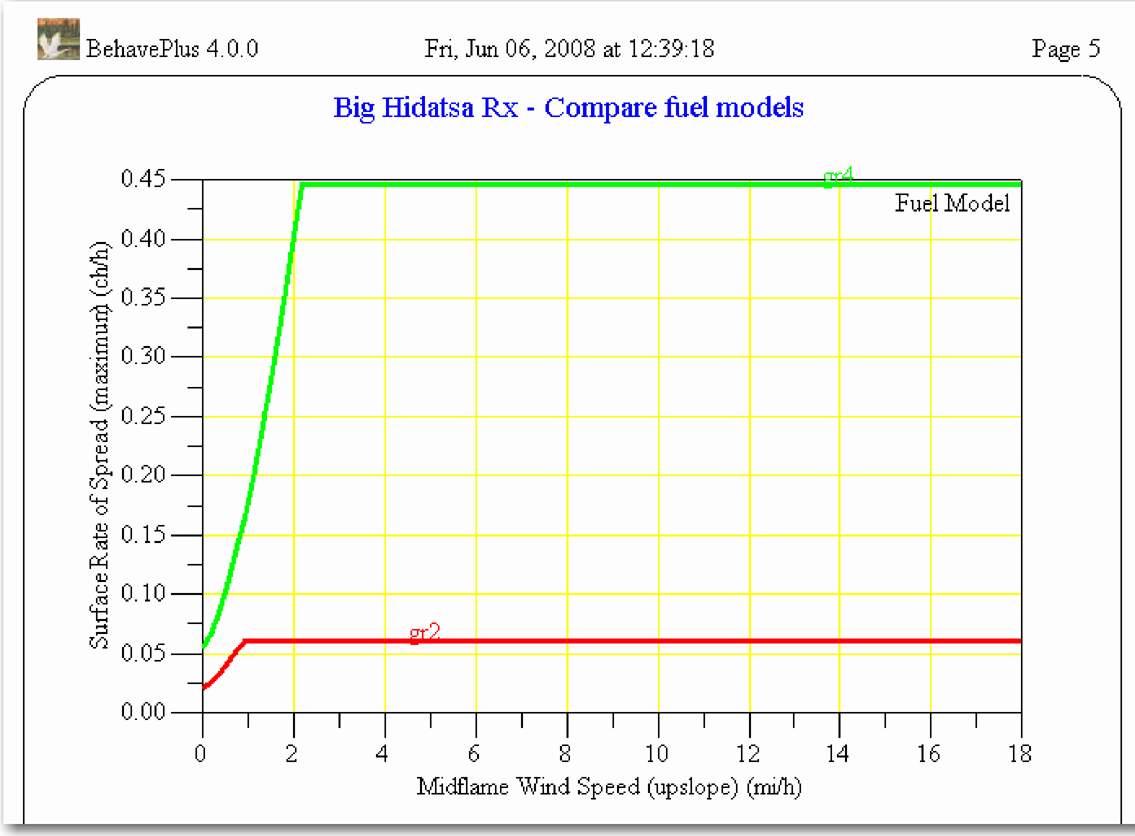
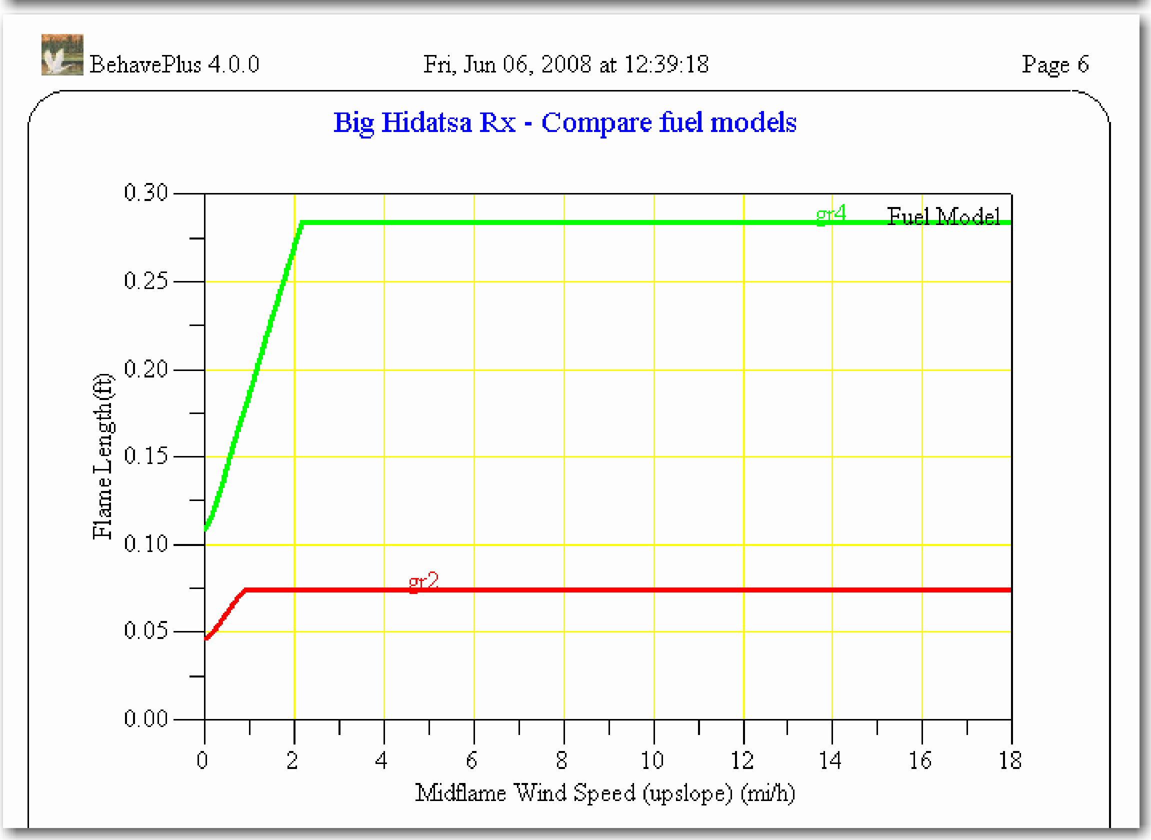
Big Hidatsa Rx - Compare fuel models
Fuel Model
gr4
gr2
Flame Length (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
2
4
6
8
10
12
14
16
18
Midflame Wind Speed (upslope) (mi/h)

We now remove fuel model 1 and look at the plots for only GR2 andGR4.





It seems unrealistic that the wind limit would be so low a for fuel models GR2 and GR4. The wind limit is so low because of the low reaction intensity for those fuel models at high live fuel moisture values. The field observations show rate of spread and flame length that are higher than these predictions.

Effect of not imposing wind limit

The following run is the same as above, with the option changed to maximum reliable wind is not imposed.

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Big Hidatsa Rx - Compare fuel models

Surface Rate of Spread (maximum) (ch/h)

Fuel Model	Midflame Wind Speed (upslope) mi/h			
	0.0	10.0	12.0	18.0
gr2	0.0	1.4	1.8	3.2
gr4	0.1	3.7	4.8	8.6

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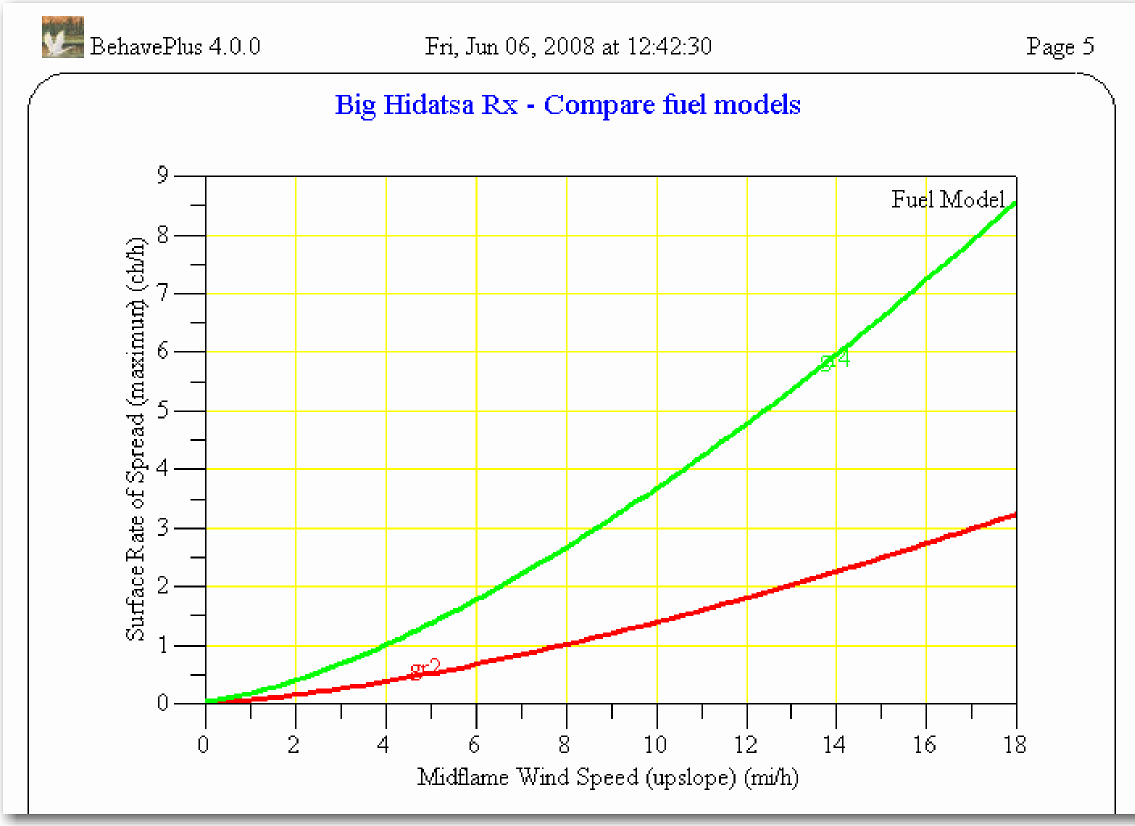
Big Hidatsa Rx - Compare fuel models

Flame Length (ft)

Fuel Model	Midflame Wind Speed (upslope) mi/h			
	0.0	10.0	12.0	18.0
gr2	0.0	0.3	0.4	0.5
gr4	0.1	0.7	0.8	1.1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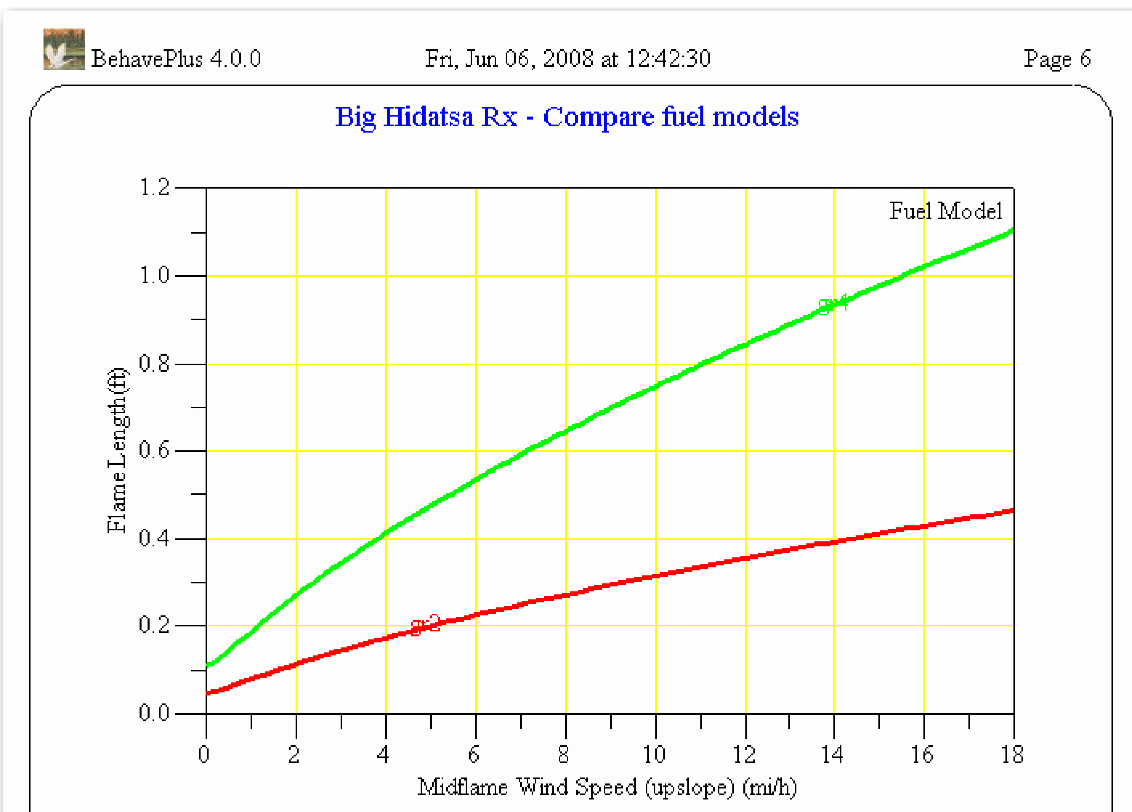
Page 5
Big Hidatsa Rx - Compare fuel models
Surface Rate of Spread (maximum) (ch/h)
Midflame Wind Speed (upslope) (mi/h)
Fuel Model
gr2
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12
14
16
18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Big Hidatsa Rx - Compare fuel models
Flame Length (ft)
Midflame Wind Speed (upslope) (mi/h)
Fuel Model
gr2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
2
4
6
8
10
12
14
16
18

The calculated values are still less than observed. In the next section we see if we can improve the results using the new dynamic curing option.

Dynamic fuel models

The original 13 fuel models are all ‘static’, meaning the fuel model parameters do not change. Seventeen of the 40 fuel models are ‘dynamic’, including all of the grass (GR) fuel models. The fuel loads listed for 1-h and for live herbaceous fuel are the values before fuel is transferred from the live to the dead category as a representation of the curing process. The original formulation of dynamic fuel models uses live herbaceous fuel moisture to calculate the fuel load transfer portion. For live herbaceous fuel moisture over 120%, no live fuel is transferred to the dead category.

Version 4.0 of BehavePlus offers the option of specifying the portion of load transfer rather than using the calculated value.

Table 2 shows the calculated and observed portion of live fuel. For fuel model GR4 and live fuel moisture of 70%, the calculated portion of live fuel is 39.2% compared to an observed value of 20-30%, which is close. But there is a very large difference at 220% live fuel moisture. The field observation was 40-50% live fuel. The calculation says that 0% would be transferred from live to dead, which is 88.4% live fuel for fuel model GR4. (There is dead fuel in the fuel model even at 0% curing.)

The previous runs use the default option of automatic calculation of load transfer portion (curing). We now select the option of user entry of a value for fuel load transfer portion.

Enter a value of 50% fuel load transfer portion rather than accepting the calculated value of 0%.

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Inputs: SURFACE

Description: Big Hidatsa Rx - Compare fuel models

Fuel/Vegetation, Surface/Understory

Fuel Model		gr2, gr4
Fuel Load Transfer Portion	%	50

Fuel Moisture

Dead Fuel Moisture	%	10
Live Fuel Moisture	%	220

Weather

Midflame Wind Speed (upslope)	mi/h	10 12 18

Terrain

Slope Steepness	%	0

Run Option Notes

Maximum reliable effective wind speed limit is not imposed [SURFACE].

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Big Hidatsa Rx - Compare fuel models

Surface Rate of Spread (maximum) (ch/h)

Fuel Model	Midflame Wind Speed (upslope) mi/h		
	10.0	12.0	18.0
gr2	14.6	18.9	34.0
gr4	30.7	39.9	71.6

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Big Hidatsa Rx - Compare fuel models

Flame Length (ft)

Fuel Model	Midflame Wind Speed (upslope) mi/h		
	10.0	12.0	18.0
gr2	2.1	2.4	3.1
gr4	4.1	4.6	6.0

GR4 now produces values close to the observed fire behavior (ROS 40 90 ch/hr and flame length 2 – 5 ft).

Next, let's produce a table of values using the GR4 fuel model.

BehavePlus 4.0.0 Wed, May 14, 2008 at 07:57:07 Page 1

Inputs: SURFACE

Description: Big Hidatsa Rx - Compare fuel models

Fuel/Vegetation, Surface/Understory

Fuel Model		gr4
Fuel Load Transfer Portion	%	50

Fuel Moisture

Dead Fuel Moisture	%	10
Live Fuel Moisture	%	220

Weather

Midflame Wind Speed (upslope)	mi/h	10 12 18

Terrain

Slope Steepness	%	0

Run Option Notes

Maximum reliable effective wind speed limit is not imposed [SURFACE].

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Big Hidatsa Rx - Compare fuel models

Midflame Wind Speed mi/h	ROS (max) ch/h	Flame Length ft	Fuel Load Transfered %	Percent Dead Fuel
10.0	30.7	4.1	50	56
12.0	39.9	4.6	50	56
18.0	71.6	6.0	50	56

Following are calculations for the Artifact Rx burn, with lower live fuel moisture, more dead fuel, and lower wind speeds.

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Inputs: SURFACE

Description: Artifact Research Rx

Fuel/Vegetation, Surface/Understory

Fuel Model		gr4
Fuel Load Transfer Portion	%	75

Fuel Moisture

Dead Fuel Moisture	%	12
Live Fuel Moisture	%	70

Weather

Midflame Wind Speed (upslope)	mi/h	5 6 10

Terrain

Slope Steepness	%	0

Run Option Notes

Maximum reliable effective wind speed limit is not imposed [SURFACE].

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Artifact Research Rx

Midflame Wind Speed mi/h	ROS (max) ch/h	Flame Length ft	Fuel Load Transfered %	Percent Dead Fuel
5.0	47.2	6.1	75	78
6.0	61.0	6.9	75	78
10.0	126.4	9.6	75	78

The rates of spread are in the range of observed values, but the flame lengths are higher than observed.

It is worth noting that under essentially the same conditions the observed rate of spread on one plot was 43.6 ch/h and 90.9 ch/h on the other. The variation in fuel, moisture, and wind must be recognized as they change across the landscape and over time. In addition, it is difficult to accurately measure fuel moisture, wind, rate of spread, and flame length in the field.

With the limited data set, the objective cannot be to precisely match predicted and observed values, but rather to use the observations to guide selection of a fuel model that performs reasonably well under the conditions associated with the prescribed fires.

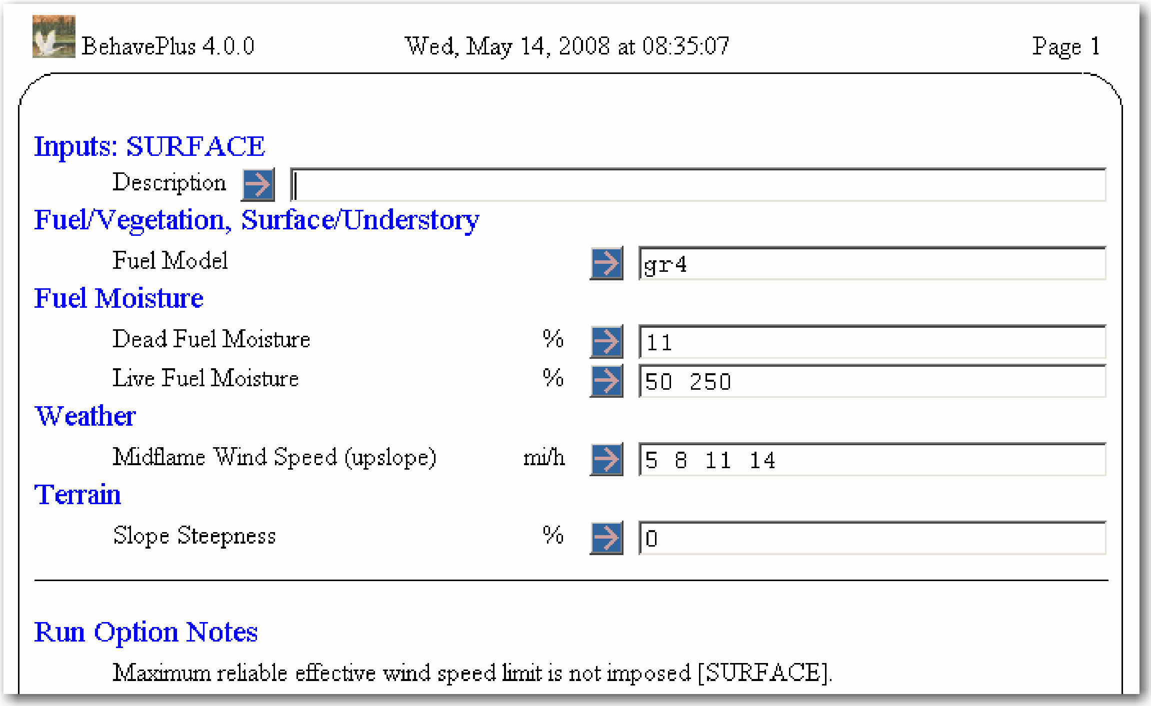
A summary of observations and calculations is given in table 3.

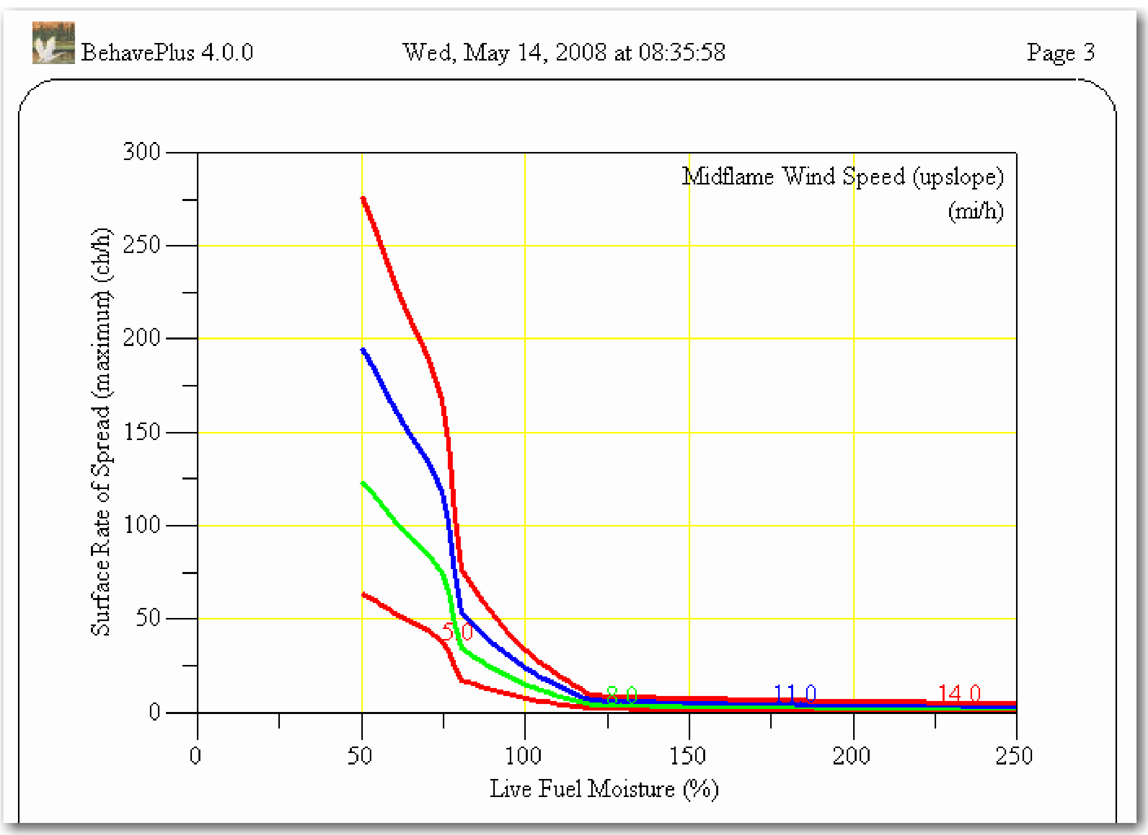
Direct entry of dynamic curing load transfer

The increased flexibility of dynamic fuel models comes with the added responsibility for users to understand how they work. It takes some effort to fully understand them.

Next, we do some additional runs to illustrate the difference in calculated load transfer versus direct entry for this example.

The two fires had live fuel moisture values of 70% and 220%. Let’s look at the rate of spread for a range of live fuel moistures from 50 to 250% and wind speeds from 5 to 14 mi/h.





The graphs show that there is essentially no spread with live fuel moisture over 120%. However, the prescribed fire conducted with live fuel moisture of 220% did burn. There is a large drop in calculated spread rate at about 75%. A look at the table shows the large change in spread rate for a little change in live fuel moisture.

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Surface Rate of Spread (maximum) (ch/h)

Live Fuel Moisture %	Midflame Wind Speed (upslope) mi/h 5.0	8.0	11.0	14.0
70	44.1	85.8	135.4	191.7
72	42.0	81.7	129.0	182.6
74	39.0	75.9	119.8	169.6
76	34.2	66.4	104.9	148.5
78	25.8	50.2	79.2	112.1
80	17.8	34.7	54.7	77.5
82	16.6	32.2	50.8	72.0
84	15.4	29.9	47.1	66.7

At a midflame wind of 8 mi/h, spread rate is 66.4 ch/h at 76% moisture and 34.7 ch/h at 80% moisture. This is close to a doubling of spread rate for a 4% drop in live fuel moisture. The sensitivity of the model to changes in live fuel moisture is unrealistic. And it is essentially not possible to know the live fuel moisture to that level of precision.

These results are due to the combined effect of live fuel moisture in the rate of spread calculations and the use of live fuel moisture to change the dynamic fuel model.

The following run uses the option of calculated fuel load transfer portion, only 8 mi/h wind, and additional output variables. We will compare these results to those resulting from the option of direct entry of fuel load transfer portion.

BehavePlus 4.0.0 Wed, May 14, 2008 at 08:43:50 Page 1

Inputs: SURFACE

Description

Fuel/Vegetation, Surface/Understory

Fuel Model		gr4

Fuel Moisture

Dead Fuel Moisture	%	11
Live Fuel Moisture	%	50 60 70 80 90 200 220 250

Weather

Midflame Wind Speed (upslope)	mi/h	8

Terrain

Slope Steepness	%	0

Run Option Notes

Maximum reliable effective wind speed limit is not imposed [SURFACE].

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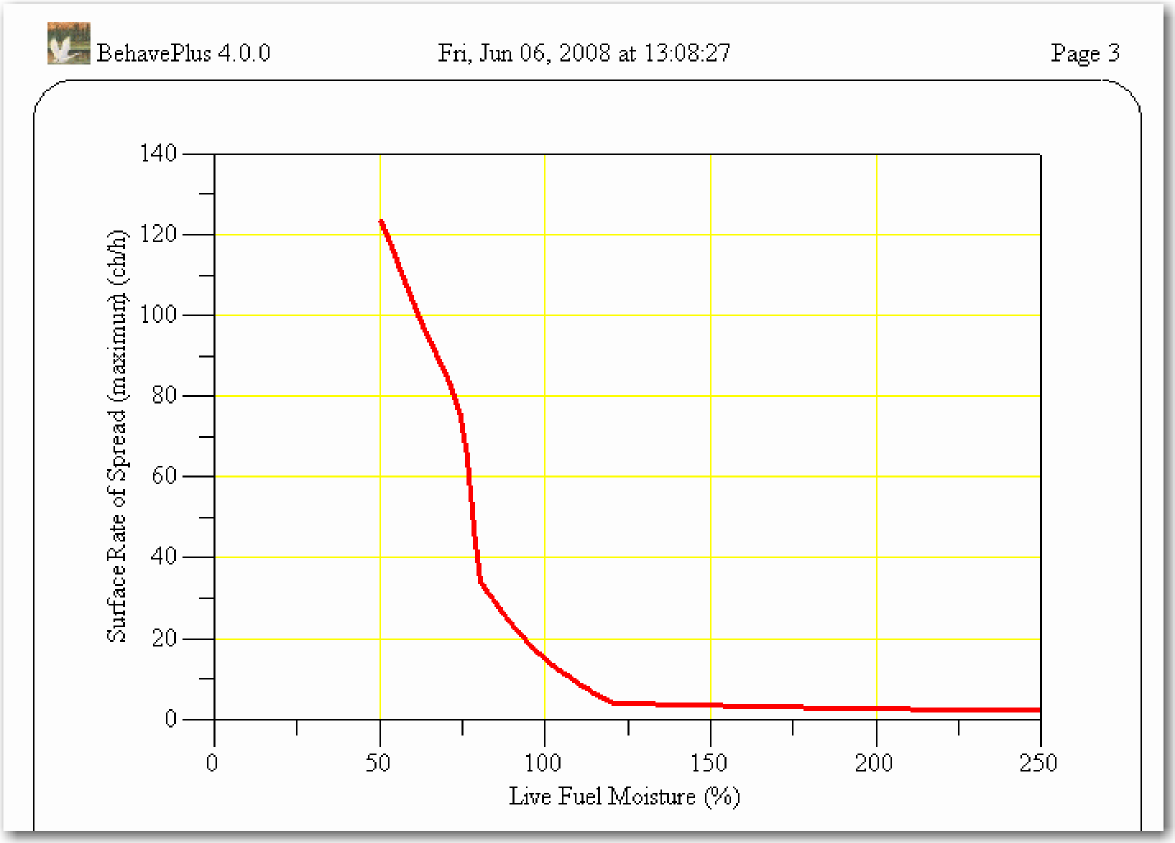
Live Fuel Moisture %	ROS (max) ch/h	Flame Length ft	Fuel Load Transfered %	Percent Dead Fuel
50	123.8	10.3	78	80
60	103.4	9.3	67	71
70	85.8	8.5	56	61
80	34.7	4.0	44	51
90	23.6	3.0	33	41
200	2.7	0.6	0	12
220	2.5	0.6	0	12
250	2.2	0.6	0	12



We now change the option to direct entry of fuel load transfer portion.

BehavePlus 4.0.0 Wed, May 14, 2008 at 08:46:35 Page 1

Inputs: SURFACE

Description

Fuel/Vegetation, Surface/Understory

Fuel Model		gr4
Fuel Load Transfer Portion	%	50 60 70 80

Fuel Moisture

Dead Fuel Moisture	%	11
Live Fuel Moisture	%	50 60 70 80 90 200 220 250

Weather

Midflame Wind Speed (upslope)	mi/h	8

Terrain

Slope Steepness	%	0

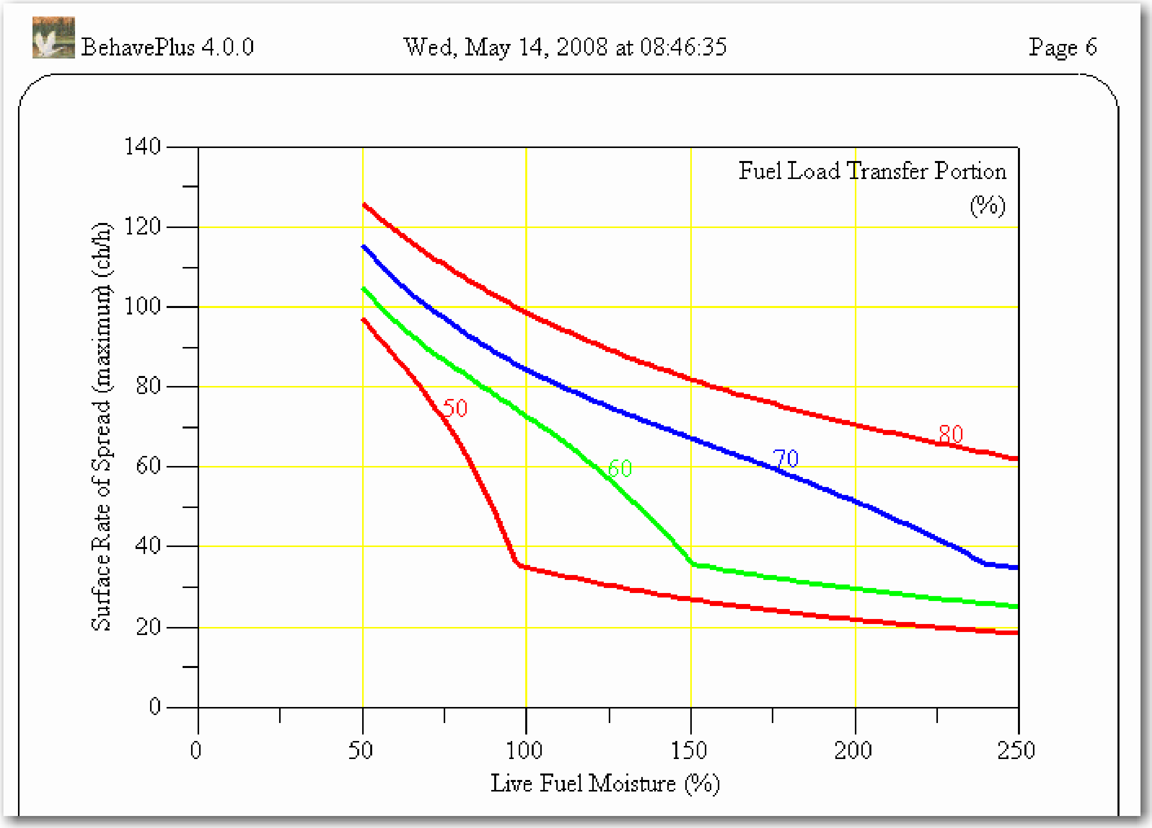
Run Option Notes

Maximum reliable effective wind speed limit is not imposed [SURFACE].

BehavePlus 4.0.0 Wed, May 14, 2008 at 08:46:35 Page 2

Surface Rate of Spread (maximum) (ch/h)

Live Fuel Moisture %	Fuel Load Transfer Portion % 50	60	70	80
50	97.1	105.1	115.6	125.9
60	87.7	96.6	107.1	119.2
70	77.5	89.7	100.1	113.3
80	65.0	83.8	94.1	107.9
90	49.3	78.3	88.9	103.1
200	21.9	29.6	51.4	70.7
220	20.4	27.6	44.1	67.0
250	18.4	25.2	34.8	62.0



Note the difference in spread rate for live fuel moisture over 120%. Compare this graph to the previous graph. It demonstrates the differences in fire behavior predictions using the automatic calculation of fuel load transfer and the direct entry of estimated curing.

Summary

It is useful to compare predicted and observed rates of spread and flame lengths to choose the most appropriate fuel model for a project or incident under similar conditions. Data from even two fires is worthwhile. Additional data can be used to confirm or revise the selection.

It is not just a matter of selecting a fuel model. Two modifications in Version 4.0 of BehavePlus (removal of Maximum Effective wind speed and direct entry of fuel load transfer portion) can improve predictions for prescribed and wildland fire management.

Variation in both time and space and the difficulty of recording observations in both conditions and fire behavior must be recognized when comparing predicted and observed values.

Table 1 – Observed conditions and fire behavior.

Observed / Measured									
Fire	Big H	Big H	Big H		Art	Art	Art		
Location	Youess, N	Poly, N	Avg		Youess, L	Poly, H	avg		
Date	Apr 28, 2005				Sep.28, 2005				
Time	1115	1220			1230	1400			
Fuel model	x				x				
Dead fuel mois., %	9.6	10.0	10		13.7	11.6	12.7		
Live fuel mois, %	218.2	221.0	220		60	79	70		
Wind speed, mi/h	10-12 G 19 NW (1100)	10-12 G 18 WNW (1200)	10-12 G 19		5 G 8-10 WNW (1230)	6 G 8-10 WNW (1315)	5-6 G 10		
Portion live fuel, %	40-50	40-50	40-50		20-30	20-30	20-30		
Fuel load transfer, %	50-60	50-60	50-60		70-80	70-80	70-80		
Fuel load, ton/ac	2.68	1.89	2.28		2.51	1.21	1.86		
Direction	Head	Head			Head	Head			
ROS, ch/h	40	40	40		43.6	90.9			
Flame length, ft	2-5	2-5	2-5		2-5	1.5-4.5			

Table 2—Fuel model parameters for standard grass fuel models. Observed values for the two burn sites.

Fuel Model	**1**	**2**	**3**	**GR1**	**GR2**	**GR4**	**GR7**	**B.H.**	**A.R**
Dynamic or Static	S	S	S	D	D	D	D		
1-h load, ton/ac	0.74	2.0	3.0	0.1	0.1	0.25	1.0		
10-h load	--	1.0	--	--	--	--	--		
100-h load	--	0.5	--	--	--	--	--		
Live herb load	--	0.5	--	0.3	1.0	1.9	5.4		
Live woody load	--	--	--	--	--	--	--		
Fuel bed depth, ft	1.0	1.0	2.5	0.4	1.0	2.0	3.0		
Dead mois. of ext, %	12	15	25	15	15	15	15		
Total load, live and dead	1.74	4.0	3.0	0.4	1.1	2.15	6.4	2.28 (2.68, 1.89)	1.86 (2.51, 1.21)
% load transfer at 220% live mois.	-0-	-0-	-0-	0	0	0	0		
% dead fuel ad 220%	100	87.5	100	25.0	9.1	11.6	15.6	50	xx
% live fuel at 220%	0	12.5	0	75.0	90.9	88.4	84.4	50	xx
% load transfer at 70% live mois.	-0-	-0-	-0-	56	56	56	56		
% dead fuel at 70%	100	87.5	100	66.7	59.6	60.8	62.5	xx	75
% live fuel at 70%	0	12.5	0	33.3	40.4	39.2	37.5	xx	25

Table 3—Calculated and observed fire behavior.

	Big H					**Art**				
Fuel model	GR4	GR4	1	1		GR4	GR4	1		
Curing	Calc curing	Input curing	Static	Static		Calc curing	Input curing	Static		
Dead fuel mois., %	10	10	10	10		12	12	12		
Live fuel mois, %	220	220				70	70			
Wind speed, mi/h	10-18	10-18	10-18	10-18		5-10	5-10	5-10		
Input Fuel load transfer, %	x	50				x	75			
Calc. Portion dead fuel, %	x	56				x	78			
Calc. Fuel load transfer, %	0	x				56	x			
ROS, ch/h	4-9	31-72	217-729	65-65		35-94	47-126	0		
Flame length, ft	.5-1	4-6	5.5-9.7	3.2-32.		5-8	6-9	0		
Wind limit imposed	No	No	No	Yes		No	No	No		
Obs. ROS, ch/h	40					67.2 (43.6 90.9)				
Obs. Flame length, ft	2-5					2-5 1.5-4.5				