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1. INTRODUCTION

The BehavePlus fire modeling system is based on a collection of models that describe fire behavior, fire effects, and the fire environment. BehavePlus is the successor to the BEHAVE fire behavior prediction and fuel modeling system (Andrews 1986, Andrews and Chase 1989, Andrews and Bradshaw 1990, Burgan and Rothermel 1984). It is called the *BehavePlus fire modeling system* to reflect its expanded scope.

Version 1.0 of BehavePlus was a complete redesign of BEHAVE, with the fire models being essentially the same. Version 2.0, released in July 2003, offers additional fire modeling capabilities and design features. Development of version 3.0 is in progress.

BehavePlus is a flexible system that produces tables, graphs, and simple diagrams (figure 1). Input is supplied directly by the user.

Projecting the growth and behavior of ongoing fires by Fire Behavior Analysts is a key application of BehavePlus (Rothermel 1983). BehavePlus is also used for prescribed fire planning to identify conditions under which a burn can be safely conducted and meet management objectives. Contingency planning involves calculating the potential behavior of a fire that might occur outside the designated burn area and the suppression forces necessary to contain it. Fuel assessment involves calculating potential fire behavior in various fuel types over a range of moisture and wind conditions.

BehavePlus is designed to be a training tool. Users can easily vary an input value and examine the effect on the prediction. Each input and output variable is defined and described within the program. Because the fire models in BehavePlus are the same as those in the FARSITE fire area simulator (Finney 1998) and the FlamMap fire behavior mapping and analysis system, a person can learn about the models, their limitations and assumptions and then move on to the spatial application of those models.

BehavePlus is used to make fire behavior calculations in the interagency fire behavior courses S-390, S-490, and S-590.

Rate of Spread (maximum) (ch/h)

Fuel Model	Midflame Wind Speed (upslope) mi/h					
	0.0	2.0	4.0	6.0	8.0	10.0
2	2.1	7.9	22.8	45.5	75.6	112.6
5	0.6	4.2	9.9	17.0	25.1	34.0
8	0.2	0.7	1.5	2.6	3.9	4.9

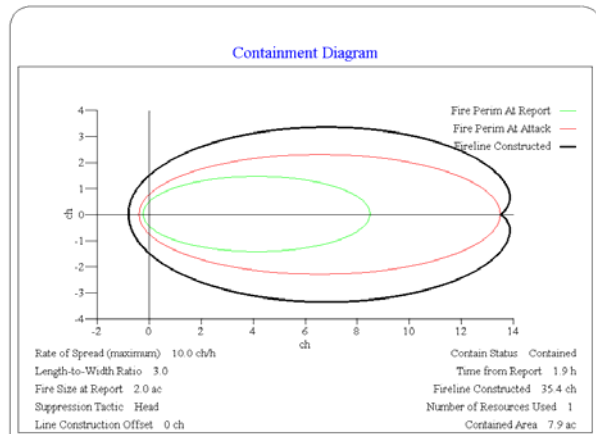
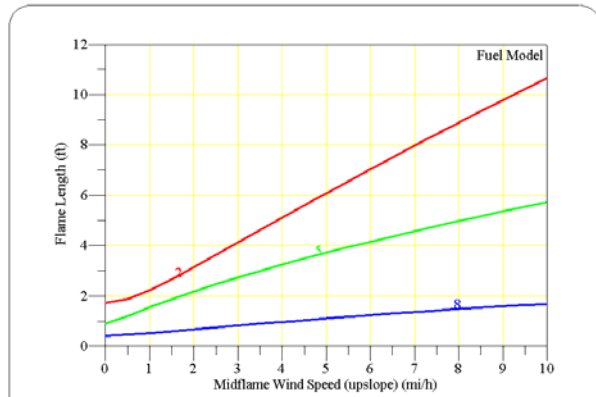


Figure 1. Example table, graph, and diagram output from BehavePlus.

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2. FIRE MODELING CAPABILITIES

The primary fire modeling capabilities are organized as modules:

- SURFACE. Rate of spread, intensity, and flame length of surface fire are calculated for the direction of maximum spread or for any specified direction (Rothermel 1972, Byram 1959).
- SAFETY. The size of a safety zone is calculated. Results can be the size of a circular shaped area or a separation distance (Butler and Cohen 1998).
- SIZE. The area and perimeter of an elliptically shaped point source fire is calculated (Anderson 1983, Andrews 1986).
- CONTAIN. Final size and perimeter of a fire that is contained by suppression action is calculated. Multiple resources with various production rates and arrival times, and direct or parallel attack from either the fire head or rear can be specified (Fried and Fried 1996).
- SPOT. Maximum spotting distance from torching trees, a burning pile, or a wind-driven surface fire is calculated (Albini 1979, 1981, 1983).
- SCORCH. Crown scorch height is calculated (Van Wagner 1973).
- MORTALITY. Probability of tree mortality is calculated (Ryan and Reinhardt 1988).
- IGNITE. Probability of ignition from a fire brand or from a lightning strike are calculated (Schroeder 1969, Latham and Schlieter 1989).

Other modeling capabilities in BehavePlus include the following:

- Surface fuel model parameters can be adjusted to create a custom fuel model.
- Surface fire behavior can be calculated using a dynamic palmetto-gallberry fuel model (Hough and Albini 1978). Fuel input includes age of rough, height of understory, palmetto coverage, and overstory basal area.
- A weighted rate of spread within a two fuel model complex can be calculated by three methods: 2-dimensional expected spread (Finney 2003), harmonic mean (Fujioka 1985), and area weighted (Rothermel 1983).
- A set of fuel moisture values can be defined as a 'moisture scenario' so that multiple scenarios can be run simultaneously and their effects compared.
- Fine dead fuel moisture can be estimated from tables (Rothermel 1983).
- Relative humidity or dew point can be calculated from user input.
- Sunrise, sunset, dawn, and dusk can be calculated for any location and date.

3. OPERATION FEATURES

Some of the key features of the BehavePlus system are as follows:

- Multiple values can be entered for almost any input variable, including fuel models and moisture scenarios.
- The user has selection control of input and output variables.
- The user has control of the units of measure and number of decimal places to be displayed.
- The user interface language can be dynamically changed (currently English and Portuguese).
- Diagrams can be produced for point source fire shape, shape of a contained fire, fire characteristics chart, and wind-slope-spread directions.
- Photographs and a selection key are available for the 13 standard surface fuel models (Anderson 1982, Rothermel 1983).
- Distances can be output in map units.
- To keep BehavePlus from becoming yet another boring program with a gray personality, we've inserted some paintings (with permission from Monte Dolack) (figure 2). (If you prefer the gray approach, you have the option of eliminating the pictures.)

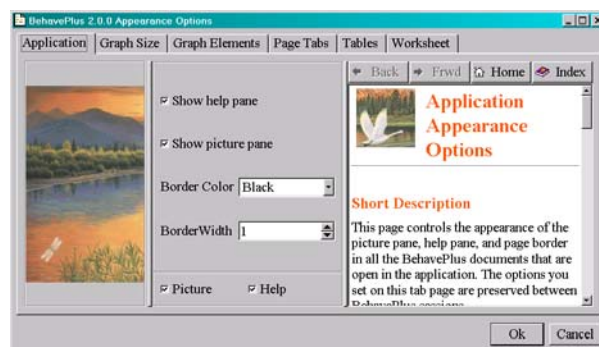


Figure 2. Portions of Monte Dolack paintings are inserted throughout the program for visual relief.

4. SUPPORTING MATERIAL

Material has been developed to support use of the BehavePlus system: a web site, a User's Guide, a help system built into the program, and a set of tutorials. Additional material is being developed.

4.1 Web Site

The BehavePlus software and supporting material are available for download from the web site, www.fire.org. You can report bugs, make suggestions, and register for information on updates. You can check the 'Frequently Asked Questions' and 'Known Bugs' for help. A 'Credits' section acknowledges funding by the Joint Fire Science Program and Forest Service Fire and Aviation Management and recognizes those who have worked on the project. A 'News' section points out the latest information.

4.2 User's Guide and Help system

A new User's Guide was prepared for version 2.0 (Andrews et al. 2003). It also serves as the Help system for the program. The table of contents of the User's Guide serves as the index to information in the help system (figure 3).

The User's Guide addresses only operation of the program. The fire models, associated variables, and application will be described in future publications.

In addition to 'program help', BehavePlus screens include a help browser pane that describes input and output variables and operation relative to the current screen (figure 4).

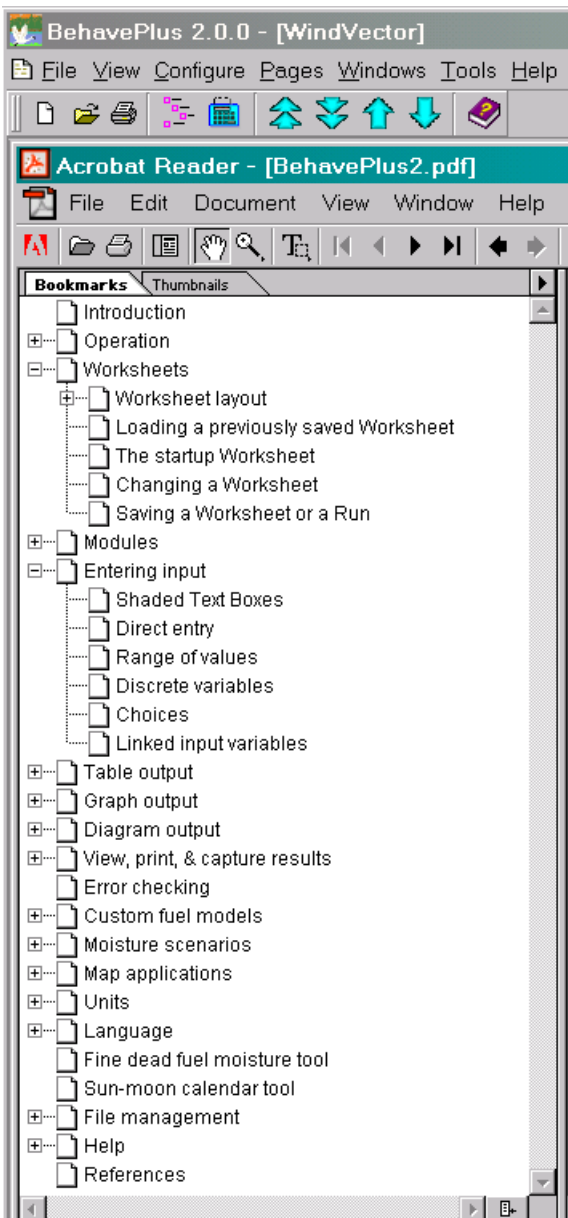


Figure 3. The published User's Guide also serves as online help for program operation.

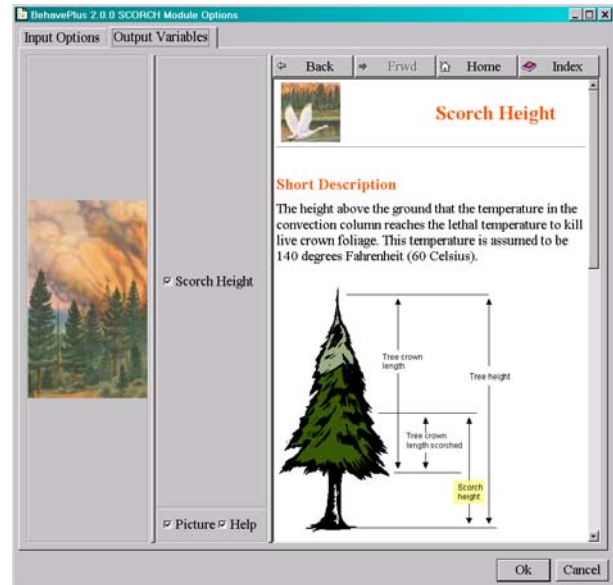


Figure 4. A browser pane provides definition of input and output variables.

4.3 Training

A set of self-study tutorials is available to cover various aspects of operation of the program. These tutorials are not training on the fire models in BehavePlus or on the proper application of the program. Additional training material will be developed to support use of the BehavePlus fire modeling system. Following is a brief description of the operation tutorials:

- **Basic Start** covers basic operation of the program without addressing the many options that are available and covered in subsequent lessons.
- **Worksheets** covers selecting, changing, and saving worksheets, which are the forms used to enter input.
- **Input Methods** covers several ways to supply input to the BehavePlus program.
- **Calculation** shows how to do the calculations, producing tables and graphs.
- **Direction Options** demonstrates the various ways of specifying directions for wind, slope, and spread.
- **Moisture Scenarios** shows how to define, save, and use sets of fuel moisture values.
- **Custom Fuel Models** shows how to adjust fuel model parameters, compare the results to other fuel models, save, and use custom fuel models. (There is much more to custom fuel modeling than what is included in this lesson.)
- **File Management** describes the file management system for saving runs, worksheets, moisture scenarios, images, and fuel models.
- **Print and Capture Images** shows how to print worksheets, tables, and graphs, and how to include BehavePlus output in another document.
- **Units** shows how to change between metric and English and how to develop a custom units set.

5. FUTURE DEVELOPMENT

BehavePlus will be updated as new models and methods become available. Following are planned additions:

- Data file output so that values can be input to a spreadsheet for further analysis or display.
- Additional surface fire fuel models with dynamic load transfer feature.
- A fire characteristics chart 'tool' that allows more user control over display of plotted rate of spread, heat per unit area, fireline intensity, and flame length (Andrews and Rothermel 1982).
- Output table shading options to aid prescribed fire planning.
- Models for transition to crown fire and crown fire spread rate.
- Models for post-frontal combustion, intensity, consumption, and smoke production.

6. REFERENCES

- Albini, F.A. 1979. Spot fire distance from burning trees—a predictive model. USDA Forest Service, Gen. Tech. Rep. INT-56, 73 pp.
- Albini, F.A. 1981. Spot fire distance from isolated sources—extensions of a predictive model. USDA Forest Service, Res. Note INT-309, 9 pp.
- Albini, F.A. 1983. Potential spotting distance from wind-driven surface fires. USDA Forest Service, Res. Pap. INT-309, 27 pp.
- Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. USDA Forest Service, Gen. Tech. Rep. INT-122, 22 pp.
- Anderson, H.E. 1983. Predicting wind-driven wild land fire size and shape. USDA Forest Service, Res. Pap. INT-305, 26 pp.
- Andrews, P.L. 1986. BEHAVE: fire behavior prediction and fuel modeling system--BURN subsystem, Part 1. USDA Forest Service Gen. Tech. Rep. INT-194. 130 pp.
- Andrews, P.L., C.D. Bevins, and R.C. Seli. 2003. BehavePlus fire modeling system, version 2.0: User's Guide. USDA Forest Service Gen. Tech. Rep. RMRS-GTR-106WWW. 132 pp.
- Andrews, P.L. and L.S. Bradshaw. 1990. RXWINDOW: Defining windows of acceptable burning conditions based on desired fire behavior. USDA Forest Service, Gen. Tech. Rep. INT-273. 54 pp.
- Andrews, P.L., C.H. Chase. 1989. BEHAVE: fire behavior prediction and fuel modeling system--BURN subsystem, Part 2. USDA Forest Service, Gen. Tech. Rep. INT-260. 93 pp.
- Andrews, P.L. and R.C. Rothermel. 1982. Charts for interpreting wildland fire behavior characteristics. USDA Forest Service, Gen. Tech. Rep. INT-131. 21 pp.
- Burgan, R.E. and R.C. Rothermel. 1984. BEHAVE: fire behavior prediction and fuel modeling system—FUEL subsystem. USDA Forest Service, Gen. Tech. Rep. INT-167. 126 pp.
- Butler, B.W. and J.D. Cohen. 1998. Firefighter safety zones: a theoretical model. *Int. J. of Wildland Fire* 8(2):73-77.
- Byram, G.M. 1959. Combustion of forest fuels. In: Davis, K.P., ed. *Forest fire control and use*. New York. McGraw-Hill.
- Finney, M.A. 1998. FARSITE: Fire Area Simulator—model development and evaluation. USDA Forest Service, Res. Pap. RMRS-RP-4. 47 pp.
- Finney, M.A. 2003. Calculation of fire spread rates across random landscapes. *Int. J. of Wildland Fire*. 12:167-174.
- Fried, J.S. and B.D. Fried. 1996. Simulating wildfire containment with realistic tactics. *Forest Science*. 42(3):267-281
- Fujioka, F.M. 1985. Estimating Wildland fire rate of spread in a spatially non-uniform environment. *Forest Science*. 31(3):21-29.
- Hough, W.A. and F.A. Albini. 1978. Predicting fire behavior in palmetto-gallberry fuel complexes. USDA Forest Service, Res. Pap. SE-174. 44 pp.
- Latham, D.J. and J.A. Schlieter. 1989. Ignition probabilities of wildland fuels based on simulated lightning discharges. USDA Forest Service, Res. Pap. INT-411. 16 pp.
- Rothermel, R.C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA Forest Service, Res. Pap. INT-115. 40pp.
- Rothermel, R.C. 1983. How to predict the spread and intensity of forest and range fires. USDA Forest Service, Gen. Tech. Rep. INT-143. 161 pp.
- Ryan, K.C. and E. Reinhardt. 1988. Predicting post-fire mortality of seven western conifers. *Canadian J. of For. Res.* 18:1291-1297.
- Schroeder, M.J. 1969. Ignition probability. USDA Forest Service. Fort Collins, CO. RMRS unpublished report.
- Van Wagner, C.E. 1973. Height of crown scorch in forest fires. *Can. J. of For. Res.* 3:373-378.

7. ACKNOWLEDGMENTS

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