

## ***Introduction***

This lesson, providing a general overview of the BehavePlus fire modeling system, is based on 'BehavePlus fire modeling system: past, present, and future' presented at the 7<sup>th</sup> Symposium on Fire and Forest Meteorological Society, October 2007. The paper is available on the BehavePlus Publications page of [www.firemodels.org](http://www.firemodels.org). It is appropriate to provide that paper as a handout.

## ***Objectives***

1. Understand the relationship of BehavePlus to other fire behavior systems: FlamMap, FARSITE, and FSPRo.
2. Understand the relationship of BEHAVE to BehavePlus.
3. See an overview of the fire modeling capabilities of BehavePlus.
4. See ideas regarding the future of BehavePlus.

## ***Where This Lesson Fits In***

This lesson is the first in the Overview Unit. It is a PowerPoint lesson. This is not a hands-on lesson; therefore the BehavePlus program is not run.

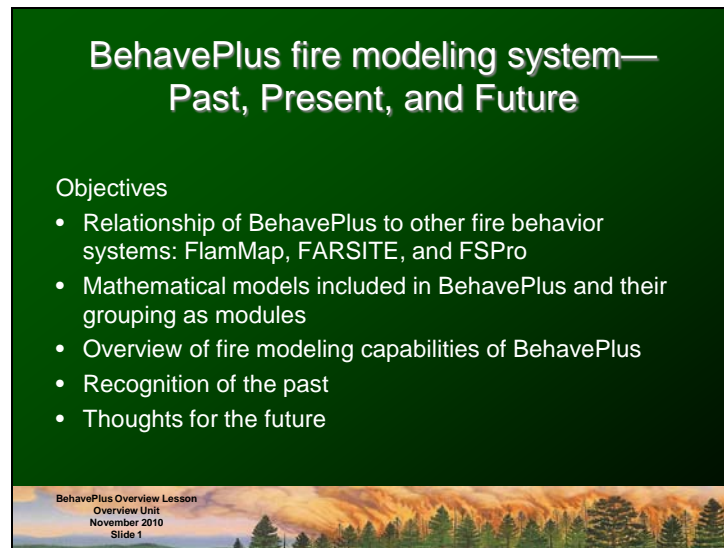
As a self-study, a person can view the PowerPoint slides in **Normal** mode to see the notes associated with each slide.

Following are the notes in a form that a presenter can use when showing the **Slide Show**.

## ***Lesson Changes: V4.0 to V5.0***

Changes to the BehavePlus program required some minor changes to this lesson. We updated the headers and footers, but did not redo many of the screen captures labeled BehavePlus 4.0.0.

## Slide 1

The slide has a dark green background with white text. The title is centered at the top. Below it, the word 'Objectives' is followed by a bulleted list. At the bottom, there is a small horizontal image of a forest fire with smoke, and text to its left.

**BehavePlus fire modeling system—  
Past, Present, and Future**

Objectives

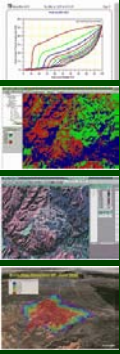
- Relationship of BehavePlus to other fire behavior systems: FlamMap, FARSITE, and FSPro
- Mathematical models included in BehavePlus and their grouping as modules
- Overview of fire modeling capabilities of BehavePlus
- Recognition of the past
- Thoughts for the future

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Slide 1

- This lesson is based on a presentation to the 7th Symposium on Fire and Forest Meteorological Society, October 2007.
- A paper related to this presentation is available on the BehavePlus publications page of [www.firemodels.org](http://www.firemodels.org)
- We will start with a brief discussion of the relationship of BehavePlus to other fire behavior systems: FlamMap, FARSITE, and FSPro.
- We will then demonstrate how mathematical models are grouped together as modules in BehavePlus.
- A brief overview of the fire modeling capabilities of BehavePlus will be given.
- I will then say a few words about the history of BEHAVE, which is now BehavePlus.
- And we have some thoughts for the future of BehavePlus and other systems.

## Slide 2

### Suite of fire behavior systems

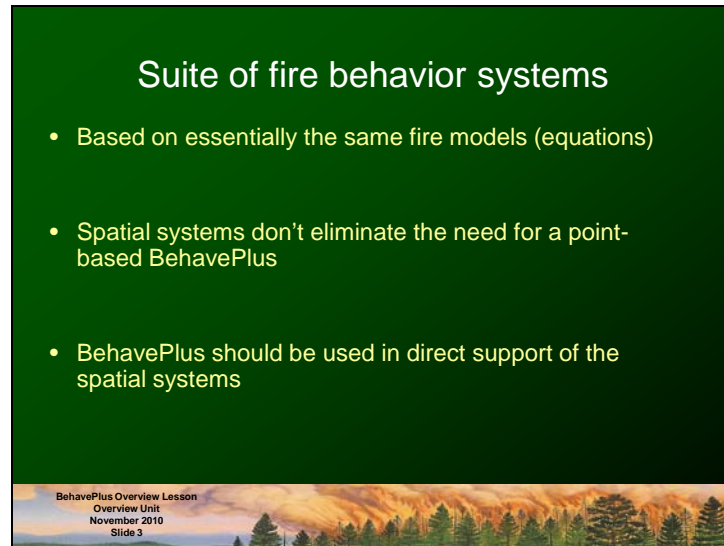


- BehavePlus fire modeling system
- FlamMap fire behavior mapping and analysis system
- FARSITE fire area simulator
- FSPro fire spread probabilities

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- We start with the question of whether BehavePlus even has a future given the availability of the more sophisticated spatial systems.
- The simple answer is 'yes'.
- We will start with a brief overview of the relationship of BehavePlus to these other fire behavior systems, which we call a 'suite of fire behavior systems'.

## Slide 3



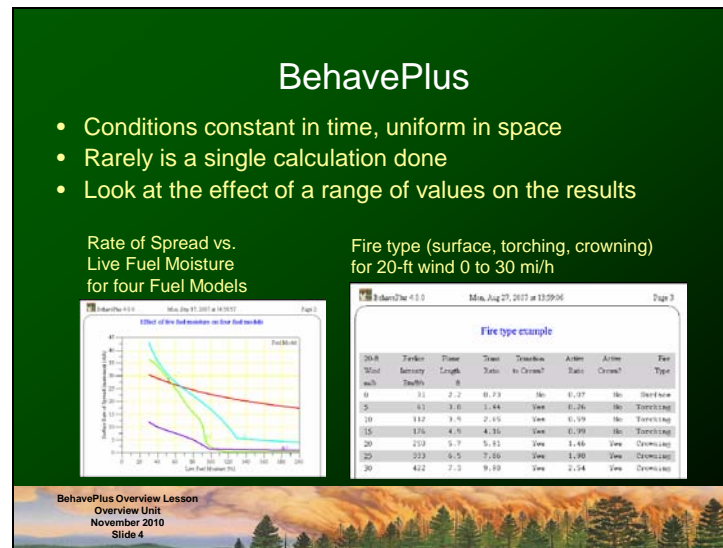
**Suite of fire behavior systems**

- Based on essentially the same fire models (equations)
- Spatial systems don't eliminate the need for a point-based BehavePlus
- BehavePlus should be used in direct support of the spatial systems

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Slide 3

- We call this a 'suite of fire behavior systems' because they are all based on essentially the same mathematical fire models (the equations that form the basis of the systems).
- The spatial systems don't eliminate the need for the point-based BehavePlus fire modeling system.
- In fact, the value of BehavePlus might be increased because it should be used in direct support of the spatial fire behavior systems.
- A person should use the tables and graphs produced by BehavePlus to understand the models (e.g. crown fire, wind adjustment factor).
- Then the user can focus on spatial data and application of the spatial systems.

## Slide 4

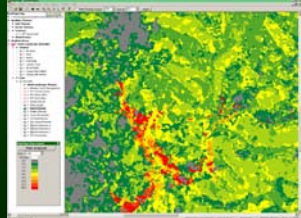


- While the fire models at the foundation of the systems are essentially the same, there are differences in temporal and spatial aspects of the systems.
- Each calculation in BehavePlus is for conditions that are assumed to be constant in time and uniform in space.
- It is sometimes referred to as a 'point' system because these conditions are static for a given run.
- But rarely is a single calculation done.
- Tables and graphs are used to look at the effect of a range of values on the results.
- The plot on the left shows calculated surface fire rate of spread for live fuel moisture from 30 to 300% for four fuel models.
- This graph shows the implications of choice of fuel model in spatial fuel model data layers.
- The table on the right shows fire type (surface, torching, crowning) for 20-ft wind speeds ranging from 0 to 30 mi/h.

## Slide 5

## FlamMap

- Adds the spatial component
- Point calculations are done for each pixel
- Conditions are constant in time, but vary in space for basic options
- Also minimum travel time and  
fuel treatment optimization options



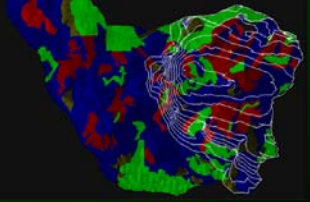
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Slide 5

- FlamMap adds the spatial component.
- For the basic FlamMap products, point calculations are done for each pixel. It is as if an independent BehavePlus run is performed for each pixel.
- The calculations for a given point (cell or pixel) are independent of neighboring cells.
- Conditions (fuel, wind, and fuel moisture) are constant in time, but vary in space.
- FlamMap now offers features beyond the basic products just described.
- It includes calculation of minimum travel time and fuel treatment optimization options.


## Slide 6

## FARSITE

- Conditions vary in both space and time
- Fire growth simulation
- Fire perimeter projection
- The fire behavior in a pixel depends on the adjoining pixels and the time of day that it burned



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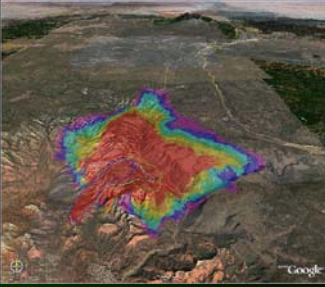


- FARSITE has the spatial features of FlamMap but adds an additional temporal component.
- Therefore, conditions vary in both space and time.
- The result is a fire growth simulation which gives fire perimeter projections.
- The fire behavior in a given pixel depends on where the fire came from, whether it is a backing or head fire, and the conditions under which it burned, which can vary by time of day.

## Slide 7

### FSPro

- Produces hundreds or thousands of fire growth simulations
- Simulates seasonal weather from fire danger climatology
- The probability of the fire reaching each point from the known fire perimeter during the specified simulation duration (e.g. 14 days)
- **Not** fire perimeter probability




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- FSPro has the temporal and spatial features of FARSITE, but adds an additional probability component.
- Results are based on hundreds or thousands of fire growth simulations.
- Each simulation is driven by simulated seasonal weather which is derived from fire danger climatology.
- This is a means of projecting beyond available weather forecasts.
- The result is **not** a fire perimeter probability. It is rather the probability of the fire reaching each point from the known perimeter during the simulated time.

## Slide 8

### BehavePlus -- Past

- The old BEHAVE system consisted of 5 programs
  - BURN subsystem: FIRE1, FIRE2, RxWindow
  - FUEL subsystem: NEWMDL, TSTMDL




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- We have just two slides on the 'past' of BehavePlus. There is much more information in the paper.
- The BehavePlus system replaces the 5 programs that made up the old BEHAVE fire behavior prediction and fuel modeling system.
- BEHAVE was first available for field application in 1984, when computer technology made it possible.

## Slide 9

1984 –  
BEHAVE fire behavior prediction and fuel modeling system  
Silent 700 remote terminals  
“Are you using a computer with a screen?”  
... **NO** ...



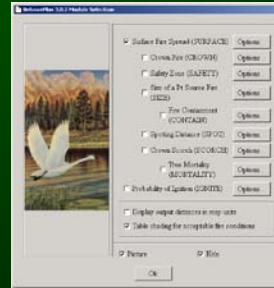
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- The BEHAVE programs had the question “Are you using a computer with a screen?”
- Can you imagine answering ‘No’? (I’m sure that some of you can.)
- The answer of ‘No’ put the program into the ‘terse’ mode where fewer words were typed on the paper.

## Slide 10

- Fire Models are grouped into Modules

- SURFACE – Surface fire spread
- CROWN – Crown fire
- SAFETY – Safety zone size
- SIZE – Size of a point source fire
- CONTAIN – Fire containment
- SPOT – Spotting distance
- SCORCH – Crown scorch
- MORTALITY – Tree mortality
- IGNITE – Probability of ignition



- 'BEHAVE' is not equal to 'Rothermel's fire model'

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- And now, back to the 'present'.
- A number of things have changed since 1984.
- The many fire models in BehavePlus are grouped according to modules.
- BEHAVE or BehavePlus is sometimes incorrectly used as a synonym for Rothermel's surface fire spread model.
- However, that is only one of the models in BehavePlus (although a very important one).

## Slide 11

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

41 models, 44 references

BehavePlus Module	Model	Reference and notes
SURFACE	Surface heat flux rate of spread, reaction intensity, fuel air unit, area, characteristics dead fuel moisture, live fuel moisture of extinction, etc.	(Rothermel 1972) (Abbin 1978a) minor adjustments
	Flame intensity	(Byram 1955) with adjustments to work with Rothermel's surface fire spread model by (Abbin 1978a)
	Flame length	(Abbin 1978a)
	Surface fire flame residence time (used to calculate flame intensity)	(Abbin 1978a)
	Direction of maximum spread	(Rothermel 1981) using empirical weighting (Rothermel 1981) (Finney 1988) calculations based on Rothermel's wind and slope factors
	Fire characteristics chart, relationship among rate of spread, heat per unit area, flame intensity, and flame length	(Finney 1988)
	Spread in direction from ignition point from a point source fire	(Andrews 1986)
	Effective wind speed	(Abbin 1978a)
	Wind adjustment factor	(Abbin and Baughman 1979, Baughman and Abbin 1980, Rothermel 1981)
	Wind speed at 10 m adjusted to 20 ft	(Cramer and Jensen 1978)
	13 standard fire behavior fuel models	(Rothermel 1972) 11 fuel models (Abbin 1978a) eight revision of the 11 plus two new fuel models (Anderson 1982) fuel model selection guide
	All standard fire behavior fuel models	(Cramer and Burgen 2003)
	Custom fire behavior fuel models	(Burgen and Rothermel 1984, Burgen 1987)
	Dynamic fuel load transfer	(Burgen 1979) (Burgen and Rothermel 1984, Andrews 1986, as used in BEHAVE) (Cramer and Burgen 2003) as used in the 2005 standard fire behavior fuel models
	Two fuel models, weighted rate of spread	(Rothermel 1983)
	Two fuel models, harmonic mean	(Fujikura 1985)
	Two fuel models, 2-dimensional expected spread	(Finney 2003)
	Parimeter gallery special case fuel model	(Hough and Abbin 1978)
	Western aspen special case fuel model	(Brown and Zimmerman 1985) Brown and Chelius 1987 for mortality
CROWN	Critical surface intensity needed for transition from surface to crown fire	(Van Wagner 1977)
	Transition to crown fire, relationship of surface fire intensity and critical crown fire intensity	(Finney 1988) (Scott and Reinhardt 2001)
	Crown fire rate of spread, area, and perimeter	(Rothermel 1981)
	Critical crown fire rate of spread, needed for an active crown fire	(Van Wagner 1983)
	Active crown fire, relationship of crown fire rate of spread and critical crown fire rate of spread	(Finney 1988) (Scott and Reinhardt 2001)
	Fire spot surface, burning, conditional crown, crowning	(Finney 1988) (Scott and Reinhardt 2001)
	Crown fire flame length	(Thomas 1983)
	Crown fire intensity	(Rothermel 1981)
	Power of the fire, power of the wind	(Byram 1956)
SAFETY	Safety zone size, separation distance, radius	(Butler and Cohen 1980, 1989), et
SIZE	Edgeless fire size and shape, area, perimeter, length-to-width ratio	(Andrews 1982) inside ellipse (Andrews 1986) simplified to simple ellipse
CONTAIN	Fire containment	(Abbin and others 1978) in the old BEHAVE (Finney and Finney 1986) in BehavePlus
SPOT	Spotting distance from burning trees	(Abbin 1978, Chase 1991)
	Spotting distance from a burning pile	(Abbin 1981)
	Spotting distance from a wind-driven surface fire	(Abbin 1983a, Abbin 1983b, Chase 1994)
SCORCH	Crown scorch height	(Van Wagner 1973)
MORTALITY	Tree mortality	(Byram and Reinhardt 1988, Reinhardt and Crockett 2001) Hood, S., S. Smith, D. Cook, E. Reinhardt, and J. Ryan, 2003, updates for version 5.0
	Bark thickness	(Byram and Reinhardt 1988, Reinhardt and Crockett 2001)
IGNITE	Probability of ignition from firebrand	(Zemmel 1980)
	Probability of ignition from lightning	(Latham and Schreier 1985)
	Fire dead fuel moisture letters	(Rothermel 1983)
	Fire dead fuel moisture	
	Test	



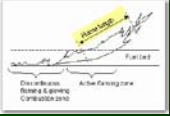
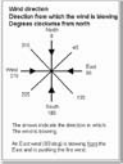
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- The paper includes a table of the 41 mathematical models included in BehavePlus.
- It is not important that you can't read the words in this slide.
- The number of models depends on how you count.
- The 53 standard fuel models were counted as one model.
- Rothermel's surface fire spread model also counts as one model, although the model has many possible outputs.
- The main point of this discussion is that BehavePlus is much more than Rothermel's model.
- These *models* are grouped as *modules* for ease of application.

## Slide 12

• **SURFACE module**

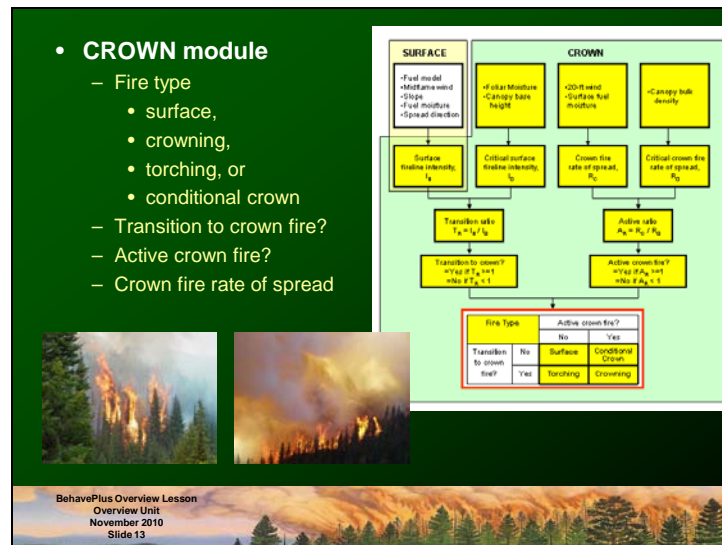
- Surface fire spread and intensity
- Wind / slope / spread direction
- Wind adjustment factor
- Fuel models
  - 53 standard (13 + 40)
  - Custom
- etc.

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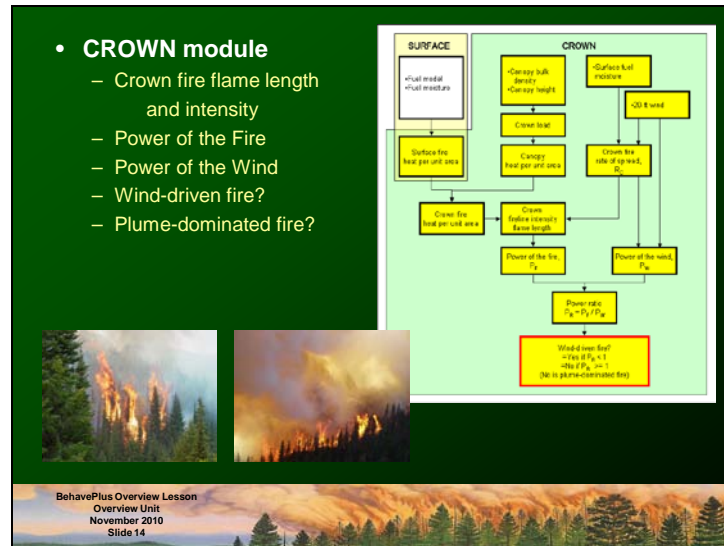
- Following is a quick overview of the fire modeling capabilities in each of the modules:
- The SURFACE module is used to calculate surface fire spread and intensity.
- It includes many models and offers many options. It is the core of the BehavePlus fire modeling system.
- There are options for wind, slope, and fire spread directions.
- The wind adjustment factor (which reduces 20-ft wind to midflame wind) can be calculated.
- The 53 standard fuel models are available.
- Custom fuel models can be developed and saved.
- And more...

## Slide 13



- The CROWN module calculates fire type: surface, torching, conditional crown, or crown.
- Conditions indicate whether a fire will transition from surface to crown fire and whether an active crown fire is possible.
- Crown fire rate of spread can be estimated.

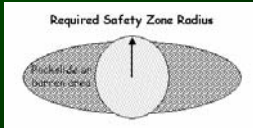


## Slide 14



- The CROWN module also calculates crown fire flame length and intensity.
- Power of the fire and power of the wind are calculated.
- Guidance is given on whether the fire might be wind-driven or plume-dominated.

## Slide 15

- **SAFETY module**
  - Safety zone size
    - Area
    - Radius
    - Separation distance
  - Based on flame length

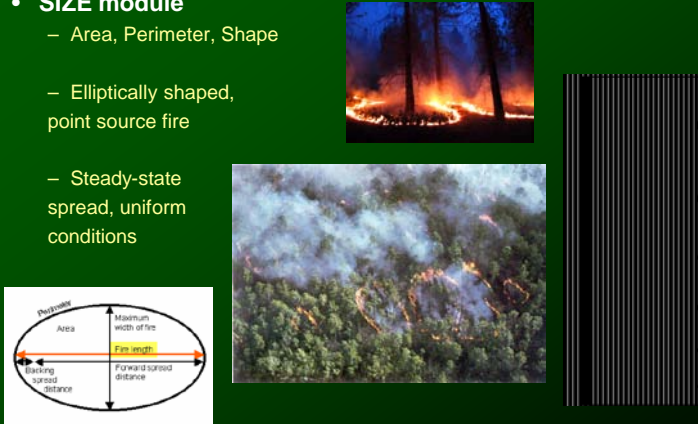


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- The SAFETY module is used to calculate safety zone size, which is estimated from flame length.

## Slide 16

- **SIZE module**
  - Area, Perimeter, Shape
  - Elliptically shaped, point source fire
  - Steady-state spread, uniform conditions




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- The SIZE module calculates fire size and shape for a point source, elliptically shaped fire.
- The modeling is applicable only when conditions are close to uniform in both space and time.

## Slide 17

- **CONTAIN module**
  - Containment of an elliptically shaped fire
    - Arrival time
    - Duration
    - Line production rate
  - Containment success
    - Time to containment
    - Final fire size
    - Fireline constructed


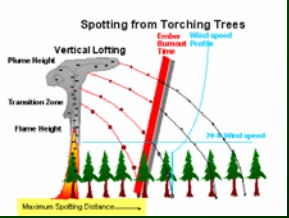



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- The CONTAIN module is especially useful for contingency planning for prescribed fire.
- The success of containment is modeled for given fire behavior and resource availability.
- There are options on number of resources, arrival time, line production rate, and so on.

## Slide 18

- **SPOT module**
  - Maximum spotting distance from
    - Torching trees
    - Burning pile
    - Wind-driven surface fire



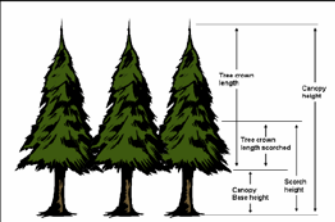


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- The SPOT module calculates maximum spotting distance from torching trees, from a burning pile, or from a wind-driven surface fire.

## Slide 19

- **SCORCH module**
  - Scorch height from surface fire flame length
- **MORTALITY module**
  - Probability of tree mortality
  - From crown scorch

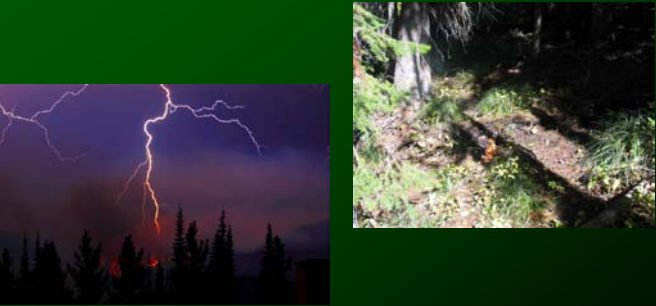


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- The SCORCH module calculates scorch height from surface fire flame length and from wind speed (as it affects flame tilt).
- The MORTALITY module calculates the probability of tree mortality primarily from crown scorch.
- The mortality models were updated for some species in Version 5.0.

Slide 20

- **IGNITE module**
  - Probability of ignition by firebrand
  - Probability of ignition by lightning

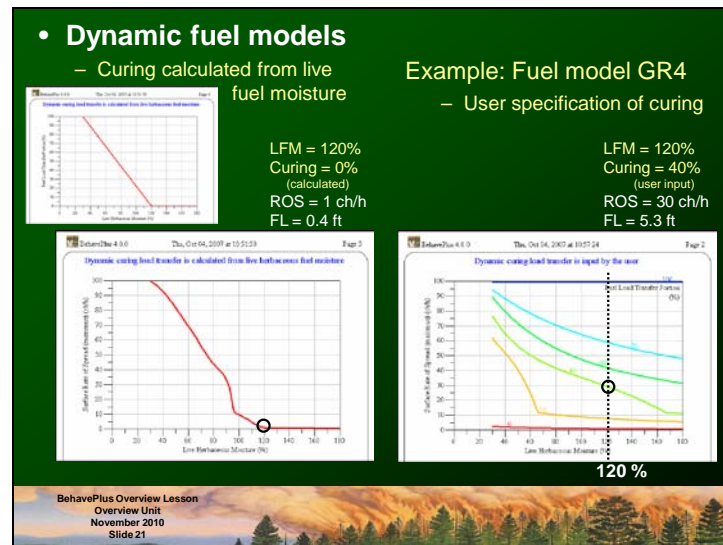


The slide features two photographs. The left photograph shows a bright lightning bolt striking a forest of evergreen trees at night. The right photograph is a close-up of a firebrand, a small piece of burning wood, lying on a forest floor covered with grass and fallen leaves.

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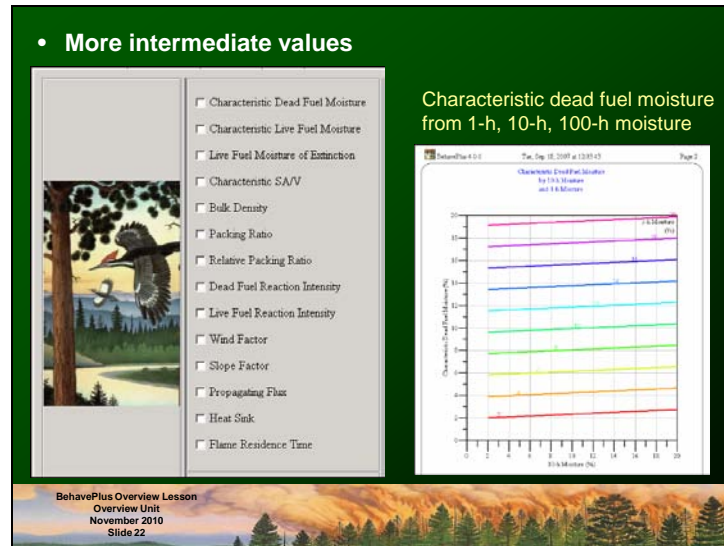
- The IGNITE module calculates probability of ignition from either a firebrand or from a lightning strike.

## Slide 21



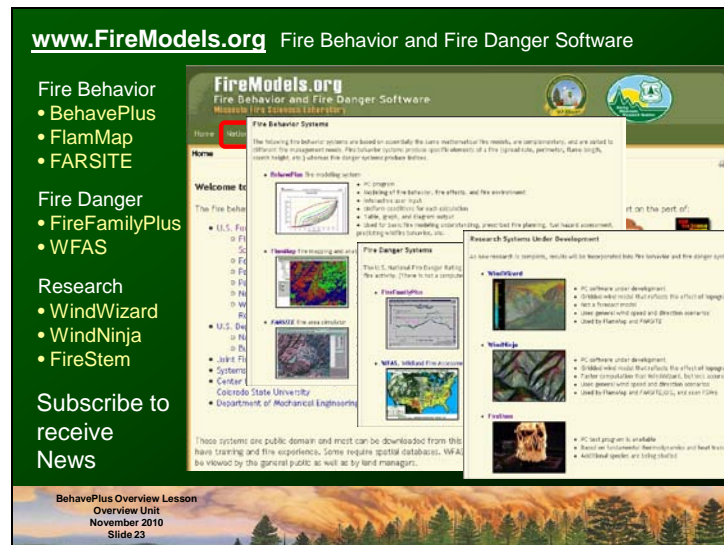
- One of the options added to version 4 is related to the dynamic fuel models. Some of the newer 40 fuel models include a transfer of load from the live to the dead class as a function of live fuel moisture as shown by the plot in the upper left graph.
- This can have a significant effect on fire behavior. The second plot shows calculated surface rate of spread for the grass fuel model GR4 for live herbaceous moisture from 30 to 180%.
- The black circle indicates the point where live fuel moisture (LFM) is 120%. According to the fuel load transfer function, curing is calculated to be 0%. No fuel is transferred to the dead category.
- In this case, rate of spread is 1 ch/h and flame length is less than ½ foot.
- You now have the option of entering a value for curing if you know it, rather than using the load transfer function.
- The graph on the right shows a curve for six values of curing: 0, 20, 40, 60, 80, and 100%.
- The circle indicates the point where live fuel moisture is 120% (as before) but with the user specification that curing is 40%.
- In this case, rate of spread is 30 ch/h and flame length is 5.3 ft.
- This is a huge difference (an understatement).
- This is an example of the importance of a person understanding the implication of choices and of the influence of various factors on results.
- BehavePlus will help you understand the models and influence of input values on results.

## Slide 22



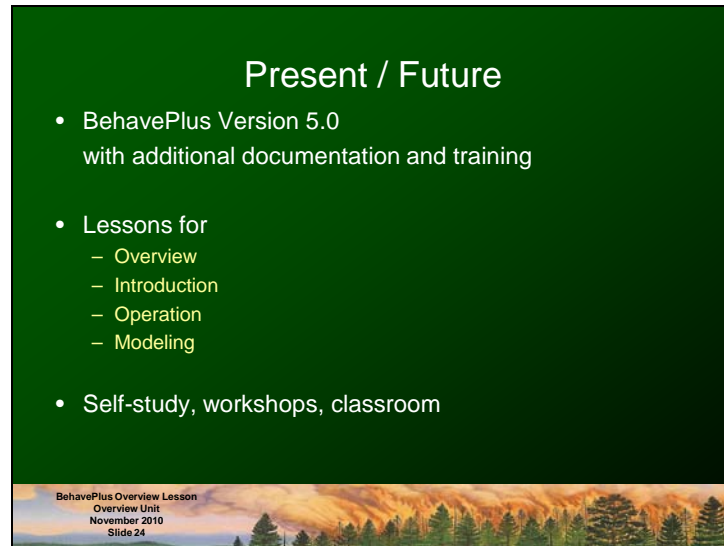
- Version 4 added more intermediate output variables.
- This is especially useful for someone who wants to better understand Rothermel's surface fire spread model.
- One of the intermediate values is characteristic dead fuel moisture, which is a weighted value of 1-h, 10-h, and 100-h moisture values.
- It can be used to assess the relative influence of 1-h and 10-h moisture.
- [A tip on this topic is available on [www.firemodels.org](http://www.firemodels.org)]

## Slide 23



- The latest information on BehavePlus and other fire behavior and fire danger systems is available on [www.firemodels.org](http://www.firemodels.org).
- The menu is near the top of the page; hovering on National Systems or Research Systems will open the menu.
- You can subscribe to receive news on the systems you are interested in.

## Slide 24



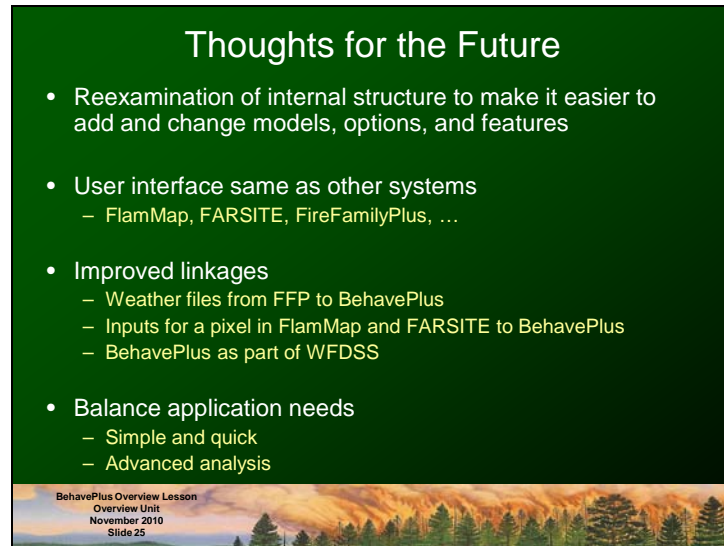
Present / Future

- BehavePlus Version 5.0  
with additional documentation and training
- Lessons for
  - Overview
  - Introduction
  - Operation
  - Modeling
- Self-study, workshops, classroom

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- We hope to have a stable, well-documented program for field application while options for future systems are examined.
- A series of lessons are available. More are being developed. This lesson is in the Overview Unit.
- The Introduction Unit includes 4 lessons which cover basic operation of the program.
- Other aspects of operation are covered in the Operation Unit (e.g., Table Shading, Units and Decimals).
- Various modeling capabilities are covered in the Modeling Unit.
- Specific applications are given in the Application Unit.
- Lessons can be completed as self-study or can be presented in a classroom.

## Slide 25



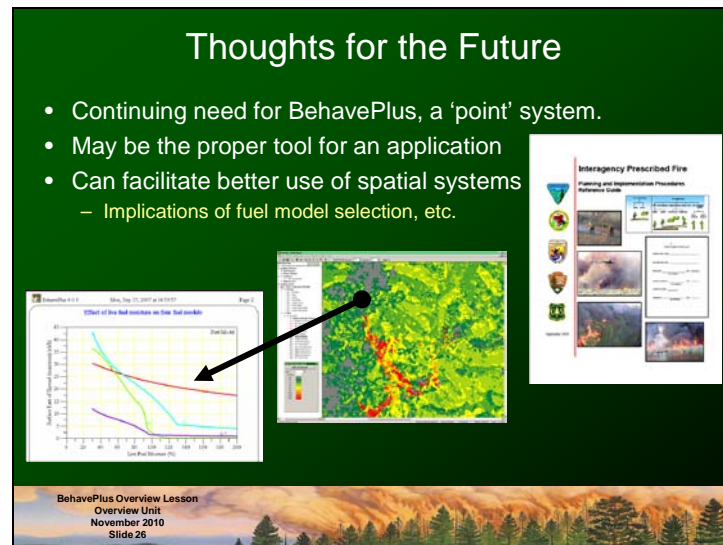
### Thoughts for the Future

- Reexamination of internal structure to make it easier to add and change models, options, and features
- User interface same as other systems
  - FlamMap, FARSITE, FireFamilyPlus, ...
- Improved linkages
  - Weather files from FFP to BehavePlus
  - Inputs for a pixel in FlamMap and FARSITE to BehavePlus
  - BehavePlus as part of WFDSS
- Balance application needs
  - Simple and quick
  - Advanced analysis

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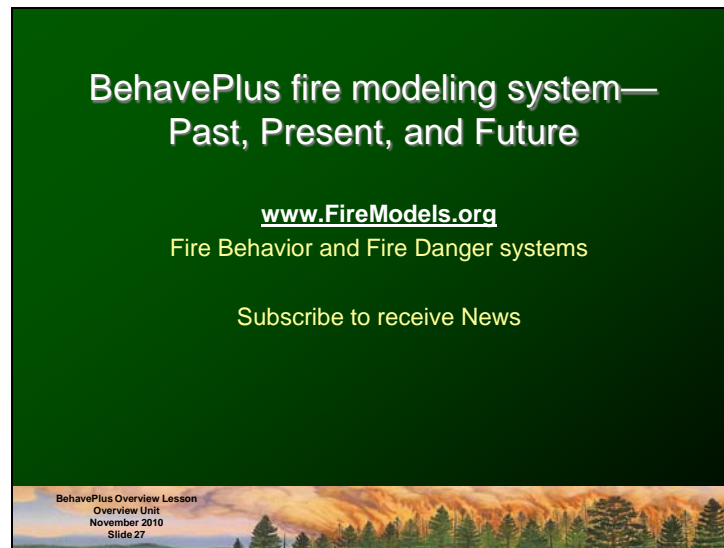
- In thinking about the future, there is a lot to think about.
- In the future, we may need to reexamine the internal structure of the model so that it is easier to make changes.
- Having a consistent user interface across the various fire behavior systems would make it easier for the user to move from one system to the next.
- It would also be helpful if input information from the various systems could be extracted in such a way that it could be used in a different system (e.g., extract inputs for a given FlamMap pixel for use in BehavePlus).
- There is always the challenge of satisfying people who want a program that is quick and easy to use as well as those who have need for more advanced analysis.

## Slide 26



- In addition to using BehavePlus to understand the models in the spatial systems, specific direct linkages between the models might be developed.
- For example, a click on a pixel could provide the input to BehavePlus for further analysis – assigning values for fuel model, fuel moisture, slope, etc.
- This example shows the implication of other fuel models and live fuel moisture on calculated fire behavior.
- Prescribed fire planning includes the need for fire modeling.
- The graphs, tables, and table shading options in BehavePlus are well-suited to this application.

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Past, Present, and Future

[www.FireModels.org](http://www.FireModels.org)  
Fire Behavior and Fire Danger systems

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Slide 27

The slide features a dark green background with white text. At the bottom, there is a horizontal strip showing a landscape with trees and a fire in the background. The text on the slide promotes the BehavePlus fire modeling system, provides the website URL, and encourages users to subscribe for news. A footer at the bottom left identifies the slide as part of the BehavePlus Overview Lesson, Overview Unit, dated November 2010, and labeled as Slide 27.