Sonoma Technology, Inc.
Air Quality Research and Innovative Solutions

Technical Memorandum

February 1, 2012 STI-910902-4341-TM

To: John Cissel, Joint Fire Science Program (JFSP)

From: Stacy A. Drury, Erin M. Banwell, and ShihMing Huang

Re: A Comparison of the Functionality in BehavePlus 5.0.5 and in IFTDSS Version 1.0

The Interagency Fuels Treatment Decision Support System (IFTDSS) is a software integration framework that provides a portal for existing fire and fuels software applications and makes them available through one user interface. IFTDSS Version 1.0 provides fire behavior modeling tools to support prescribed burn planning and the development of a burn plan document. A subset of the tools in IFTDSS includes the scientific algorithms and software modules that are available in BehavePlus. This memorandum compares the tools and functionality in BehavePlus 5.0.5 to the functionality implemented in IFTDSS Version 1.0.

BehavePlus is a powerful desktop software system for modeling fire behavior that has been in development for over 30 years. The intent of IFTDSS is not to reproduce the entire BehavePlus 5.0.5 user experience, but to make the scientific algorithms and models used by BehavePlus available through the IFTDSS application so that they can be used for prescribed burn planning and used in combination with other tools available within IFTDSS (i.e., burn plan document template and mapping tools).

We conducted extensive interviews with fuels treatment specialists who are responsible for planning prescribed burns. In working with this group, we determined that many of them use the modules in BehavePlus when preparing their prescribed burn plans. In response, we worked with a subset of the prescribed burn planning community to understand and prioritize the tools and associated functionality most important to the user community, and we then implemented those tools and functionality in IFTDSS.

Summary

In IFTDSS Version 1.0, eight of the nine software modules (available in BehavePlus 5.0.5) for simulating stand level fire behavior potentials—SURFACE, CROWN, IGNITE, SAFETY, SCORCH, SPOT, SIZE, and CONTAIN—have been implemented using the Fire Behavior Software Development Kit (FBSDK) code (http://www.fire.org) and BehavePlus code libraries provided by Collin Bevins with Systems for Environmental Management (SEM). The tree mortality module available in BehavePlus (MORTALITY) has not been implemented in IFTDSS; instead, tree mortality can be calculated in IFTDSS using the latest equations available in the First Order Fire Effects Model (FOFEM).

BehavePlus 5.0.5 provides six tools for estimating additional variables—fine dead fuel moisture, relative humidity, slope from map measurements, converting slope based distance measures to horizontal map distances, unit conversion—and a tool for creating Sun-Moon calendars. The unit conversion tool is the only one of these additional tools currently available in IFTDSS. The fine dead fuel moisture, relative humidity, slope from map measurements, converting slope based distances to horizontal map distance, and the creating Sun-Moon calendar tools are not available in IFTDSS Version 1.0 but are being considered for inclusion in future versions depending on end-user needs and feedback.

A comparison between the functionality available in BehavePlus 5.0.5 and the functionality available in IFTDSS for prescribed burn planning is summarized here to inform IFTDSS users of both the similarities and differences between IFTDSS and BehavePlus. Each module (as implemented in BehavePlus) was evaluated individually to identify the input and output options and to clarify linkages among individual modules. Next, the functionality of each module was compared to the functionality in IFTDSS Version 1.0. The concluding section of this memorandum outlines the BehavePlus functionality that has not been implemented in IFTDSS, discusses plans for including additional, planned BehavePlus functionality, and identifies areas where more discussion is needed to determine whether including unplanned BehavePlus functionality is warranted.

SURFACE Input Parameters

Table 1 shows the input and output options for the SURFACE module as implemented in IFTDSS Version 1.0.

Fire Behavior Fuel Models

BehavePlus 5.0.5 inputs fuel parameters using the fire behavior fuel model concept as described in Anderson (1982) and Scott and Burgan (2005). Users can select fire behavior fuel models from the original 13 (Anderson 1982), the more recent standard 40 (Scott and Burgan 2005), several special case fuel models (palmetto-gallberry, western aspen, and southern California chaparral), and the two-fuel model concept (2-D expected spread, harmonic mean, or area-weighted). BehavePlus has an additional feature that allows users to create and use custom fuel models that can be exported for use in other fire behavior modeling systems including FARSITE and Nexus.

IFTDSS currently supports the 13 fuel models from Anderson (1982) and the 40 fuel models from Scott and Burgan (2005). At this time, IFTDSS does not support custom fuel modeling, special case fuel models (palmetto-gallberry, western aspen, or southern California chaparral), the two-fuel models concept (2-D expected spread, harmonic mean, or area weighted), or exporting custom fuel model sets.

Table 1. SURFACE model input parameter comparison.

Module	Type	Choose One	Parameters	
			BehavePlus	**IFTDSS**
SURFACE (Inputs)	FFuel		Fuel models (standard or custom)	Fuel Models (standard *only*)
			Fuel parameters (custom modeling)	*Not implemented*
			Two fuel models (2-D expected spread)	*Not implemented*
			Two fuel models (harmonic mean)	*Not implemented*
			Two fuel models (area weighted)	*Not implemented*
			Special case fuel model (palmetto-gallberry)	*Not implemented*
			Special case fuel model (western aspen)	*Not implemented*
	Dynamic curing load transfer is		Calculated from live herbaceous fuel moisture	Calculated from live herbaceous fuel moisture
			Input directly	*Not implemented*
	Moisture	Moisture is entered by	Dead and live category	*Not implemented*
			Individual size class	Individual size class
			Moisture scenario	*Not implemented*
	Wind Speed	Wind speed is entered as	Midflame height	Midflame height
			20-ft wind and input WAF	*Not implemented*
			20-ft wind and calculated WAF	*Not implemented*
			10-m wind and input WAF	*Not implemented*
			10-m wind and calculated WAF	*Not implemented*
		Impose maximum reliable effective wind speed limit?	Yes	Yes
			No	*Not implemented*
	Directions	Surface fire spread direction is	Only in the direction of maximum spread	Only in the direction of maximum spread
			In directions specified on the worksheet	*Not implemented*
		Wind is	Specified on the worksheet	Specified on the worksheet
			Upslope	*Not implemented*
		Wind and spread directions are	Degrees clockwise from upslope	*Not implemented*
			Degrees clockwise from north	Degrees clockwise from north
	Slope steepness is		Specified as percent	Specified as percent
			Specified as degrees	*Not implemented*
			Specified on the worksheet	Specified on the worksheet
			Calculated from map measurements	*Not implemented*

Fuel Moisture Inputs

BehavePlus 5.0.5 allows for the direct input of fuel moisture values (percent dry weight) by fuel size class (1-hr, 10-hr, 100-hr, live herbaceous, live woody), by fuel status (live or dead), or by moisture scenarios (Scott and Burgan (2005) and user-defined custom scenarios).

In IFTDSS Version 1.0, moisture is entered by individual size classes. IFTDSS does not currently support moisture scenarios or direct input of moisture by live and dead fuel categories.

Dynamic Curing Load Transfer

BehavePlus 5.0.5 utilizes the dynamic curing load transfer concept described by Scott and Burgan (2005). In this concept, the live herbaceous fuel loading is slowly transferred from the live to dead category as the fuel ages seasonally. Seventeen of their standard 40 fire behavior fuel models are dynamic. BehavePlus provides two methods for determining the proportion of live herbaceous fuel loading to dead fuel loading:

1. Based on live herbaceous fuel moisture, with the assumption that as live fuel dries it behaves more like dead fuel
2. Based on percentage live and dead fuel load as input directly by the user

IFTDSS currently supports dynamic curing load transfer calculated from live herbaceous fuel moisture, but it does not allow the transfer of live fuel load to dead fuel load to be input directly.

Wind Speed

In BehavePlus 5.0.5, wind speed can be entered for a number of heights above ground including the midflame height, the 20-ft wind speed with a user-supplied wind speed adjustment factor (WAF), 20-ft wind speed using a default-calculated wind speed adjustment factor, 10-m wind speed with user-supplied wind adjustment factor, and a 10-m wind speed with a calculated wind speed adjustment factor. BehavePlus also provides the option of either imposing a maximum wind speed effectiveness limit or not. If this option is implemented, wind speeds above a designated maximum reliable wind speed (based on reaction intensity) are lowered to the maximum reliable wind speed.

IFTDSS currently supports midflame wind speed but does not give the user the option of entering 20-ft or 10-m wind speeds with input WAF or calculated WAF. IFTDSS always uses the maximum reliable effective wind speed.

Directions

BehavePlus 5.0.5 provides several options for inputting wind and fire spread directions. Surface fire spread direction can be entered as the direction of maximum spread as calculated by BehavePlus or can be entered by the user. Wind direction can be selected as upslope or can be specified by the user. Both wind direction and fire spread direction can be modified so the user can enter the values as degrees clockwise from north or can be entered as degrees clockwise from upslope.

IFTDSS Version 1.0 supports surface fire spread direction in the direction of maximum spread. In addition, the user can specify to receive fire behavior output for backing fire (180 degrees from direction of maximum spread) or flanking fire (30, 45, 60 or 90 degrees from the

direction of maximum spread). At this time, wind direction is specified in degrees from north with no option to have winds traveling in an upslope direction.

Slope

BehavePlus 5.0.5 allows users to enter slope values directly in degrees or as percent. In addition, in BehavePlus, slope can be calculated from map measurements.

IFTDSS Version 1.0 supports the use of percent as a measure of slope steepness. Percent values are entered directly by the user. The option for manually entering slope in degrees or calculating slope steepness using map measurements has not been implemented.

SURFACE: Basic Output Parameters

Table 2 shows the BehavePlus 5.0.5 SURFACE outputs compared to the output parameters in IFTDSS. The SURFACE module produces a set of nine standard fire behavior output parameters: surface rate of spread, heat per unit area, fireline intensity, flame length, reaction intensity, direction of maximum spread, surface spread distance, a wind/slope/spread direction diagram, and a fire characteristics chart.

Table 2. SURFACE standard output parameter comparison.

Module	Type	Parameters	
		BehavePlus	**IFTDSS**
SURFACE (Outputs)	Standard	Surface Rate of Spread	Surface Rate of Spread (head)
			Surface Rate of Spread (backing)
			Surface Rate of Spread (flanking)
		Heat per Unit Area	Heat per Unit Area
		Fireline Intensity	Fireline Intensity (head)
			Fireline Intensity (backing)
			Fireline Intensity (flanking)
		Flame Length	Flame Length (head)
			Flame Length (backing)
			Flame Length (flanking)
		Reaction Intensity	Reaction Intensity
		Direction of Maximum Spread	Direction of Maximum Spread (head)
			Direction of Maximum Spread (backing)
		Surface Spread Distance	Surface Spread Distance (head)
			Surface Spread Distance (backing)
			Surface Spread Distance (flanking)
		Wind/Slope/Spread Direction Diagram	*Not implemented*
		Fire Characteristics Chart	*Not implemented*

IFTDSS Version 1.0 currently supports seven of the nine standard fire behavior outputs - surface rate of spread, heat per unit area, fireline intensity, flame length, reaction intensity, direction of maximum spread, and surface spread distance for backing and flanking fires in addition to the head fire estimates provided by BehavePlus.

SURFACE: Other Output and Intermediate Values

SURFACE in BehavePlus 5.0.5 provides access to several optional and intermediate outputs related to adjusting wind speeds, editing and producing custom fuel models, and calculating the standard fire behavior outputs (**Table 3**).

BehavePlus 5.0.5 allows users to enter alternative values for wind speed such as 10-m wind speeds. Currently, IFTDSS supports the use only of midflame wind speeds for calculating fire behavior predictions. Many of the wind speed output parameters not included in IFTDSS, such as outputting midflame wind speed, depend on additional input values that are also not currently implemented in IFTDSS. For example, to have midflame wind speed as an output in BehavePlus, an alternative wind speed value such as 10-m winds is needed as BehavePlus calculates the midflame wind speed based on the 10-m wind speed.

IFTDSS currently does not support fuel model editing or the creation of custom fuel models, so there are no outputs for the custom fuel variables shown in Table 3.

Table 3. SURFACE other output and intermediate parameter comparison.

Module	Type	Parameters	
		BehavePlus	**IFTDSS**
SURFACE (Outputs)	Wind	Midflame Wind Speed	*Not implemented*
		Wind Adjustment Factor	*Not implemented*
		Crown Ratio	*Not implemented*
		Crown Fill Portion	*Not implemented*
		WAF Calculation	*Not implemented*
		Effective Wind Speed	Effective Wind Speed
		Effective Wind Speed Limit	*Not implemented*
		Maximum Effective Wind Exceed	*Not implemented*
	Slope outputs from map measurement calculations	Slope Steepness	*Not implemented*
		Slope Elevation Change	*Not implemented*
		Slope Horizontal Distance	*Not implemented*
	Fuel	Fuel Load Transfer Portion	*Not implemented*
		Dead Herbaceous Fuel Load	*Not implemented*
		Live Herbaceous Fuel Load	*Not implemented*
		Total Dead Fuel Load	*Not implemented*
		Total Live Fuel Load	*Not implemented*
		Dead Fuel Load Portion	*Not implemented*
		Live Fuel Load Portion	*Not implemented*
	Aspen	1-h Fuel Load	*Not implemented*
		Live Herbaceous Fuel Load	*Not implemented*
		Live Woody Fuel Load	*Not implemented*
		1-h SA/V	*Not implemented*
		Live Woody SA/V	*Not implemented*
		Probability of Aspen Mortality	*Not implemented*
	Palmetto-gallberry	P-G Dead Fine Fuel Load	*Not implemented*
		P-G Dead Medium Fuel Load	*Not implemented*
		P-G Dead Foliage Fuel Load	*Not implemented*
		P-G Live Fine Fuel Load	*Not implemented*
		P-G Live Medium Fuel Load	*Not implemented*
		P-G Live Foliage Fuel Load	*Not implemented*
		P-G Litter Fuel Load	*Not implemented*
		Fuel bed depth	*Not implemented*
SURFACE (Intermediates)	Intermediates	Characteristic Dead Fuel Moisture	*Not implemented*
		Characteristic Live Fuel Moisture	*Not implemented*
		Live Fuel Moisture of Extinction	*Not implemented*
		Characteristic SA/V	*Not implemented*
		Bulk Density	*Not implemented*
		Packing Ratio	*Not implemented*
		Relative Packing Ratio	*Not implemented*
		Dead Fuel Reaction Intensity	*Not implemented*
		Live Fuel Reaction Intensity	*Not implemented*
		Wind Factor	*Not implemented*
		Slope Factor	*Not implemented*
		Heat Source	*Not implemented*
		Heat Sink	*Not implemented*
		Flame Residence Time	Flame Residence Time

CROWN Comparisons

Crown Input Parameters

Table 4 shows the CROWN module input options in BehavePlus 5.0.5 and the IFTDSS input parameters. Thirteen of fourteen CROWN module input parameters found in BehavePlus are also in IFTDSS. The one exception is that in BehavePlus, the user is provided the option of representing surface fire intensity using either flame length or fireline intensity (which is calculated from flame length). IFTDSS does not currently support the option of using fireline intensity as the input for surface fire intensity; instead, the user is required to enter flame length.

Table 4. CROWN input parameter comparison.

Module	Type	Choose One	Parameters	
			BehavePlus	**IFTDSS**
CROWN	Input Options	Surface fire intensity is entered as	Flame Length	Flame Length
			Fireline Intensity	*Not implemented*
	Inputs		Canopy Height	Canopy Height
			Canopy Base Height	Canopy Base Height
			Canopy Bulk Density	Canopy Bulk Density
			1-h Moisture	1-h Moisture
			10-h Moisture	10-h Moisture
			100-h Moisture	100-h Moisture
			Live Woody Moisture	Live Woody Moisture
			Foliar Moisture	Foliar Moisture
			20-ft Wind Speed	20-ft Wind Speed
			Heat per Unit Area	Heat per Unit Area
			Flame Length	Flame Length
			Elapsed Time	Elapsed Time

An additional difference between CROWN in BehavePlus and the model implementation within IFTDSS is that two input parameters that are needed to run the crown fire module; heat per unit area and flame length (or fireline intensity if that option is used) can come directly from the SURFACE module. In fact, if the user chooses to run CROWN concurrently with SURFACE in BehavePlus, BehavePlus automatically populates the heat per unit area and flame length CROWN inputs with the SURFACE outputs. In IFTDSS, the user is instructed to run the surface fire behavior module first and then input the surface module output parameters into the crown fire behavior module.

Crown Output Parameters

BehavePlus 5.0.5 produces a wide range of fire behavior output parameters including critical values useful for identifying times when a fire may transition from a surface fire to a

crown fire; active crown fire growth predictions such as crown fire rates of spread and fire size; and fire intensity predictions such as crown fireline intensity and crown fire heat per unit area (**Table 5**). The CROWN fire module output parameters can be split into three groups: crown fire transition predictors, crown fire spread estimates, and fire intensity estimates. IFTDSS produces all CROWN output parameters presented in BehavePlus 5.0.5.

Table 5. Crown output parameter comparison.

Module	Type	Parameters	
		BehavePlus	**IFTDSS**
CROWN	Crown Fire Transition Predictors	Critical Surface Intensity	Critical Surface Intensity
		Critical Surface Flame Length	Critical Surface Flame Length
		Transition Ratio	Transition Ratio
		Transition to Crown Fire? (Yes or No)	*Transition to Crown Fire? (Yes or No)*
		Crown Rate of Spread	Crown Rate of Spread
		Critical Crown Rate of Spread	Critical Crown Rate of Spread
		Active Ratio	Active Ratio
		Active Crown Fire? (Yes or No)	*Active Crown Fire? (Yes or No)*
		Fire Type	Fire Type
	Crown Fire Spread Estimates	Crown Spread Distance	Crown Spread Distance
		Crown Fire Area	Crown Fire Area
		Crown Fire Perimeter	Crown Fire Perimeter
		Crown Fire Length-to-Width Ratio	Crown Fire Length-to-Width Ratio
	Crown Fire Intensity Estimates	Crown Fireline Intensity	Crown Fireline Intensity
		Crown Flame Length	Crown Flame Length
		Power of the Fire	Power of the Fire
		Power of the Wind	Power of the Wind
		Power Ratio	Power Ratio
		Wind-driven Fire? (Yes or No)	*Wind-driven Fire? (Yes or No)*
		Crown Load	Crown Load
		Canopy Heat per Unit Area	Canopy Heat per Unit Area
		Crown Fire Heat per Unit Area	Crown Fire Heat per Unit Area

IGNITE Comparisons

Behave Plus 5.0.5 provides two options to estimate the probability of ignition: (1) probability of ignition from a lightning strike or (2) probability of ignition from a firebrand (**Table 6**). The input parameters to each probability of ignition module in BehavePlus are quite different. The firebrand ignition probability estimates are more dependent on fire weather variables including 1-hr fuel moisture, air temperature, and fuel shading, while the probability of ignition from a lightning strike estimates are based on the type of lightning strike, 100-hr fuel

moisture, and fuel type. The output parameters of the BehavePlus IGNITE module are presented as percent values. IFTDSS Version 1.0 provides all of the probability of ignition input and output parameters as the IGNITE module implemented in BehavePlus.

Table 6. IGNITE input and output parameter comparison.

Module	Type	Parameters	
		BehavePlus	**IFTDSS**
IGNITE	Firebrand Inputs	1-Hour Fuel Moisture	1-Hour Fuel Moisture
		Air Temperature	Air Temperature
		Fuel Shading from the Sun	Fuel Shading from the Sun
	Lightning Inputs	Lightning Ignition Fuel Type	Lightning Ignition Fuel Type
		Lightning Duff and Litter Depth	Lightning Duff and Litter Depth
		100-h Moisture	100-h Moisture
		Lightning Strike Type	Lightning Strike Type
	Firebrand Output	Probability of Ignition from a Firebrand	Probability of Ignition from a Firebrand
	Lightning Output	Probability of Ignition from Lightning	Probability of Ignition from Lightning

SAFETY Comparisons

The SAFETY module in BehavePlus provides estimates of the minimum distance required to ensure that a firefighter will not be injured or that firefighting equipment is not damaged by radiant energy from the flames. Input parameters include flame length, number of personnel, equipment numbers, and the average area present for each person and piece of equipment (**Table 7**). Each of the three SAFETY output parameters is directly (safety zone separation distance) or indirectly (safety zone size and safety zone radius) related to the flame length input. In the BehavePlus SAFETY module, flame length can be entered directly by the user, or the flame length output from SURFACE can be automatically entered into the SAFETY module if SAFETY and SURFACE are run at the same time. The SAFETY module is not linked to the CROWN fire behavior module in BehavePlus.

Table 7. SAFETY inputs and outputs comparison.

Module	Type	Parameters	
		BehavePlus	**IFTDSS**
SAFETY	Inputs	Flame Length	Flame Length
		Number of Personnel	Number of Personnel
		Area per Person	Area per Person
		Number of Heavy Equipment	Number of Heavy Equipment
		Area per Heavy Equipment	Area per Heavy Equipment
	Outputs	Safety Zone Separation Distance	Safety Zone Separation Distance
		Safety Zone Size	Safety Zone Size
		Safety Zone Radius	Safety Zone Radius

IFTDSS allows the user to input all of the parameters provided in BehavePlus and produces the same output parameters; however, the option of auto-populating the SAFETY module calculation inputs from surface or crown fire behavior simulations in IFTDSS does not currently exist. For Version 1.0, users are instructed to run the fire behavior modules of interest, record the fire behavior outputs, and enter these outputs into the IFTDSS safety module.

SIZE Comparisons

BehavePlus 5.0.5 provides the functionality to estimate fire size on the basis of a single point source ignition. Fire size variables, including fire area, fire perimeter, and fire length, are calculated (**Table 8**) from three input parameters: effective wind speed, rate of spread, and elapsed time. As with CROWN and SAFETY, SIZE can be run with the SURFACE module, which automatically populates the effective wind speed and surface rate of spread inputs. Crown fire behavior is not linked to the SIZE module in BehavePlus Version 5.0.5.

Table 8. SIZE input and output parameter comparison.

Module	Type	Parameters	
		BehavePlus	**IFTDSS**
SIZE	Inputs	Effective Wind Speed	Effective Wind Speed
		Surface Rate of Spread	Surface Rate of Spread
		Elapsed Time	Elapsed Time
	Outputs	Area	Area
		Perimeter	Perimeter
		Length-to-Width Ratio	Length-to-Width Ratio
		Forward Spread Distance	Forward Spread Distance
		Backing Spread Distance	Backing Spread Distance
		Fire Length	Fire Length
		Maximum Fire Width	Maximum Fire Width
		Fire Shape Diagram	*Not implemented*

IFTDSS Version 1.0 includes all of the BehavePlus SIZE input and output options except for the fire shape diagram. IFTDSS also includes linking and automatically populating the size estimation module input parameters with the surface fire behavior module output parameters.

SPOT Comparisons

BehavePlus Version 5.0.5 provides the option of estimating the distance a fire will spot from three different sources: a wind-driven surface fire, torching trees (crown fire), and burning piles (**Table 9**). A single spotting distance is the standard output from BehavePlus for each of these fire sources; however, BehavePlus does provide the option of displaying a set of intermediate SPOT output variables (listed in **Table 10**).

IFTDSS provides all of the input and output options found in BehavePlus 5.0.5 for spotting distance.

Table 9. SPOT input comparison.

Module	Type	Parameters	
		BehavePlus	**IFTDSS**
SPOT Inputs	Torching Tree Inputs	Downwind Canopy Height	Downwind Canopy Height
		Torching Tree Height	Torching Tree Height
		Spot Tree Species	Spot Tree Species
		Diameter at Breast Height	Diameter at Breast Height
		20-ft Wind Speed	20-ft Wind Speed
		Ridge-to-Valley Elevation Difference	Ridge-to-Valley Elevation Difference
		Ridge-to-Valley Horizontal Distance	Ridge-to-Valley Horizontal Distance
		Spotting Source Location	Spotting Source Location
		Number of Torching Trees	Number of Torching Trees
	Burning Pile Inputs	Downwind Canopy Height	Downwind Canopy Height
		20-ft Wind Speed	20-ft Wind Speed
		Ridge-to-Valley Elevation Difference	Ridge-to-Valley Elevation Difference
		Ridge-to-Valley Horizontal Distance	Ridge-to-Valley Horizontal Distance
		Spotting Source Location	Spotting Source Location
		Flame Height from a Burning Pile	Flame Height from a Burning Pile
	Wind Driven Surface Fire Inputs	Downwind Canopy Height	Downwind Canopy Height
		20-ft Wind Speed	20-ft Wind Speed
		Ridge-to-Valley Elevation Difference	Ridge-to-Valley Elevation Difference
		Ridge-to-Valley Horizontal Distance	Ridge-to-Valley Horizontal Distance
		Spotting Source Location	Spotting Source Location
		Flame Length	Flame Length

Table 10. Spot output comparison.

Module	Type		Parameters	
			BehavePlus	**IFTDSS**
SPOT Outputs	Standard Outputs	Torching Trees	Spotting Distance from Torching Trees	Spotting Distance from Torching Trees
		Burning Pile	Spotting Distance from a Burning Pile	Spotting Distance from a Burning Pile
		Wind-Driven Surface Fire	Spotting Distance from a Wind-Driven Surface Fire	Spotting Distance from a Wind-Driven Surface Fire
	Intermediate Outputs	Torching Trees	Cover Height Applied for Spotting Distance from Torching Trees	Cover Height Applied for Spotting Distance from Torching Trees
			Steady State Flame Height Ratio for Torching Trees	Steady State Flame Height Ratio for Torching Trees
			Steady State Flame Duration from Torching Trees	Steady State Flame Duration from Torching Trees
			Firebrand Height from Torching Trees	Firebrand Height from Torching Trees
			Flat Terrain Spotting Distance from Torching Trees	Flat Terrain Spotting Distance from Torching Trees
		Burning Pile	Cover Height Applied for Spotting Distance from a Burning Pile	Cover Height Applied for Spotting Distance from a Burning Pile
			Firebrand Height from a Burning Pile	Firebrand Height from a Burning Pile
			Flat Terrain Spotting Distance from a Burning Pile	Flat Terrain Spotting Distance from a Burning Pile
		Wind-Driven Surface Fire	Cover Height Applied for Spotting Distance from a Wind-Driven Surface Fire	Cover Height Applied for Spotting Distance from a Wind-Driven Surface Fire
			Firebrand Height from a Wind-Driven Surface Fire	Firebrand Height from a Wind-Driven Surface Fire
			Firebrand Drift Distance from a Wind-Driven Surface Fire	Firebrand Drift Distance from a Wind-Driven Surface Fire
			Flat Terrain Spotting Distance from a Wind-Driven Surface Fire	Flat Terrain Spotting Distance from a Wind-Driven Surface Fire

CONTAIN Comparison

The CONTAIN module in BehavePlus 5.0.5 provides the additional ability to do contingency planning. For example, if a fire spots and a new fire is ignited from a firebrand, CONTAIN helps users identify what resources might be needed to extinguish the fire. The CONTAIN module in BehavePlus allows the user to estimate the effectiveness of different fire attack strategies, the number of resources needed for containment, and the time it takes for a resource to arrive on site (**Table 11**). The CONTAIN module can evaluate the effectiveness of suppression efforts by a single resource or the combined efforts of multiple resources. Input parameters to the CONTAIN module include fire variables such as surface rate of spread and fire size in addition to resource variables such as suppressions tactics and resource availability

metrics. CONTAIN can also be linked to SURFACE in BehavePlus 5.0.5 to auto-populate the surface rate of spread input requirement.

Table 11. CONTAIN input and output parameter comparison.

Module	Type	Choose One	Parameters	
			BehavePlus	**IFTDSS**
CONTAIN	Input Options		A single resource	A single resource
			Multiple resources	*Not implemented*
	Inputs		Surface Rate of Spread (maximum)	Surface Rate of Spread (maximum)
			Fire Size at Report	Fire Size at Report
			Length-to-Width Ratio	Length-to-Width Ratio
			Suppression Tactic	Suppression Tactic
			Line Construction Offset	Line Construction Offset
			Resource Line Production Rate	Resource Line Production Rate
			Resource Arrival Time	Resource Arrival Time
			Resource Duration	Resource Duration
			Resource Base Cost	Resource Base Cost
			Resource Hourly Cost	Resource Hourly Cost
	Outputs		Fire Area at Initial Attack	Fire Area at Initial Attack
			Fire Perimeter at Initial Attack	Fire Perimeter at Initial Attack
			Contain Status	Contain Status
			Time from Report	Time from Report
			Contained Area	Contained Area
			Fireline Constructed	Fireline Constructed
			Number of Resources Used	Number of Resources Used
			Cost of Resources Used	Cost of Resources Used
			Containment Diagram	*Not implemented*

IFTDSS Version 1.0 provides all of the BehavePlus input functionality to estimate escaped fire containment success for the suppression efforts of a single resource. IFTDSS also provides all of the BehavePlus output parameters for a single resource except the BehavePlus fire containment diagram. IFTDSS does not include the multiple resource options found in BehavePlus nor the ability to automatically populate the surface rate of spread input in CONTAIN with modeled rate of spread from IFTDSS fire behavior modules.

SCORCH Comparisons

BehavePlus 5.0.5 calculates scorch height as an input for the MORTALITY module (**Table 12**). Input options include flame length (default) and fireline intensity. If the user selects the flame length option, SCORCH can be run with SURFACE, and BehavePlus populates the flame length or the fireline intensity input with the modeled values. Additional inputs include midflame wind speed and air temperature.

IFTDSS calculates scorch height using manually entered variables for flame length, midflame wind speed, and air temperature. Currently, there is no option to auto-populate the flame length input with modeled values. The option to calculate crown scorch using fireline intensity has not been implemented in the IFTDSS Version 1.0.

Table 12. SCORCH inputs and outputs comparison.

Module	Type	Choose One	Parameters	
			BehavePlus	**IFTDSS**
SCORCH	Input Options	Surface fire intensity is entered as	Flame Length	Flame Length
			Fireline Intensity	*Not implemented*
	Inputs		Midflame Wind Speed	Midflame Wind Speed
			Air Temperature	Air Temperature
	Outputs		Scorch Height	Scorch Height

MORTALITY

BehavePlus 5.0.5 provides functionality to calculate tree mortality using a set of equations from FOFEM 4.0 and Sharon Hood's final report to the JFSP (Hood et al., 2008). Output parameters for the tree mortality model include the probability of tree mortality (**Table 13**) and the intermediate values of bark thickness, tree crown length scorched, and tree crown volume scorched.

The BehavePlus 5.0.5 MORTALITY module has not been implemented in IFTDSS. IFTDSS Version 1.0 currently includes a more complete set of FOFEM algorithms and options for calculating tree mortality. FOFEM and BehavePlus use many of the same tree mortality algorithms, but the FOFEM module in IFTDSS provides for a greater range of tree mortality outputs (Table 13). We elected to use the FOFEM module, as FOFEM provides the same measure of mortality (percent mortality) and much more information useful for designing a prescribed burn (including how many trees would be left in a stand post-fire, how much of the canopy would be removed by prescribed burning, and the size of the trees post-prescribed burn).

Table 13. MORTALITY input and output parameter comparison.

Module	Type	Parameters	
		BehavePlus	**IFTDSS (FOFEM tree mortality module)**
MORTALITY	Inputs	Canopy Height	Tree Species
		Crown Ratio	Stand Density
		Mortality Tree Species	Diameter at Breast Height
		Diameter at Breast Height	Tree Height
		Scorch Height	Crown Ratio
			Option to Use Scorch Height or Flame Length
			Fire Severity
	Primary Output	Probability of Mortality	Pre-Fire Tree Density
			Post-Fire Tree Density
			Trees per Acre Killed
			Percent Mortality
			Pre-Fire Basal Area
			Post-Fire Basal Area Live
			Post-Fire Basal Area Killed
			Pre-Fire Canopy Cover
			Post-Fire Canopy Cover
	Intermediate Values	Bark Thickness	
		Tree Crown Length Scorched	
		Tree Crown Volume Scorched	

BehavePlus Tools

BehavePlus 5.0.5 includes six tools as aids for fire behavior modeling (**Table 14**). The fine dead fuel moisture tool provides estimates of dead fuel moisture for 1-hour fuels. The relative humidity tool estimates relative humidity by temperature and elevation. The unit conversion tool allows users to convert input parameter units to units used by BehavePlus or convert output parameter units to user-selected units. The slope from map measurements tool allows users to estimate slopes indirectly from topographical map measurements. The calculate horizontal map distances from slope distances tool allows users to convert modeled distances (such as spotting distance and surface spread distance) that incorporate slope in their distance calculations into horizontal map distances for plotting on maps. The last tool provided by BehavePlus 5.0.5 produces a Sun-Moon calendar (for example, sunrise and sunset times) for specific geographic locations.

Table 14. BehavePlus 5.0.5 tool comparison.

Tools	
BehavePlus	**IFTDSS**
Fine Dead Fuel Moisture	*Not implemented*
Relative Humidity	*Not implemented*
Unit Converter	Unit Converter
Slope from Map Measurements	*Not implemented*
Slope vs. Horizontal Map Distance	*Not implemented*
Sun-Moon Calendar	*Not implemented*

A unit conversion tool that allows users the opportunity to convert units is included in IFTDSS Version 1.0.

Other BehavePlus 5.0.5 Functionality Not Implemented in IFTDSS Version 1.0

a. **Acceptable fire conditions.** The acceptable fire conditions functionality allows users to create the output and build display tables of the ranges of acceptable fire behavior. With this feature, the user can select a range of acceptable conditions and use the data to build data tables indicating when the fire will be in prescription.

b. **Display output distances in map units.** This functionality runs the slope vs. horizontal map distance tool and automatically converts the surface fire behavior output (such as spotting distance) to values that can be directly entered on maps.

c. Viewing fuel model parameters. BehavePlus allows the user to view and customize the properties for each fuel model. The IFTDSS provides a summary table of the fuel model properties in the help documentation for each of the standard fuel models but does not provide the user the ability to edit fuel model properties within the system.

Adding More BehavePlus Functionality to the IFTDSS

The intent of the IFTDSS project is not to reproduce the BehavePlus 5.0.5 user experience, but to make select tools and functionality in BehavePlus available for IFTDSS users. Implementation of the BehavePlus functionality currently in IFTDSS was based on our interpretations of user needs garnered from interviews with prescribed burn planners. We do not provide a lengthy summary table of all the functionality currently in IFTDSS Version 1.0, as the details are discussed above. However, the discussion and summary tables below outline the BehavePlus functionality that has not been implemented in the IFTDSS; whether adding this additional functionality has been planned (**Table 15** and **Table 16)**; and whether including this additional functionality is not currently planned and needs to be discussed (**Table 17**).

Table 15. Additional functionality planned for implementation in IFTDSS Version 1.1.

BehavePlus 5.0.5 Module	Functionality Description
SURFACE: Use of fuel moisture scenarios	Option of using a set of pre-determined fuel moisture scenarios published by Scott and Burgan (2005) or creating and saving custom fuel moisture scenarios.
CONTAIN: Multiple resources option	Ability to include multiple resources (people, equipment) concurrently in their analysis of containing an escaped fire or spot fire
BehavePlus Tools: fine dead fuel moisture prediction tool	Ability to estimate fine dead fuel moisture from stand level environmental variables such as relative humidity and temperature
BehavePlus Tools: Relative humidity calculator	Ability to estimate relative humidity from temperature and elevation parameters

Table 16. Additional functionality planned for implementation in IFTDSS Version 1.2.

BehavePlus 5.0.5 Module	Functionality Description
SURFACE: Wind speed options - maximum reliable effective wind speed	Ability to select whether the maximum reliable effective wind speed is used or not
SURFACE: Wind speed options – alternative wind speed heights and wind adjustment factors	Options for entering 20-ft wind speeds, 10-meter wind speeds, manually entering a wind adjustment factor, or internally calculating a wind adjustment factor
SURFACE: Wind direction options	The option for wind and fire spread direction inputs to be in user-defined degrees clockwise from north or in degrees clockwise from upslope
SURFACE: Slope steepness units	The option to specify slope steepness in degrees or percent

Table 17. BehavePlus 5.0.5 functionality not currently planned to be implemented in IFTDSS. No decision was made to implement this functionality, as it was not directly requested by the prescribed burn planners we interviewed. More internal discussion by the IFTDSS development team is needed to determine whether we will include this additional functionality.

BehavePlus 5.0.5 Module	Functionality Description
SURFACE: Special Case Fire Behavior Fuel Models	Set of additional fire behavior fuel models. Not included in Anderson 13 nor the Scott and Burgan 40.
SURFACE: Custom Fire Behavior Fuel Modeling	Ability to create and export custom Fire Behavior Fuel Models to represent local conditions or unusual fuel types.
SURFACE: Two model concept	Ability to simulate fire movement across a landscape consisting of a mixture of two fuel models
SURFACE: Direct input of live and dead fuel	Option to input fuel moisture by live and dead categories. This option does not separate fuels by size class or fuel type (woody or herbaceous)
SURFACE: Dynamic curing load transfer	Ability to manually set the percentage of live herbaceous fuel loading in the live and dead categories
SURFACE: Calculating slope steepness from map measurements	Ability to calculate slope steepness based on map measurements such as map scale, contour interval, and map distance.
SURFACE: Fire characteristics chart	Ability to create a fire characteristics chart which can be used to communicate the potential intensity of a fire and what containment strategies may be effective.
SURFACE: Wind/slope/spread direction diagram	Provides the option of viewing the relative directions slope, wind, and fire spread on a single chart.
SURFACE: Intermediate and output parameters	The complete list of optional and intermediate output variables available in BehavePlus 5.0.5 but no currently implemented in IFTDSS is too long to replicate here. Please see Table 3, the complete list of what has not been implemented in the IFTDSS.
CROWN: Input fireline intensity option – option of using fire line intensity as the input for surface fire intensity.	The option of flame length or fire line intensity as input for calculating crown fire behavior.
CROWN: Link surface fire behavior modules to CROWN module	Option of running surface fire behavior modules linked with the CROWN module to automatically populate the CROWN input variables of heat per unit area and flame length (or fireline intensity) with modeled values.

Table 17. BehavePlus 5.0.5 functionality not currently planned to be implemented in IFTDSS. No decision was made to implement this functionality, as it was not directly requested by the prescribed burn planners we interviewed. More internal discussion by the IFTDSS development team is needed to determine whether we will include this additional functionality.

Page 2 of 2

BehavePlus 5.0.5 Module	Functionality Description
SAFETY: Link SURFACE module to SAFETY module	Ability to automatically populate the flame length input for SAFETY with modeled flame length output from fire behavior modules.
SIZE: Fire shape diagram	Ability to create and export a fire shape diagram for use in contingency planning
SIZE: Link crown fire behavior modules to SIZE	Ability to populate SIZE module inputs of effective wind speed and rate of spread with modeled crown fire behavior output
CONTAIN: Link the CONTAIN module in IFTDSS with fire behavior prediction modules.	Ability to populate CONTAIN module rate of spread input with modeled fire behavior output
SCORCH: Fireline intensity option	Option of calculating crown scorch using fireline intensity or flame length as inputs.
SCORCH: Link SCORCH to fire behavior modules	Ability to populate SCORCH module flame length or fireline intensity inputs with modeled fire behavior output
BehavePlus Tools: Slope from map measurements tool	Ability to manually estimate slope steepness indirectly from topographical map measurements.
BehavePlus Tools: Calculate horizontal distances tool	Ability to convert calculated distances that incorporate slope into horizontal map distances for plotting on maps
BehavePlus Tools: Sun_Moon Calendar	Produces local calendar of events such as sunrise and sunset
Additional functionality: Acceptable Fire Conditions	Ability to users to create the output and build display tables of the ranges of acceptable fire behavior.
Additional functionality: Display output distances in map units.	Ability to automatically convert surface fire behavior output to map distances
Additional functionality: Viewing Fuel Model Parameters	Ability to view fuel model variable such as packing ratio, fuel depth, and fuel loading.

References

Anderson H.E. (1982) Aids to determining fuel models for estimating fire behavior. Technical report by the USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT, General Technical Report INT-122, June. Available on the Internet at http://www.fs.fed.us/rm/pubs_int/int_gtr122.pdf.

Hood S., Smith S., Cluck D., Reinhardt E., and Ryan K. (2008) Delayed tree mortality following fire in western conifers. Final report prepared for the Joint Fire Science Program, JFSP #05-2-1-105, June 30.

Scott J.H. and Burgan R.E. (2005) Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Technical report by the USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, General Technical Report RMRS-GTR-15, June. Available on the Internet at http://www.fs.fed.us/rm/pubs/rmrs_gtr153.pdf.