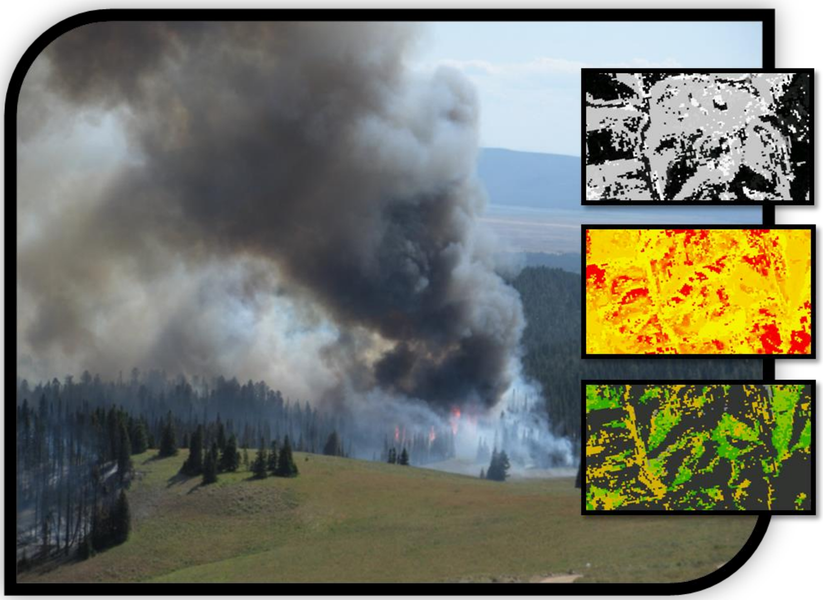
Wildland Fire Assessment Tool User's Guide

Version 2.4.0

February 2014



Integrating science, technology and fire management.

Wildland Fire Management RD&A

Preface

The Wildland Fire Assessment Tool (WFAT) is a custom ArcMap toolbar that provides an interface between ArcGIS desktop software, FlamMap4 algorithms (Finney 2006), First Order Fire Effects Model (FOFEM) algorithms (Reinhardt 2003), and FuelCalc (Reinhardt and others 2006) algorithms to produce predicted fire behavior, fire effects, and post-fire fuels map layers. WFAT is the successor to the Fire Behavior Assessment Tool (FBAT; Hamilton and others 2007) and the Fire Order Fire Effects Model Mapping Tool (FOFEMMT; Hamilton and others 2009) and incorporates the functionality of both tools into one convenient software application. WFAT spatially displays outputs from FuelCalc but does not provide all of the functionality of the tool. WFAT also provides a landscape file (.lcp) generator and an import tool to convert FARSITE and FlamMap ASCII Grids into ESRI Grid format for use on the ArcGIS platform.

The primary objectives behind the creation of WFAT were to develop a tool that would assist managers in 1) prioritizing fuel treatments on the basis of predicted fire behavior, fire effects, and post-fire fuels, and 2) assessing the effectiveness of fuel treatment proposals *in a geospatial context*. Having WFAT on the ArcGIS platform allows easy integration of other spatial data (such as land ownership, areas of special concern, and digital imagery) into wildland fire analysis. WFAT uses spatial data that are in the ESRI Grid format and saves all outputs to this format as well. Consequently, there is no need to convert files back and forth between ASCII Grid and ESRI Grid formats as with other fire modeling systems. WFAT can also be used to support fire analysis and to calibrate fuel input layers for more complex applications, such as those available in FARSITE (Finney 2006).

In essence, WFAT is a planning tool that can be used to help:

- Define and identify the location of hazardous fuels;
- Prioritize, design, and evaluate fuel treatment projects;
- Develop burn plans for prescribed fire;
- Predict fire behavior, fire effects, and post-fire fuels for planning and monitoring documents; and
- Calibrate fuel data layers based upon observed fire behavior.

Future versions of WFAT may incorporate additional features, so be sure to check the NIFTT website (www.niftt.gov) for possible tool updates and enhancements as well as for associated updates to this user's guide.

Prerequisites

WFAT serves as an interface between ArcMap, FOFEM, FlamMap, and portions of FuelCalc, and imports FARSITE and FlamMap output files. Users should therefore be familiar with all relevant software to fully utilize the functionality of WFAT. More importantly, users should have a good understanding of fire behavior, fire effects, and fuels, including knowledge of fire effects fuel models and fire behavior fuel models, weather, topography, and wildland fire situations. Users should also understand the relationships between disturbance, vegetation attributes, and fuel characteristics. This understanding should be accompanied by an ability to use non-spatial fire behavior and fire effects prediction systems such as BehavePlus, NEXUS, FOFEM, and FFI (FEAT/FIREMON Integrated). WFAT users should be capable of using fire behavior, fire effects, and fuels programs to directly analyze the effects of various input changes on outputs. In addition, because of its complexity, only those with the proper training and experience should use WFAT whenever the outputs are to be used in fire and land management decisions.

This guide is created for version 2.4.0 of WFAT, which requires ArcGIS 10.1 or ArcGIS 10.2. For Arc 10.0 users, WFAT version 2.2.0 is still available (at www.niftt.gov); all information in this guide is relevant to WFAT 2.0.0 with the exception of the information on FuelCalc (Section 4.3). Regardless of the version of ArcGIS you are using, it is important to have the most current service pack installed, which can be downloaded from support.esri.com. Specific computer requirements are described in detail in Chapter 1 of this guide.

Obtaining copies

To obtain additional copies of this WFAT User's Guide or to obtain the WFAT Tutorial, follow these steps:

1. Go to www.niftt.gov.
2. Click on **Tools and User Documents**.
3. Select the tool or material you wish to download.

Register for the WFAT Online Course, as follows:

1. Go to www.niftt.gov.
2. Click on **Training.**
3. Select your desired course.

What's new in WFAT Version 2.4.0

A variety of enhancements to WFAT were made available with version 2.4.0. These include the following outputs:

- Percent Consumed Fuel Loading
- Surface Fuel Load
- Total Fuel Load
- FRCC Severity
- Percent Mortality > 4"
- Percent Mortality > 21"

Credits

WFAT was developed for the National Interagency Fuels, Fire, and Vegetation Technology Transfer (NIFTT) by Dale Hamilton of Systems for Environmental Management (SEM LLC), Jody Bramel, Marc Dousset, and Chris Finlayson of Axiom IT Solutions. Technical guidance was provided by Mark Finney, Wendel Hann, Don Helmbrecht, Jeff Jones, Bob Keane, Laurie Kurth, Duncan Lutes, and Elizabeth Reinhardt of the USDA Forest Service.

Support for the development of WFAT was provided by the National Interagency Fuel Coordination Group through NIFTT. Funding was provided by the USDA Forest Service and the U.S. Department of the Interior.

The Wildland Fire Assessment Tool User's Guide was written by Deb Tirmenstein, Jennifer Long, and Heather Heward of SEM LLC – borrowing select material from the FBAT User's Guide (Jones and Tirmenstein 2008) and the FOFEMMT User's Guide (Helmbrecht and Tirmenstein 2009) – and edited by Christine Frame (SEM LLC).

Your input

We value your input. Please forward any questions, comments, reports of bugs, or ideas to the National Interagency Fuels, Fire, and Vegetation Technology Transfer (NIFTT) at helpdesk@niftt.gov.

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To cite the Wildland Fire Assessment Tool (WFAT) and User's Guide, use the following references:

Hamilton, Dale. 2012. Wildland Fire Assessment Tool (WFAT). National Interagency Fuels, Fire, & Vegetation Technology Transfer. Available: www.niftt.gov.

Heward, Heather; Tirmenstein, Deb; Long, Jennifer. 2012. Wildland Fire Assessment Tool (WFAT) User's Guide. National Interagency Fuels, Fire, & Vegetation Technology Transfer. Available: www.niftt.gov.

About the Wildland Fire Assessment Tool User's Guide

1.1 Before you begin
1.2 How to use this guide
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1.1 Before you begin

This user's guide describes the basic operation of the Wildland Fire Assessment Tool (WFAT). Because it is assumed that WFAT users have experience operating and understanding ArcMap, FOFEM, FlamMap, and FuelCalc applications (as well as ArcGIS and Microsoft Windows in general), this user's guide will not repeat specific instructions for using any of this software. Instead, users are encouraged to refer to the help functions available with these programs should questions arise.

1.2 How to use this guide

You need not read this entire guide to understand WFAT's functionality and subject matter or to carry out a specific task. Once you are familiar with the basic concepts associated with WFAT, you can quickly locate commonly performed tasks by reviewing the headings in the Table of Contents located near the beginning of this guide and then refer to the specific section pertaining to your needs. Wherever appropriate, screen captures are used to illustrate the steps required to complete a task.

The WFAT User's Guide is not intended to provide step-by-step guidance on the tool's operation using specific examples; rather, it is intended to serve as a reference guide. The WFAT Tutorial, available at www.niftt.gov, provides step-by-step instructions using specific examples of tool applications. The WFAT Online Course, available at www.niftt.gov, further illustrates the use and function of WFAT with many different examples of tool applications, and provides a detailed exercise as well as a course completion certificate.

1.3 Computer requirements

Ensure the following programs are installed and functioning properly on your computer:

- ArcGIS 10.1 or ArcGIS 10.2 with current service pack installed
  (WFAT version 2.2.0 is available for ArcGIS 10.0)
- Spatial Analyst extension of ArcGIS
- Microsoft Access (2000 or higher) with current service pack installed

Although system requirements to run ArcGIS 10 will suffice to run WFAT, at least 10 GB of free hard drive space and 2 GB of RAM are recommended. Generally, faster processors, more memory, and increased free hard drive space will improve performance. In addition, NIFTT tools were developed for Windows Operating Systems.

Where possible, we recommend that you uninstall all NIFTT programs, such as previous versions of WFAT, before installing new versions of ArcGIS. We also recommend that you uninstall any earlier versions of WFAT before running the most current version of the tool. It is not necessary to uninstall FBAT and FOFEMMT before running WFAT, but since WFAT replaces these programs, both FBAT and FOFEMMT can be removed.

> ***Note****: Ensure that you have sufficient space and adequate permissions for storing WFAT outputs on your computer.*
>
> ***Note****: Ensure that the WFAT version you are using correctly matches the version of ArcGIS on your computer.*
>
> - *Use WFAT version 2.4.0 only with ArcGIS 10.1 and ArcGIS 10.2.*
> - *Use WFAT version 2.1.0 and 2.2.0 only with ArcGIS 10.0.*
> - *Use WFAT version 2.0.0 only with Arc 9.x (does not include post-fire fuels functionality).*

Wildland Fire Assessment Tool Function

2.1 What does the Wildland Fire Assessment Tool do?

WFAT produces predicted spatial fire behavior, fire effects, and post-fire fuels data to support land management planning. WFAT helps answer the question "Where on a landscape are fire behavior, fire effects, and fuels likely to be most problematic in regards to specific land management objectives?"

Specifically, WFAT allows you to design, prioritize, and evaluate fuel treatment prescriptions and burn plans under given weather conditions and fuel moisture scenarios. It answers the question, "Under what fuel moisture and weather conditions will a burn result in desired fire effects or controllable fire behavior?" After a fuel treatment prescription is developed, WFAT can also be used to address the question "Will the fuel treatment prescriptions actually result in the desired fire behavior, fire effects, and fuel characteristics?"

In addition, the tool's map layers serve as visual data for inclusion into planning and monitoring documents. Maps often present a clearer picture across a landscape than do summary tables or text.

Lastly, one of the most powerful applications of WFAT is that outputs can be used to calibrate fuel input layers used in FARSITE, FlamMap, and WFAT. Fuel layers are commonly developed using vegetation characteristics as correlates; however, vegetation attributes alone can be poor predictors of the fuel complex. WFAT outputs may suggest that a certain fire behavior characteristic is difficult to simulate on a given landscape, even though that characteristic has frequently been observed during actual fire events – indicating problems with one or more of the fuel input layers. For example, the lack of simulated passive crown fire may indicate a problem with the fire behavior fuel model, canopy base height, and/or canopy cover layers. Fuel layers can then be refined or calibrated until the expected fire behavior is simulated by WFAT.

2.2 How does the Wildland Fire Assessment Tool work?

WFAT incorporates three main data processing steps. First, the tool builds the landscape file (or .lcp) from the LANDFIRE input data that are required to run FlamMap. WFAT can also utilize an existing user-specified landscape file, such as those available from LANDFIRE (www.landfire.gov). Next, WFAT runs FlamMap to condition fuel moistures – if the user has opted to do so – and to predict potential crown fire activity and scorch height. Lastly, WFAT runs FlamMap, FOFEM, and FuelCalc for each unique combination of inputs to predict potential fire behavior characteristics, first order fire effects, and post-fire fuel conditions.

FlamMap is a fire behavior mapping and analysis program that computes potential fire behavior characteristics (flame length, rate of spread, fire type or crown fire activity [CFA], and fireline intensity) at a pixel level. We chose to link ArcMap with FlamMap because FlamMap predicts fire behavior characteristics across an entire assessment area, whereas FARSITE estimates fire behavior characteristics for only those areas within the simulated fire perimeter. WFAT uses an ArcGRID format, and consequently there is no longer any need to convert files back and forth between ASCII and ArcGRID formats as required by FlamMap.

In addition, components of FlamMap were integrated into WFAT to more accurately estimate certain fire effects that are dependent on fire behavior calculations. While many fire effects are determined largely by the flaming and smoldering consumption of duff and coarse woody debris (CWD), other fire effects, such as canopy consumption and tree mortality, are better estimated using fire behavior characteristics such as crown fire activity and scorch height, which are calculated by FlamMap. FlamMap also calculates fuel moisture, which greatly influences both fire behavior and fire effects by affecting the amount of oxygen available for combustion and heat flux, and by determining the duration of flaming and smoldering combustion.

FOFEM is a non-spatial fire effects analysis program that computes potential first order fire effects (fuel consumption, smoke emissions, soil heating, and tree mortality). WFAT enhances non-spatial FOFEM by modeling and portraying fire effects outputs spatially and by simplifying the analysis of heterogeneous landscapes for multiple planning units through spatial analysis.

FuelCalc is a non-spatial software package that calculates initial fuel quantities and simulates a variety of fuel treatment scenarios (thinning, pruning, piling, and broadcast burning). All calculations are computed at the plot level, with summaries to a stratum (stand) level. Although at this time WFAT does not incorporate the treatment options of FuelCalc, it does model and portray several stand measurements spatially to show the conditions of the fuel on the site post-fire.

Input Data

3.1 Input data overview

Prediction of potential fire behavior, fire effects, and post-fire fuels requires input on site-specific fuel characteristics and topography, as well as information relating to the fuel moisture and fire weather scenario of interest. In WFAT, input data are split into three categories: – spatial inputs, model inputs, and a coarse woody debris (CWD) profile. Each category is represented as a tab on the tool's user interface. Fuel and topographic information is provided by spatial data layers specified on the *Spatial Inputs* tab. Environmental factors that describe fuel moisture and fire weather scenarios are required by the background models (FOFEM and FlamMap) and are specified on the *Model Inputs* tab. Information about the coarse woody debris profile (down woody fuel greater than or equal to 3 inches [7.6 cm] in diameter) is specified on the *CWD Profile* tab. The *Custom FEFM* tab is an optional tab that appears if a custom fire effects fuel model is selected as a spatial layer.

3.2 Spatial inputs

On WFAT's *Spatial Inputs* tab, users specify ten spatial input layers that characterize topography and fuel for a single spatial extent (Figure 3-1; Table 3-1). Some of the user-specified input layers plus additional fuel layers (duff and coarse woody grids) that are derived from the fire effects fuel model layer are used to create a landscape file (.lcp). WFAT can also be executed using an existing user-specified .lcp, such as those available from the LANDFIRE data distribution site. Fire effects relating to tree mortality are predicted using the .lcp plus the tree list layer (see Section 3.2.10 for additional information on this subject).

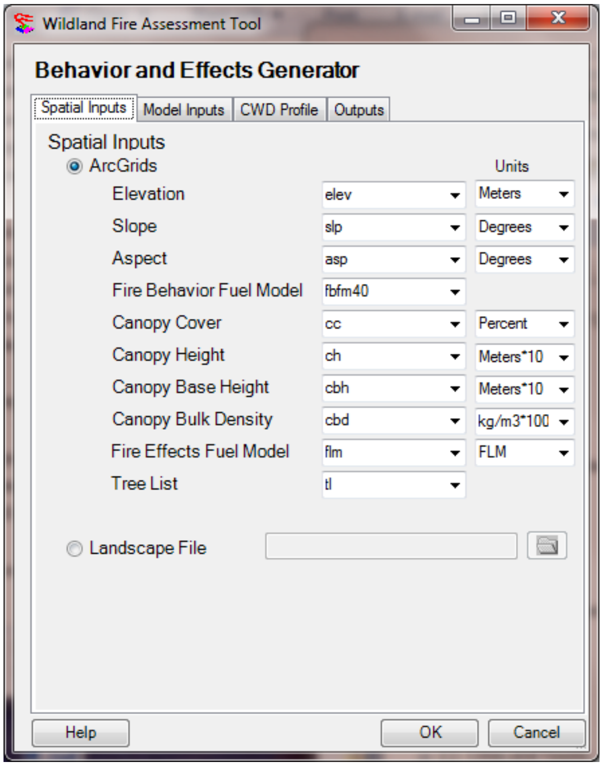


Figure 0-1 Spatial Inputs tab showing inputs for running WFAT

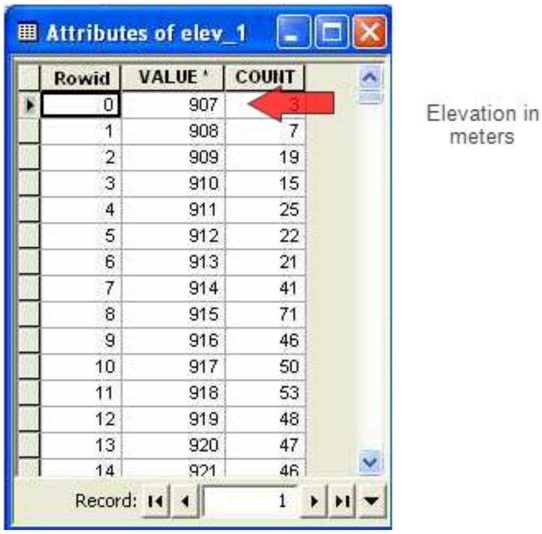
In order to successfully build an .lcp, WFAT uses the same input theme requirements as FlamMap and FARSITE. Specifically, the input layers must have identical coordinate systems, spatial extents, cell resolutions, and cell alignments. In addition, the map layers must be in ESRI Grid format and the units associated with each layer must correspond to those shown in Table 3-1.

Table 0-1 Required input grids with the default and alternate units.

Description	Default Units	Alternate Units
Elevation	Meters	Feet
Slope	Degrees	Percent
Aspect	Degrees	Class (1-25)
Fire Behavior Fuel Model	Anderson (1982); Scott and Burgan (2005)	none
Canopy Cover	Percent	Class (0-4)
Canopy Height	Meters*10	Meters, Feet, Feet*10
Canopy Base Height	Meters*10	Meters, Feet, Feet*10
Canopy Bulk Density	kg/m^3*100	Kg/m^3, lb/ft^3, lb/ft^3*1000
Fire Effects Fuel Model	Fuel Loading Model (FLM)	Fuel Characteristic Classification System (FCCS); Custom
Tree List	FOFEM format	

3.2.1 Elevation

The Elevation layer represents meters or feet above sea level, and zero values are used for those areas that are at or below sea level. Figure 3-2 shows the value attribute table of an elevation layer. WFAT uses the Elevation layer to adjust fuel moistures using adiabatic lapse rates if the user opts to condition fuel moistures. The elevation layer is also used for conversion of fire spread between horizontal and slope distances.

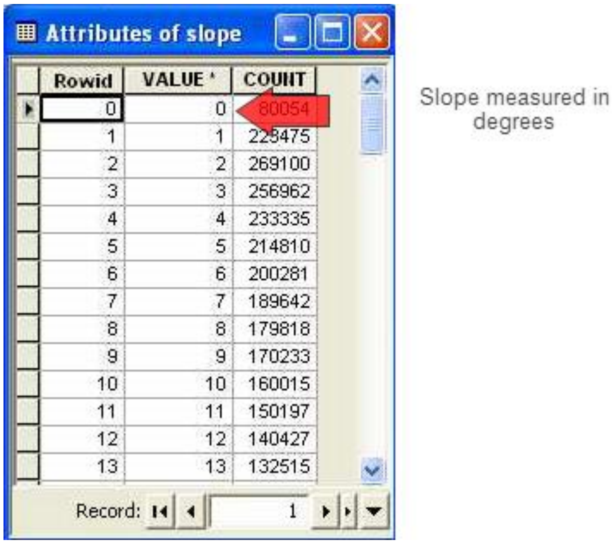


Rowid	VALUE *	COUNT
0	907	3
1	908	7
2	909	19
3	910	15
4	911	25
5	912	22
6	913	21
7	914	41
8	915	71
9	916	46
10	917	50
11	918	53
12	919	48
13	920	47
14	921	46

Figure 0-2 Example value attribute table of an Elevation layer. The Value field must depict elevation in meters or feet above sea level.

3.2.2 Slope

WFAT uses the Slope layer for computing slope effects on flame length, fire spread – and if fuel moisture conditioning is used – solar radiance. The Slope layer can have cell values represented by either floating point numbers (decimals) or integers, and the units may be expressed in either degrees or percent. Figure 3-3 displays the value attribute table of a Slope layer.

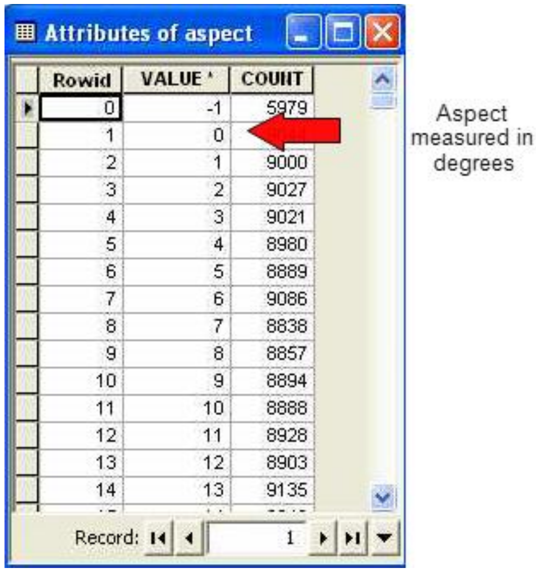


Rowid	VALUE *	COUNT
0	0	80054
1	1	223475
2	2	269100
3	3	256962
4	4	233335
5	5	214810
6	6	200281
7	7	189642
8	8	179818
9	9	170233
10	10	160015
11	11	150197
12	12	140427
13	13	132515

Figure 0-3 Example value attribute table of a Slope layer. The Value field must show slope in degrees or percent.

3.2.3 Aspect

The Aspect layer determines the effect of slope orientation on fuel moisture with respect to solar radiance when fuel moisture conditioning is used. WFAT's Aspect layer must denote slope azimuth in degrees clockwise from the north or classes 1-25 if the input grid is derived from an older version GRASS ASCII file. Cell values can be represented by either floating point numbers (decimals) or integers. Flat areas that lack an aspect are identified by a value of -1 in degree units or 25 if in class units. Figure 3-4 displays the value attribute table of an Aspect layer.



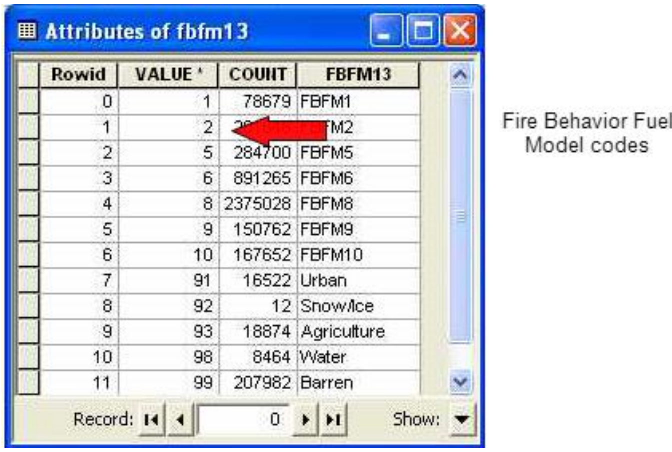
Rowid	VALUE *	COUNT
0	-1	5979
1	0	
2	1	9000
3	2	9027
4	3	9021
5	4	8980
6	5	8889
7	6	9086
8	7	8838
9	8	8857
10	9	8894
11	10	8888
12	11	8928
13	12	8903
14	13	9135

Figure 0-4. Example value attribute table of an Aspect layer. The Value field must depict aspect in degrees or classes. (A value of -1 denotes flat areas that have no aspect if the units are degrees.)

3.2.4 Fire Behavior Fuel Model

Fire Behavior Fuel Models represent distinct distributions of fuel loading found among surface fuel components (live and dead), size classes, and fuel types. The fuel models are described by the most common fire-carrying fuel type, loading and surface area-to-volume ratio by size class and component, fuelbed depth, and moisture of extinction. WFAT uses the Fire Behavior Fuel Model layer to predict potential fire behavior that influences fire effects (crown fire activity and scorch height) as well as to initialize the fuel moisture values of the fine woody debris (less than 3 inches [7.6 cm] in diameter) for fuel moisture conditioning.

WFAT can use either the 13 fire behavior fuel models characterized by Anderson (1982) or the 40 characterized by Scott and Burgan (2005). However, WFAT cannot use a fuel layer containing custom fire behavior fuel models. Cells must contain integers denoting the numeric codes of Anderson's (1982) models (values: 1 to 13) or the Scott and Burgan (2005) models (values: 91 to 204) (see Figure 3-5). Non-burnable fuel must be denoted by values 91, 92, 93, 98, and 99, which characterize urban/developed, snow/ice, agriculture, water, and bare ground, respectively. Additional attributes (such as a text descriptor of the model) are commonly included in the Fire Behavior Fuel Model layer.



Rowid	VALUE *	COUNT	FBFM13
0	1	78679	FBFM1
1	2	[illegible]	[illegible]M2
2	5	284700	FBFM5
3	6	891265	FBFM6
4	8	2375028	FBFM8
5	9	150762	FBFM9
6	10	167652	FBFM10
7	91	16522	Urban
8	92	12	Snow/Ice
9	93	18874	Agriculture
10	98	8464	Water
11	99	207982	Barren

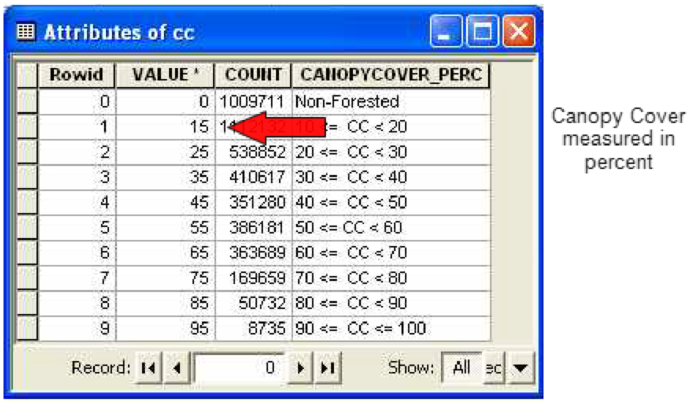
Figure 0-5 . Example value attribute table for a Fire Behavior Fuel Model (FBFM) layer (Anderson 1982). The Value field must correspond to the numeric fire behavior fuel model codes of Anderson (1982) or Scott and Burgan (2005).

3.2.5 Canopy Cover

Canopy Cover as used by LANDFIRE is a forested stand attribute that corresponds to the vertical projection of the forest canopy to the ground. The Canopy Cover layer is used to compute the wind reduction factor attributable to the canopy and the subsequent wind speed at the mid-flame height. The Canopy Cover layer is also used to modify solar radiance when fuel moisture conditioning is used. WFAT requires that the Canopy Cover layer be expressed in percent (0 – 100) or in classes (0 – 4). WFAT assumes the classes represent the following ranges:

0 – 0%
1 – 1-20%
2 – 21-50%
3 – 51-80%
4 – 81-100%

A cell value of 0 in this layer indicates that the pixel is non-forested. The cell values can be denoted by either floating point numbers (decimals) or integers. Figure 3-6 shows the value attribute table of a Canopy Cover layer. In this example, the *Value* field denotes canopy cover in percent and canopy cover has been grouped into ten classes in which the cell value corresponds to the class mid-point. Thus, a cell value of 15 represents a canopy cover class with values ranging from 10 to 20 percent. A value of 0 indicates a non-forested setting (this is the LANDFIRE standard).

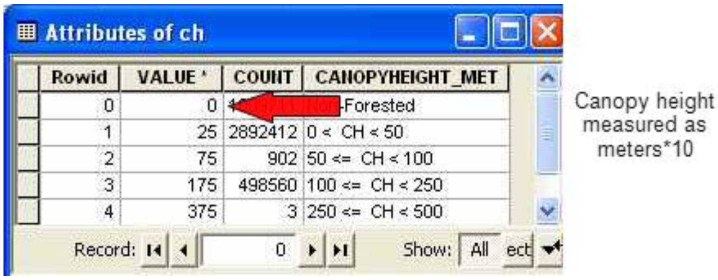


Rowid	VALUE *	COUNT	CANOPYCOVER_PERC
0	0	1009711	Non-Forested
1	15	[illegible]	[illegible]= CC < 20
2	25	538852	20 <= CC < 30
3	35	410617	30 <= CC < 40
4	45	351280	40 <= CC < 50
5	55	386181	50 <= CC < 60
6	65	363689	60 <= CC < 70
7	75	169659	70 <= CC < 80
8	85	50732	80 <= CC < 90
9	95	8735	90 <= CC <= 100

Figure 0-6. Example value attribute table for a Canopy Cover layer.

3.2.6 Canopy Height

Canopy Height is (in LANDFIRE data) a stand attribute that reflects the average height of the dominant and co-dominant overstory trees in a stand. The Canopy Height layer is used to compute the wind reduction factor attributable to the canopy and the subsequent wind speed at the mid-flame height. WFAT requires the Canopy Height layer units to be in meters * 10 (Figure 3-7), meters, feet X 10, or feet. A cell value of 0 in this layer indicates that the pixel is non-forested. The cell values can be denoted by either floating point numbers (decimals) or integers. . In this example, the units are in meters*10 and the canopy heights have been grouped into five classes in which the cell value corresponds to the mid-point of the class (this is the LANDFIRE standard).

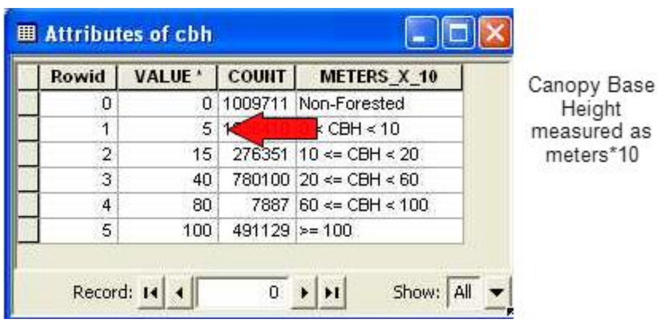


Rowid	VALUE *	COUNT	CANOPYHEIGHT_MET
0	0	[illegible]	[illegible]-Forested
1	25	2892412	0 < CH < 50
2	75	902	50 <= CH < 100
3	175	498560	100 <= CH < 250
4	375	3	250 <= CH < 500

Figure 0-7. An example value attribute table for a Canopy Height layer.

3.2.7 Canopy Base Height

Canopy Base Height is a forested stand attribute that denotes the lowest height above the ground that has sufficient canopy or ladder fuel to propagate fire vertically. The Canopy Base Height layer is necessary for determining the transition from a surface fire to a crown fire. Typically, lower canopy base heights increase the likelihood of torching or passive crown fire. WFAT requires the Canopy Base Height layer units to be in meters*10 (Figure 3-8), meters, feet*10, or feet. A cell value of 0 in this layer characterizes a non-forested pixel. Cell values can be denoted by either floating point numbers (decimals) or integers. In Figure 3-8, the *Value* field depicts heights expressed in meters*10. Thus, a cell value of 20 corresponds to a two-meter canopy base height (this is the LANDFIRE standard).


Attributes of cbh

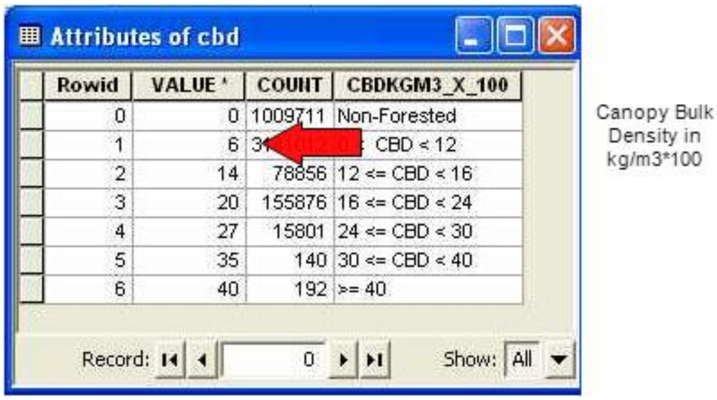
Rowid	VALUE *	COUNT	METERS_X_10
0	0	1009711	Non-Forested
1	5	1[illegible]	[illegible] CBH < 10
2	15	276351	10 <= CBH < 20
3	40	780100	20 <= CBH < 60
4	80	7887	60 <= CBH < 100
5	100	491129	>= 100

Record: 0 Show: All

Figure 0-8. Example value attribute table for a Canopy Base Height layer.

3.2.8 Canopy Bulk Density

Canopy Bulk Density is a stand attribute that refers to the weight (mass) of available canopy fuel, both dead and live, per unit volume of canopy. "Available" refers to fuel that is of a size and type that would be consumed in the flaming front. WFAT uses Canopy Bulk Density to determine the transition between passive and active crown fire. (See Scott and Reinhardt [2001] for a discussion on the derivation of crown fire activity). WFAT requires the units of the Canopy Bulk Density layer to be expressed in kg/m^3 *100 (Figure 3-9), kg/m^3, lb/ft^3*1,000, or lb/ft^3. A cell value of 0 in this layer indicates that the pixel is non-forested. Cell values can be represented by floating point numbers (decimals) or integers. . In Figure 3-9, the *Value* field depicts canopy bulk density in kg/m^3 *100. Thus a cell value of 20 corresponds to a 0.2 kgm^3 canopy bulk density. A value of 0 identifies a non-forested area.



Attributes of cbd

Rowid	VALUE *	COUNT	CBDKGM3_X_100
0	0	1009711	Non-Forested
1	6	3[illegible]	[illegible] CBD < 12
2	14	78856	12 <= CBD < 16
3	20	155876	16 <= CBD < 24
4	27	15801	24 <= CBD < 30
5	35	140	30 <= CBD < 40
6	40	192	>= 40

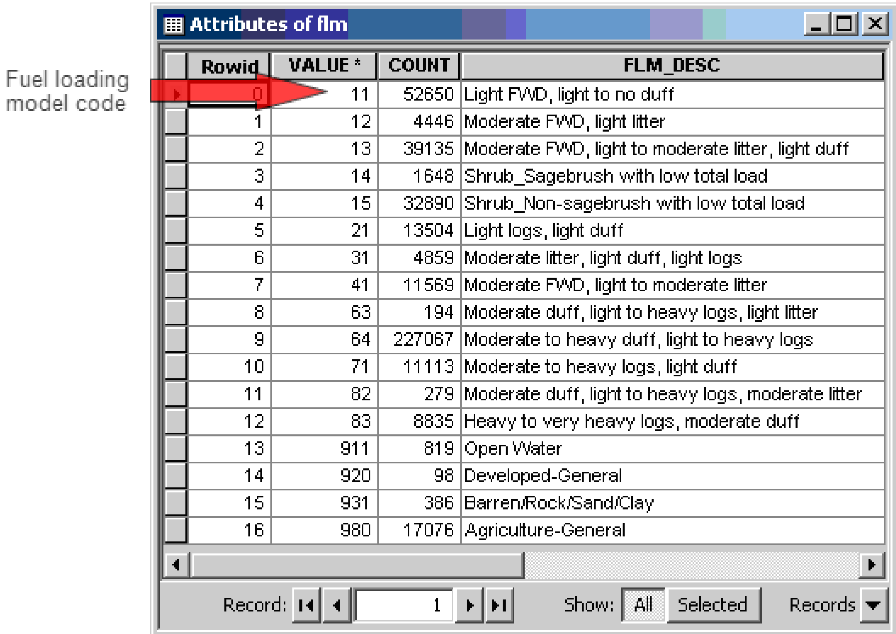
Figure 0-9. Example value attribute table for a Canopy Bulk Density layer.

3.2.9 Fire Effects Fuel Model

Fire Effects Fuel Models (FEFMs) represent categories of on-site fuel loading characteristics necessary to predict fire effects. Fire Effects Fuel Models representing forested stands are described by eight surface fuel loading values: litter, duff, 1-hour, 10-hour, 100-hour, 1000-hr, shrub, and herbaceous. Non-forested models are described by total fuel loading.

WFAT accepts two standard FEFM characterizations mapped by the LANDFIRE Program: Fuel Loading Models (FLMs; Lutes and others 2008) and Fuel Characteristics Classification System (FCCS; Ottmar and others 2007) fuelbeds – as well as a custom FEFM layer. The fuel loadings are listed in the *FuelLoadingAttributes.mdb* table located in */Program Files/NIFTT/Wildland Fire Assessment Tool v2.2.0/FuelLoadingAttributes/*. See Section 3.5 for a discussion of the custom FEFM layer.

Figure 3-10 shows the value attribute table of an example FLM layer. These values correspond to a table of surface fuel loadings, which is determined by selecting the units for FEFM. By default, the units for this grid are FLM, so remember to change them if selecting an FCCS or custom grid.



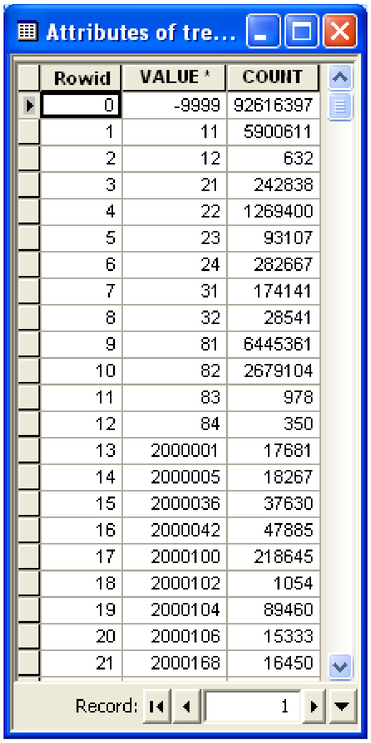
Rowid	VALUE *	COUNT	FLM_DESC
0	11	52650	Light FWD, light to no duff
1	12	4446	Moderate FWD, light litter
2	13	39135	Moderate FWD, light to moderate litter, light duff
3	14	1648	Shrub_Sagebrush with low total load
4	15	32890	Shrub_Non-sagebrush with low total load
5	21	13504	Light logs, light duff
6	31	4859	Moderate litter, light duff, light logs
7	41	11569	Moderate FWD, light to moderate litter
8	63	194	Moderate duff, light to heavy logs, light litter
9	64	227067	Moderate to heavy duff, light to heavy logs
10	71	11113	Moderate to heavy logs, light duff
11	82	279	Moderate duff, light to heavy logs, moderate litter
12	83	8835	Heavy to very heavy logs, moderate duff
13	911	819	Open Water
14	920	98	Developed-General
15	931	386	Barren/Rock/Sand/Clay
16	980	17076	Agriculture-General

Figure 0-10. Example value attribute table of a Fuel Loading Model (FLM) layer. The Value field corresponds to fuel loading model codes (Lutes and others 2008).

3.2.10 Tree List for Mortality

Tree List grids are necessary for estimating tree mortality (Drury 2011). As of the time of this user's guide's creation, the Tree List grids are not yet available via LANDFIRE. Check the NIFTT website (www.niftt.gov) for the latest status on Tree List grid availability. Local tree list data can be used if they are available.

Each cell in the Tree List layer corresponds to a tree species list that represents a stand of trees (Figure 3-11). A tree species list includes a list of tree species that occur in a stand with related density (trees/acre), DBH (in), height (ft), canopy base height (ft), and crown class (co-dominant, dominant, emergent, open grown, intermediate, or suppressed). WFAT uses the tree species list to compute all tree mortality related fire effects. The Tree List attributes are listed in the *FuelLoadingAttributes.mdb* located in */Program Files/NIFTT/Wildland Fire Assessment Tool v2.2.0/FuelLoadingAttributes/.*



Rowid	VALUE *	COUNT
0	-9999	92616397
1	11	5900611
2	12	632
3	21	242838
4	22	1269400
5	23	93107
6	24	282667
7	31	174141
8	32	28541
9	81	6445361
10	82	2679104
11	83	978
12	84	350
13	2000001	17681
14	2000005	18267
15	2000036	37630
16	2000042	47885
17	2000100	218645
18	2000102	1054
19	2000104	89460
20	2000106	15333
21	2000168	16450

Figure 0-11. Example value attribute table of a Tree List layer.

3.3 Model inputs

On WFAT's *Model Inputs* tab, the user specifies input parameters that describe the fire environment, specify the crown fire calculation method, and determine consumption algorithms in WFAT background fire modeling systems – FlamMap and FOFEM (Figure 3-12).

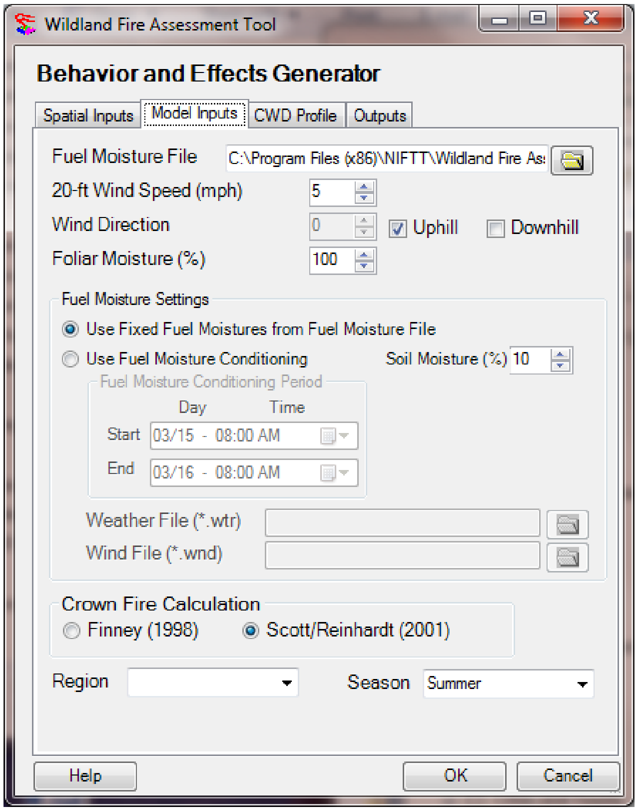


Figure 0-12. WFAT's Model Inputs tab

3.3.1 Fuel Moisture File

Like FlamMap, WFAT requires a text file (.fms) that specifies the initial fuel moisture values of the 1-hr, 10-hr, 100-hr, live herbaceous, and live woody fuel components for each of the fire behavior fuel models. The most important step in selecting appropriate fuel moisture values is to describe the type of fire weather and fuel moisture scenario to be simulated. For example, simulations designed for prescribed fire applications would likely have higher fuel moistures than those used for simulating rare event large wildfires in the extremes of the wildfire season. We recommend using data provided by the Weather Information Management System (WIMS) and FireFamily Plus to identify appropriate fuel moisture values for specific simulation scenarios.

The Fuel Moisture File used by WFAT is a space-delimited text file that has an .fms extension instead of a .txt extension. A column header is not included in the file; it is therefore very important that users understand the format. There are six columns in the .fms that denote fire behavior fuel model, 1-hour dead fuel moisture (1-hr), 10-hour dead fuel moisture (10-hr), 100-hour dead fuel moisture (100-hr), live-herbaceous fuel moisture (LH), and live-woody fuel moisture (LW), respectively (Figure 3-13). The values representing fire behavior fuel models (FBFMs) correspond to the numeric codes used by Anderson (1982) or Scott and Burgan (2005). Fuel moisture values represent percent moisture and must be integers (in other words, no decimals). (See Appendix B for additional information on fuel moisture values).

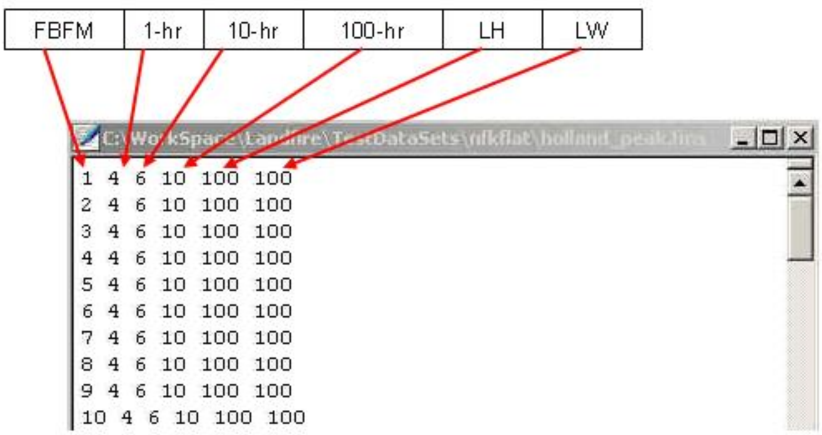


Figure 0-13. Example Fuel Moisture File that includes the first ten fuel models characterized by Anderson (1982). (FBFM = fire behavior fuel model; 1-hr = 1-hr fuel moisture; 10-hr = 10-hr fuel moisture; 100-hr = 100-hr fuel moisture; LH = live herbaceous fuel moisture; LW = live woody fuel moisture.)

3.3.2 20-ft Wind Speed (mph)

The 20-ft Wind Speed input refers to the speed of the wind that occurs 20 feet above the canopy of the dominant vegetation. Thus, in grasslands, the wind speed denotes winds at 20 ft (6.1 m) above the grass, whereas in forests, the value represents winds 20 ft (6.1 m) above the trees. Values must be integers that express wind speed in miles per hour. Using wind reduction factors, 20-ft wind speed is converted to mid-flame wind speed, which helps predict scorch height.

3.3.3 Wind Direction

Three options are available for entering Wind Direction. WFAT users may specify that the wind is blowing uphill, downhill, or they may enter an azimuth in degrees indicating the direction that the wind is blowing from. Selecting the **Wind Direction Uphill** option will maximize potential fire behavior for any given pixel.

> ***Note:*** *Checking* ***Uphill*** *or* ***Downhill*** *will overwrite the value entered for wind direction.*

3.3.4 Foliar Moisture (%)

Foliar Moisture represents the percent moisture contained by live leaves or needles of the overstory. Foliar moisture influences the transition between surface and crown fires. Typical foliar moisture values range from 80 to 130 percent. A value of 100 percent is frequently used for typical conditions and is used as the default value in WFAT. A value of 80 percent typically reflects the effects of cumulative drought in systems where average annual precipitation is less than 30 inches (76 cm), while 100 percent would reflect those same areas after recovery from drought. A value of 130 percent would reflect moist forest systems in a normal year, whereas 100 percent may reflect moist forest systems experiencing cumulative drought. Table 3-2 shows guidelines for estimating foliar moisture content based on vegetative development.

Table 0-2. Guidelines for estimating live fuel moisture content (from BehavePlus).

Moisture	Stage of Vegetative Development
300%	Fresh foliage, annuals developing, early in growing cycle
200%	Maturing foliage, still developing with full turgor
100%	Mature foliage, new growth complete and comparable to older perennial foliage
50%	Entering dormancy, coloration starting, some leaves may have dropped from the stem
30%	Completely cured, treat as dead fuel

> ***Tip****: In general, short needle species have lower foliar moisture than long needle species and dry faster during dry seasons.*

3.3.5 Fuel Moisture Settings

In WFAT, dead fuel moisture values may either be fixed or conditioned.

Fixed Fuel Moistures from Fuel Moisture File

Under the Fixed Fuel Moisture scenario, fuel moistures in the initial fuel moisture file (.fms) for 1-hour, 10-hour, and 100-hour dead fuel size classes and live herbaceous and live woody fuel components correspond directly to a fire behavior fuel model. The fuel moisture values vary spatially as the fire behavior fuel model value assigned to a cell varies across a landscape. Likewise, the 1000-hour+ (or 3"+) dead fuel moisture values specified in the Coarse Woody Debris (CWD) profile (see Section 3.4) correspond to a fire effects fuel model and only vary spatially based on the model assigned to each cell. Fuel moistures remain the same for a specific fuel model, regardless of topography or canopy cover (Figure 3-14).

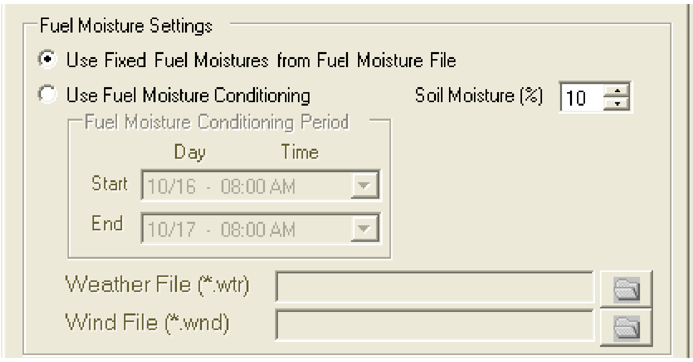


Figure 0-14. Using Fixed Fuel Moistures from the Fuel Moisture File.

Fuel Moisture Conditioning

The Fuel Moisture Conditioning function allows the program to vary fuel moisture content for dead fuel to better simulate expected variation in fuel condition. Dead fuel moisture content varies as weather and environmental conditions change. Capturing this variation can help more accurately predict fire behavior, such as rate of spread and surface fire intensity.

Fuel Moisture Conditioning adjusts the moisture content of 1-hour, 10-hour, 100-hour, and 1000-hour+ dead fuel based on variable weather conditions, conditioning period length, and site characteristics (elevation, aspect, slope, and canopy cover). If Fuel Moisture Conditioning is used, a separate fuel moisture value is calculated for each cell in the landscape. The user must specify a weather file (*.wtr), wind file (*.wnd), and conditioning period (Figure 3-15). When calculating the output grids, the dead fuel moistures from the end of the conditioning period are used, so choose a conditioning period with weather appropriate to the analysis. Live fuel moistures are *not* adjusted with this option (from the FlamMap help utility).

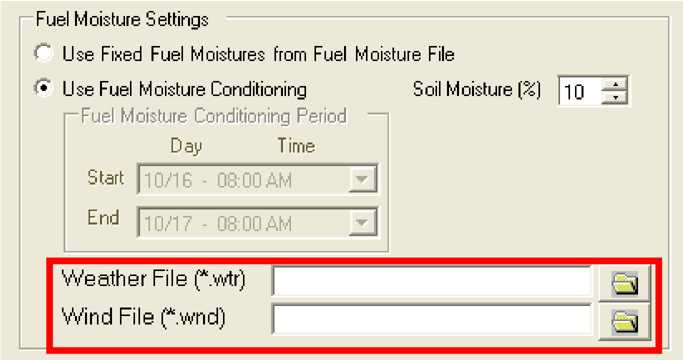


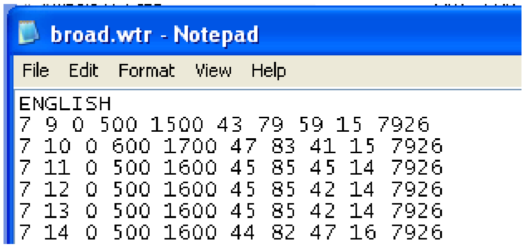
Figure 0-15. Weather and wind files are used as input for Fuel Moisture Conditioning.

Weather File (*.wtr)

A Weather File (*.wtr) contains up to five *daily* summaries of temperature, relative humidity, and precipitation. This temporal weather stream depicts a simplified version of weather changes over the days specified. The first row lists the units (for example, English units are used in the .wtr shown in Figure 3-16). Columns of the .wtr include**:**

1. Month
2. Day
3. Precipitation – the daily rain amount specified in hundredths of an inch or millimeters (integer)
4. Hour 1 – the hour at which the minimum temperature was recorded (0-2400)
5. Hour 2 – the hour at which the maximum temperature was recorded (0-2400)
6. Temperature 1 – minimum temperature in degrees Fahrenheit or Celsius (integer)

7. Temperature 2 – maximum temperature in degrees Fahrenheit or Celsius (integer)
8. Humidity 1 – maximum humidity in percent, 0 to 99 (integer)
9. Humidity 2 – minimum humidity in percent, 0 to 99 (integer)
10. Elevation - feet or meters above sea level
11. Precipitation Duration (optional) – the beginning and ending times (0-2400) of the daily rain amount. Only one time period per day is allowed. If these fields are left blank, the precipitation amount is assumed to be distributed over the entire 24-hour period. These columns are displayed only if the cumulative daily precipitation is greater than zero.



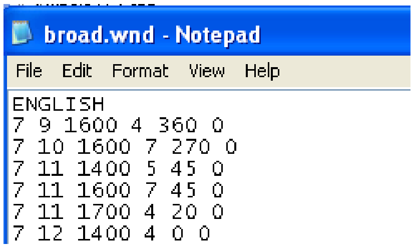
```
broad.wtr - Notepad
File Edit Format View Help
ENGLISH
7 9 0 500 1500 43 79 59 15 7926
7 10 0 600 1700 47 83 41 15 7926
7 11 0 500 1600 45 85 45 14 7926
7 12 0 500 1600 45 85 42 14 7926
7 13 0 500 1600 45 85 42 14 7926
7 14 0 500 1600 44 82 47 16 7926
```

Figure 0-16. Example of a Weather File (*.wtr).

Wind File (*.wnd)

A Wind File (*.wnd) contains *hourly* data of wind speed, wind direction, and cloud cover. This file is in text (ASCII) format. Columns of the .wnd include:

1. Month
2. Day, hour (MST)
3. Wind speed (mph)
4. Wind direction (deg from N)
5. Cloud cover (%)



```
broad.wnd - Notepad
File Edit Format View Help
ENGLISH
7 9 1600 4 360 0
7 10 1600 7 270 0
7 11 1400 5 45 0
7 11 1600 7 45 0
7 11 1700 4 20 0
7 12 1400 4 0 0
```

Figure 0-17. Example of a .Wind File (*.wnd).

Fuel Moisture Conditioning Period

The Fuel Moisture Conditioning Period is the length of time set to allow for dead fuel moistures to adjust based on weather and topography. Users must specify a start day and time as well as an end day and time. Initial fuel moistures are obtained from the fuel moisture file selected at the top of the *Model Inputs* tab.

Soil Moisture

Soil Moisture is held constant in WFAT. Typical soil moisture values range from 5% (very dry) to 25% (wet). Wet soils tend to conduct heat more rapidly than drier soils due to the conductive properties of water. A soil with higher moisture has potential to heat up more rapidly and to a greater depth than a drier soil assuming the same amount and duration of heat.

***Note**: WFAT uses the empirical relationship developed by Harrington (1982) to predict duff moisture content from the 100-hr dead fuel moisture value. If fuel moisture conditioning is used, the duff moisture equation is applied after conditioning the 100-hr fuel*.

3.3.6 Crown Fire Calculation Method

WFAT allows the user to specify the Crown Fire Calculation Method to be used: Finney (1998) or Scott and Reinhardt (2001). The choice is largely dependent on the source of the canopy bulk density (CBD) data. If the source of the CBD data is based on a method that uses biomass equations (running mean methods), the Scott and Reinhardt method (2001) should produce more accurate results, whereas the Finney (1998) method would be expected to under-predict active crown fire potential. Examples of CBD data sources based on biomass equations include LANDFIRE National, FVS-FFE, FuelCalc, and FMAPlus. If the CBD data were created or modified (for example, multiplying biomass equation derived CBD by a factor of 1.5 – 2.0) to work well with the Finney method, then the Finney method should produce the best results and the Scott and Reinhardt method would be expected to over-predict active crown fire potential. Example data sources that have modified biomass equation-derived CBD include LANDFIRE Rapid Refresh (in some areas) and some other local data projects.

***Note**: If non-biomass equation estimates of CBD are used, canopy consumption estimates and the resultant contribution to emissions may be inaccurate.*

3.3.7 Region

WFAT uses an algorithm decision key from FOFEM that selects the best available algorithm for predicting fire effects based on the conditions specified by the user. "Region" is one of the variables used within this key for selecting shrub and duff consumption algorithms. The available regions in WFAT are Interior West, Pacific West, Southeast, and Northeast (see Appendix C).

3.3.8 Season

WFAT uses the variable "Season" in the FOFEM algorithm decision key to select herbaceous and shrub consumption algorithms. The available seasons in WFAT are Spring, Summer, Fall, and Winter (see Appendix C).

3.4 Coarse Woody Debris (CWD) profile

The *Coarse Woody Debris (CWD) Profile* tab (Figure 3-18) allows the user to view the default Coarse Woody Debris profile and, if required, specify a custom profile. "Coarse woody debris" refers to down dead woody material greater than or equal to 3 inches (7.6 cm) in diameter. This material is also sometimes referred to as the 1000-hour and greater dead timelag fuel class. The information in the CWD profile is used to predict flaming and smoldering combustion of larger fuel.

The profile describes the total load, log distribution, percent rotten, and percent moisture of CWD for each model in the Fire Effects Fuel Model layer.

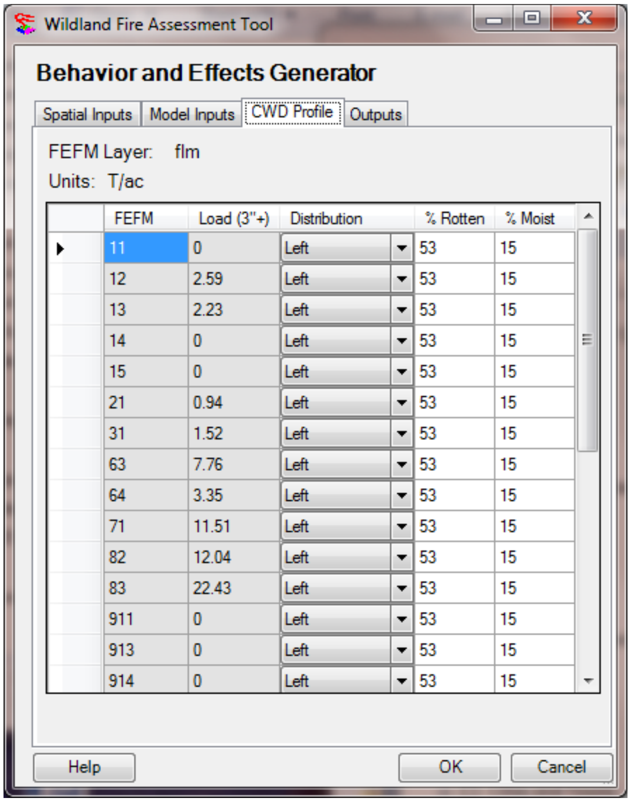


Figure 0-18. WFAT's CWD Profile tab

3.4.1 Log Distribution

Log Distribution refers to the distribution of the coarse woody debris fuel load across four diameter classes (3-5.9, 6-8.9, 9-19.9, and 20 inches and greater). Distributing the total coarse woody debris load between diameter classes improves model precision when simulating burning rate and total consumption (Lutes 2005). WFAT uses five generic representations of CWD load distribution, as follows:

1. Even – The load in all diameter classes is within 10% of each other.

2. Right - Most of the load is in pieces 9 inches (22.9 cm) and larger in diameter.

3. Left – Most of the load is in pieces 3-8.9 inches (7.6-15.0 cm) in diameter.

4. Center – Load is concentrated in the 6-19.9 inch (15.2 -22.9 cm) diameter range.

5. End – Load is in pieces 3-5.9 inches (7.6-15.0 cm) and 20 inches (50.8 cm) or greater in diameter.

Log distribution is expressed graphically as follows (Figure 3-19):

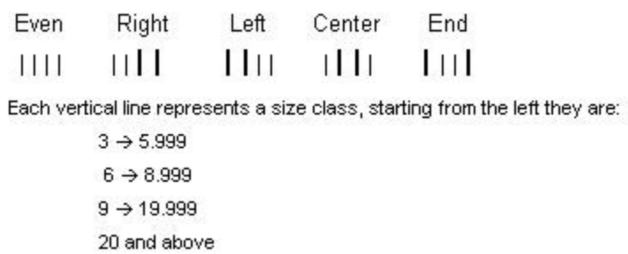


Figure 0-19. Graphical representation of a log distribution.

The CWD load in FCCS fuelbeds is distributed into three diameter classes (3-8.9, 9-19.9, and 20 inches and greater). To accommodate the four FOFEM distribution classes, the 3-8.9 inch class is first split equally into the 3-5.9 and 6-8.9 inch classes.

3.4.2 Log Percent Rotten

Percent rot of CWD is specified for each fire effects fuel model on the *CWD Profile* tab. Rotten wood has both a lower density and lower ignition temperature than sound wood. The proportion of rot within the fuel complex significantly influences consumption (Lutes 2005).

3.4.3 Log Percent Moisture

Fuel moisture greatly influences fire effects by affecting the amount of oxygen available for combustion and heat flux, and by determining the duration of flaming and smoldering combustion. Initial CWD fuel moisture values for each fire effects fuel model are specified on the *CWD Profile* tab. If Fuel Moisture Conditioning is used, these values will be modified (Section 3.3.5).

3.5 Custom FEFM

In addition to the Fuel Loading Models (FLMs; Lutes and others 2008) and Fuel Characteristics Classification System (FCCS) fuelbeds (Ottmar and others 2007), a custom FEFM layer can be used in the WFAT analysis as long as the coordinate system, spatial extent, cell resolution, and cell alignment are identical to the other input grids. To enable this option, select your custom FEFM layer from the drop-down menu as with the other inputs and select **Custom** in the *Units* column (Figure 3-20). On the *Custom FEFM* tab, you will then select the columns in the attribute table that correspond with the attribute (Figure 3-21).

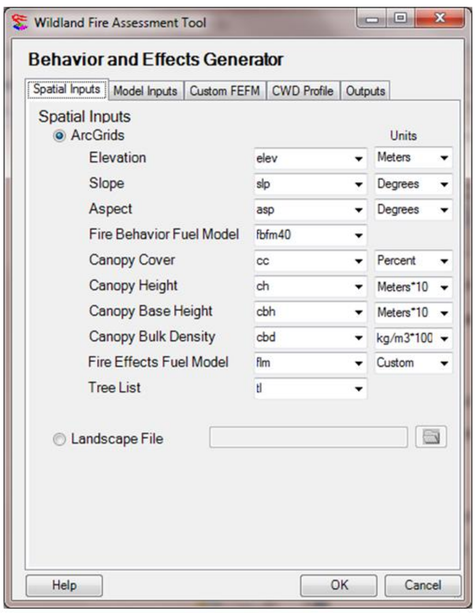


Figure 0-20. By selecting a custom FEFM and choosing Custom for the Units, a Custom FEFM tab will appear after the Model Inputs tab.

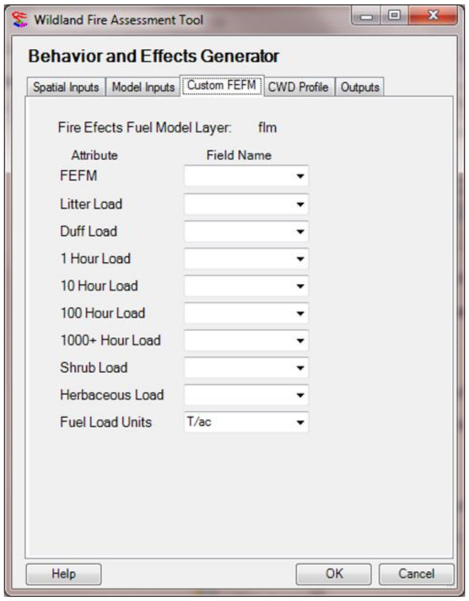


Figure 0-21. The Custom FEFM tab allows you to assign columns from the FEFM file.

The fuel loading units must be the same for all of the loading attributes. The correct format of the custom FEFM grid is critical to the successful execution of WFAT. The map layer must be in ESRI grid format and have a value attribute table with cell values represented by either floating point numbers (decimals) or integers that correspond to the following fuel component values:

- Fire Effects Fuel Model Identification Number
- Litter Load
- Duff Load
- 1-Hour Load
- 10-Hour Load
- 100-Hour Load
- 1000+ Hour Load
- Shrub Load
- Herbaceous Load

The field names in the custom grid and/or the order in which they are organized may vary from those associated with the FLM and FCCS map layers, so it is *very* important to match the custom grid field to the appropriate fuel component attribute in the *Custom FEFM* tab before running WFAT.

3.6 WFAT calculated inputs

There are several inputs that are not entered by the user but that are required by WFAT to create the many fire behavior and fire effects outputs. These missing inputs are either calculated from the inputs entered by the user or calculated from some of the outputs. For example, fire behavior outputs are needed to generate some of the fire effects outputs. A list and description of these WFAT calculated inputs can be found in Appendix D.

Output Data

4.1. WFAT outputs

WFAT outputs can be used to spatially identify areas with the potential for problematic fire behavior, fire effects, and post-fire fuels.

Fire behavior output layers are generated by WFAT as are four categories of spatial fire effects layers: fuel consumption, emissions, soil heating, and tree mortality. The following sections discuss individual outputs further.

4.2. Fire behavior and associated outputs

Table 4-1 lists both the layer and ESRI Grid names, as well as the grid format of the individual spatial outputs.

Table 0-1. Summary of WFAT's fire behavior outputs.

Fire Behavior Outputs			
Layer Name	**Grid Name**	**Grid Format**	**Units**
Flame Length	Flame	Floating point	meters
Rate of Spread	ros	Floating point	meters/minute
Fire Type	Cfa	Integer	class: 0 = non-burnable 1 = surface fire 2 = passive crown fire 3 = active crown fire
Fireline Intensity	Lineintn	Floating point	kilowatts/meter
Wildland Fire Intensity (common log of fireline intensity)	firintn	Floating point	log10(kW/meter)
Scorch Height	sh	Integer	mph
Mid-flame Wind Speed	MWS	Floating point	mph
1-hour Fuel Moisture	FMI	Integer	percent
10-hour Fuel Moisture	FMX	Integer	percent
100-hour Fuel Moisture	FMC	Integer	percent
1000-hour Fuel Moisture	FMM	Integer	percent
Duff Fuel Moisture	DM	Integer	percent
Pre-burn Canopy Fuel Load	CFL	Integer	tons/acre
Heat Released Per Area	HPA	Floating point	kJ/m^2
Max Spotting Distance	MSD	Single integer	meters
Max Spotting Direction	MSR	Single integer	degrees

Fire behavior output selections are shown in Figure 4-1. For each output tab, there is the option to "select all" which, if selected, will select all of the outputs on that tab. Once selected, you can also use it to "unselect all."

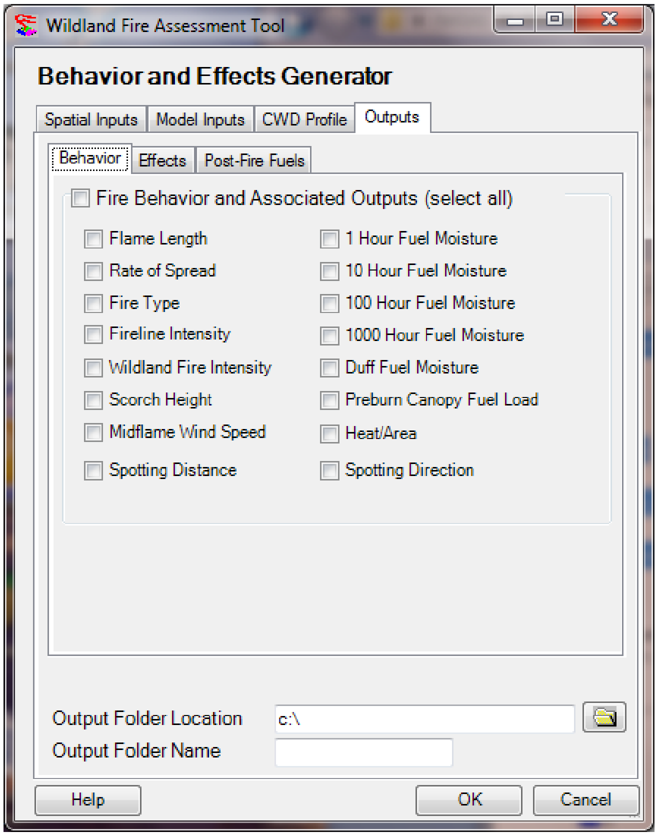


Figure 0-1. WFAT's Outputs > Behavior tab.

Note*: The default symbology for all output grids can be saved if the ArcMap project containing the outputs is saved. The default symbology is lost when the output grids are added to a new ArcMap project.*

4.2.1 Flame Length

The Flame Length output layer represents the average flame length in each map pixel. Units are expressed in meters. Flame length is the distance between the flame tip and the midpoint of the flame depth at the base of the flame (generally the ground surface). It is an indicator of fire intensity and helps predict scorch height and canopy mortality.

Selecting the Flame Length output generates both a floating point rate of spread layer and an integer Flame Length layer. WFAT's Flame Length classes are derived from the Hauling Chart (Rothermel 1983; Roussopoulo 1974).

4.2.2 Rate of Spread

The Rate of Spread layer represents the average rate of spread (ROS) in each map pixel. ROS is the speed with which a fire moves in a horizontal direction across the landscape. Units are expressed in meters per minute.

Selecting the rate of spread output generates both a floating point Rate of Spread layer and an integer Rate of Spread layer. Rate of Spread classes used by WFAT are based on and Burgan (2005).

4.2.3 Fire Type (Crown Fire Activity)

Fire Type (Crown Fire Activity) describes the type of fire that will potentially occur for each cell based on fire line intensity, canopy cover, canopy base height, canopy bulk density, and foliar moisture content. If a cell is typed to an active or passive crown fire, surface fire is also potentially occurring. Fire types are classified into four values:

Table 0-2.Name and description of Fire Type values.

Value	Fire Type	Description
0	No fire	
1	Surface fire	
2	Passive or torching fire	Low wind speed, low canopy bulk density and cover, high canopy base height
3	Active crown fire	Higher wind speed, high canopy bulk density and cover, low canopy base height

4.2.4 Fireline Intensity

The Fireline Intensity layer represents the average fireline intensity in each map pixel. Fireline intensity is the rate of heat released per unit width of fire front, regardless of its depth (Byram 1959). Units are expressed in kilowatts/meter.

4.2.5 Wildland Fire Intensity

The Wildland Fire Intensity metric was proposed by Scott (2006) to facilitate communication about and interpretation of fireline intensity. In essence, it is analogous to the logarithmic Richter scale used to measure the magnitude of earthquakes. The Wildland Fire Intensity metric is derived from the common logarithm of fireline intensity. Values typically range between zero and six, where each whole number represents an incremental increase of one order of magnitude. That is, a value of 2.0 is 10 times more intense than a value of 1.0; a value of 3.0 is 100 times more intense than a value of 1.0 and 10 times more intense than a value of 2.0. Units are expressed as Log10 (kW/meter).

4.2.6 Scorch Height

WFAT produces an output layer that represents the average scorch height or the average height of foliage browning or bole blackening caused by fire.

4.2.7 Mid-flame Wind Speed

The mid-flame wind speed is the speed of the wind at the mid-height of the flames. It is considered to be the most representative wind speed that affects fire behavior, including rate of spread. In WFAT, wind speed is calculated using the 20-ft wind speed and wind reduction factors.

4.2.8 1-Hour Fuel Moisture

The 1-Hour Fuel Moisture output grid theme is created by using the fuel moisture for each cell at the end of the optional fuel moisture conditioning period if a fuel moisture conditioning period is specified on the *Model Inputs* tab. fuel moisture file, which specifies the initial fuel moistures of the surface and ground fuel based on the fire behavior fuel model assigned to the cell.

Moisture content of dead fuel and its change over time affects fire behavior characteristics – drier fuel, in general, tends to increase rate of spread, fireline intensity, and fuel consumption.

4.2.9 10-Hour Fuel Moisture

The 10-Hour Fuel Moisture output grid theme is created using the fuel moisture for each cell at the end of the optional fuel moisture conditioning period if a fuel moisture conditioning period is specified on the *Model Inputs* tab. Otherwise, WFAT uses the fuel moistures values from the initial fuel moisture file, which specifies the initial fuel moistures of the surface and ground fuel based on the fire behavior fuel model assigned to the cell.

Moisture content of dead fuel and its change over time affects fire behavior characteristics – drier fuel, in general, tends to increase rate of spread, fireline intensity, and fuel consumption.

4.2.10 100-Hour Fuel Moisture

The 100-Hour Fuel Moisture output grid theme is created using the fuel moisture for each cell at the end of the optional fuel moisture conditioning period if a fuel moisture conditioning period is specified on the *Model Inputs* tab. Otherwise, WFAT uses the fuel moistures values from the initial fuel moisture file, which specifies the initial fuel moistures of the surface and ground fuel based on the fire behavior fuel model assigned to the cell.

Moisture content of dead fuel and its change over time affects fire behavior characteristics – drier fuel, in general, tends to increase rate of spread, fireline intensity, and fuel consumption.

4.2.11 1000-Hour Fuel Moisture

The 1000-Hour Fuel Moisture output grid theme is created using the fuel moisture for each cell at the end of the optional fuel moisture conditioning period if a fuel moisture conditioning period is specified on the *Model Inputs* tab. Otherwise, WFAT uses the fuel moistures values from the initial fuel moisture file, which specifies the initial fuel moistures of the surface and ground fuel based on the fire behavior fuel model assigned to the cell.

Moisture content of dead fuel and its change over time affects fire behavior characteristics – drier fuel, in general, tends to increase rate of spread, fireline intensity, and fuel consumption.

4.2.12 Duff Fuel Moisture

WFAT uses the empirical relationship developed by Harrington (1982) to predict duff moisture content from the 100-hr dead fuel moisture value. If fuel moisture conditioning is used, the duff moisture equation is applied after conditioning the 100-hour fuel.

4.2.13 Pre-burn Canopy Fuel Load

Pre-burn Canopy Fuel Load is calculated for each cell from canopy bulk density, canopy height, and canopy base height input grid values. It is used as a baseline to calculate canopy consumption and predict tree mortality.

4.2.14 Heat Released Per Area

The amount of heat released during the entire combustion process for the pixel. Units are in KJ/m^2.

4.2.15 Maximum Spotting Distance

The maximum distance that embers produced in this pixel could travel. Spotting Distance is heavily influence by Wind Speed.

4.2.16 Maximum Spotting Direction

The direction that embers produced in this pixel are expected to travel. Spotting Direction is heavily influenced by Wind Direction.

4.3 Fire effects outputs

WFAT produces four general categories of spatial fire effects layers: fuel loading, emissions, soil heating, and tree mortality. WFAT's fire effects outputs are summarized in the following tables.

Table 0-3: Summary table of WFAT's fire effects fuels outputs, including layer names, grid names, grid formats, and units.

Comment [DAH1]: Make sure this list is complete.

Fire Effects Outputs - Fuels			
Layer Name	**Grid Name**	**Grid Format**	**Units**
Post-burn Litter Load	litter_pos	Floating point	tons/acre
Post-burn 1-Hour Load	one_hr_pos	Floating point	tons/acre
Post-burn 10-Hour Load	ten_hr_pos	Floating point	tons/acre
Post-burn 100-Hour Load	hun_hr_pos	Floating point	tons/acre
Post-burn CWD Sound Load	cwd_snd_pos	Floating point	tons/acre
Post-burn CWD Rotten Load	cwd_rot_pos	Floating point	tons/acre
Post-burn Duff Load	duff_pos	Floating point	tons/acre
Post-burn Herbaceous Load	herb_pos	Floating point	tons/acre
Post-burn Shrub Load	shrub_pos	Floating point	tons/acre
Post-burn Canopy Load	crown_pos	Floating point	tons/acre
Post-burn Surface Load	surface_pos	Floating point	tons/acre
Total Post-burn Load	total_pos	Floating point	tons/acre
Consumed Litter Load	litter_cns	Floating point	tons/acre
Consumed 1-Hour Load	one_hr_cns	Floating point	tons/acre
Consumed 10-Hour Load	ten_hr_cns	Floating point	tons/acre
Consumed 100-Hour Load	hun_hr_cns	Floating point	tons/acre
Consumed CWD Sound Load	cwd_snd_cns	Floating point	tons/acre
Consumed CWD Rotten Load	cwd_rot_cns	Floating point	tons/acre
Consumed Duff Load	duff_cns	Floating point	tons/acre
Consumed Herbaceous Load	herb_cns	Floating point	tons/acre
Consumed Shrub Load	shrub_cns	Floating point	tons/acre
Consumed Canopy Load	crown_cns	Floating point	tons/acre
Consumed Surface Load	surface_cns	Floating point	tons/acre
Total Consumed Load	total_cns	Floating point	tons/acre
% Consumed Litter Load	litter_pct	Integer	percentage
% Consumed 1-Hour Load	one_hr_pct	Integer	percentage
% Consumed 10-Hour Load	ten_hr_pct	Integer	percentage
% Consumed 100-Hour Load	hun_hr_pct	Integer	percentage
% Consumed CWD Sound Load	cwd_snd_pct	Integer	percentage
% Consumed CWD Rotten Load	cwd_rot_pct	Integer	percentage

% Consumed Duff Load	duff_pct	Integer	percentage
% Consumed Herbaceous Load	herb_pct	Integer	percentage
% Consumed Shrub Load	shrub_pct	Integer	percentage
% Consumed Canopy Load	crown_pct	Integer	percentage
% Consumed Surface Load	surface_pct	Integer	percentage
% Consumed Total Load	total_pct	Integer	percentage
FRCC Severity	FrccSev	Integer	% Severity

Table 0-4: Summary table of WFAT's fire effects emissions outputs, including layer names, grid names, grid formats, and units.

Fire Effects Outputs - Emissions			
Layer Name	**Grid Name**	**Grid Format**	**Units**
PM10 Emissions	pm10	Integer	lbs/acre
PM2.5 Emissions	pm2_5	Integer	lbs/acre
CH_4 Emissions	ch4	Integer	lbs/acre
CO Emissions	co	Integer	lbs/acre
CO_2 Emissions	co2	Integer	lbs/acre
NOX Emissions	nox	Integer	lbs/acre
SO_2 Emissions	so2	Integer	lbs/acre

Table 0-5: Summary table of WFAT's fire effects soil outputs, including layer names, grid names, grid formats, and units.

Fire Effects Outputs - Soil			
Layer Name	**Grid Name**	**Grid Format**	**Units**
Soil Depth Heated to 60C	dep_60c	Integer	cm
Soil Depth Heated to 275C	dep_275c	Integer	cm
Percent Mineral Soil Exposed	min_exp	Integer	percent
Soil Surface Temperature	surf_temp	Integer	Celsius

Table 0-6: Summary table of WFAT's fire effects tree list outputs, including layer names, grid names, grid formats, and units.

Fire Effects Outputs - Tree List			
Layer Name	**Grid Name**	**Grid Format**	**Units**
Percent Mortality	avg_mort	Integer	percent
Percent Basal Area Mortality	perc_ba_mort	Integer	percent
Average Diameter of Fire-killed Trees	avg_dbh_k	Integer	inches
Fire Severity (Keane)	fire_sev	Integer	class

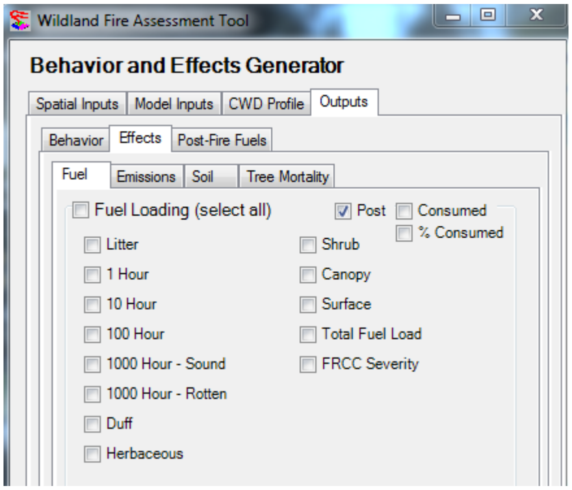


Figure 0-2. WFAT's Outputs > Effects > Fuel tab.

4.3.1 Fuel Loading (Post, Consumed and Percent Consumed)

WFAT allows the user to specify which fuel component layers are generated and whether to generate these layers for any combination of post-burn fuel load, consumed fuel load, and percent consumed fuel load. Percent consumed fuel load (PCFL) equals consumed fuel load (CFL) divided by pre-burn fuel load (PreFL) multiplied by 100. Pre-burn fuel load can be calculated as post-burn fuel load (PFL) plus consumed fuel load for any fuel components. Substituting post-burn fuel load and consumed fuel load for pre-burn fuel load, percent consumed fuel load for any fuel component can be expressed as:

PCFL = (CFL/(PFL + CFL)) * 100

Fuel components include duff, litter, 1-hr, 10-hr, 100-hr, sound and rotten CWD (1000-hr, or 3 inches [7.6 cm] and greater), herbaceous, shrub, and canopy fuel affected by crown fire.

WFAT assumes that the entire area of concern experienced fire when predicting fuel consumption. In other words, WFAT does not predict fire effects for patchy or discontinuous burns. For these situations, results should be weighted by the percent of the area burned.

WFAT via FOFEM uses the Burnup model to predict consumption of woody fuel (Albini and Reinhardt 1995; Albini and others 1995; Albini and Reinhardt 1997). Consumption of herbaceous fuel, shrub, and duff is predicted using the best available algorithm as determined by an algorithm decision key that takes into account the region, season, and cover type of the project area (see Appendix C).

Litter

The consumption of litter is calculated by the Burnup model. Generally, 100% of the litter is consumed.

1-Hour

Consumption of the 1-hour down dead woody fuel is calculated by the Burnup model. The amount of consumption is highly dependent on the amount, distribution, and moisture of this fuel component. Although FOFEM allows the user to specify the fuel category (natural, activity, or piles), WFAT assumes that the fuel category is natural.

10-Hour

The consumption of the 10-hour down dead woody fuel is calculated by the Burnup model. The amount of consumption is highly dependent on the amount, distribution, and moisture of this fuel component. Although FOFEM allows the user to specify the fuel category (natural, activity, or piles), WFAT assumes that the fuel category is natural.

100-Hour

Consumption of 100-hour down dead woody fuel is calculated by the Burnup model. The amount of consumption is highly dependent on the amount, distribution, and moisture of this fuel component. Although FOFEM allows the user to specify the fuel category (natural, activity, or piles), WFAT assumes that the fuel category is natural.

1000-Hour Sound

The consumption of sound CWD is calculated by the Burnup model. The amount of consumption is highly dependent on the amount, distribution, and moisture of the wood, as specified in the CWD profile (Section 3.4).

1000-Hour Rotten

Consumption of rotten CWD is also calculated by the Burnup model. The amount of consumption is highly dependent on the amount, distribution, and moisture of the wood, as specified in the CWD profile (Section 3.4).

Duff

A number of duff consumption algorithms are incorporated in WFAT. Separate predictions are made for percent duff consumption, duff depth consumed, and mineral soil exposure. The most appropriate algorithm is determined by the algorithm decision key (see Appendix C). Variables in WFAT that affect the selection of the duff consumption algorithm include region and cover type. Region is a user-selected variable and cover type is pre-set for fire effects fuel models in both the FLM and FCCS characterizations.

Two other variables used to determine the duff consumption algorithms in FOFEM, fuel category (natural, activity, or piles) and duff moisture method (for example, lower, upper, entire) have been set to natural and entire (average) by default in WFAT.

Herbaceous

Herbaceous fuel generally represents a small component of the total fuel load. However, for completeness, especially in the modeling of emissions, consumption is computed in WFAT. Generally, 100% of the herbaceous fuel is assumed to burn. If the cover type is "grass" and the season "spring," however, only 90% of the herbaceous fuel is consumed.

Shrub

Shrub consumption is modeled according to general rules summarized as follows:

- If the cover type is sagebrush and the season is fall, shrub consumption is 90%; for all other seasons, consumption is 50%.
- For other cover types dominated by shrubs (except in the Southeast), shrub consumption is assumed to be 80%.
- For cover types not dominated by shrubs, shrub consumption is set to 60%.
- For the southeastern region and the pocosin cover type, in spring or winter, shrub consumption is 90%; in summer or fall, it is 80%.
- For non-pocosin types in the Southeast, Hough's (1968, 1978) research was used to predict shrub consumption: percent consumption = ((3.2484 + 0.4322 * pre-burn litter and duff loading + .6765 * pre-burn shrub and regeneration loading - .0276* duff moisture – (5.0796 / pre-burn litter and duff loading) – litter and duff consumption) / pre-burn shrub and regeneration loading) * 100%.

Canopy

The canopy layer represents the consumed, post-fire or percent consumed load of canopy fuel. Units are expressed as tons per acre.

Canopy fuel load (CFL) is the oven-dry mass of available canopy fuel per unit ground area. Available canopy fuel refers to the foliage and fine branchwood (0 – 0.25 inches [0 – 6 cm]) biomass available for consumption in a crown fire.

The pre-fire canopy fuel load is calculated in WFAT using the canopy layers (CC, CH, CBD, and CBH) utilizing the following general equation:
CFL = (CBD * (CH – CBH))/2

Where,

CFL is canopy fuel load (kg/m^2)
CBD is canopy bulk density (kg/m^3)
CH is canopy height (m)
CBH is canopy base height (m)

> ***Note****: This equation assumes that the canopy bulk density data are based on a method that uses biomass equations (for example, running mean methods), such as those used in LANDFIRE National, FVS-FFE, FuelCalc, and FMAPlus. If non-biomass equation estimates of CBD are*

used, canopy consumption estimates and the resultant contribution to emissions may be inaccurate (see Section 3.3.6).

WFAT uses the Fire Type output layer values to estimate the proportion of canopy affected by crown fire. Under passive crown fire (CFA = 2), we assume that 50% of the canopy is affected. Under active crown fire (CFA = 3), we assume that 100% of the canopy is affected.

It is also assumed that the canopy fuel load consists of 10% branch biomass and 90% foliage biomass (Reinhardt personal communication). WFAT then applies the proportion of canopy affected, as based on CFA, to 100% of the foliage biomass and 50% of the branch biomass so that consumption of these fuels is represented for purposes of estimating smoke production.

Surface Fuel Load

The surface layer represents the consumed, post-fire or percent consumed load of surface fuel. Surface layer loading is comprised of the following components:

1-Hour Load
10-Hour Load
100-Hour Load
Herbaceous Load
Shrub Load

Both consumed and post-burn surface fuel loading can be expressed by summing the components listed above. Units for consumed surface load (CSL) and post-fire surface load (PSL) are expressed as tons per acre. Percent consumed surface load is expressed as a percentage as follows:

Percent Consumed Surface Load (PCSL) = (CSL/(CSL+PSL)) * 100

Total Fuel Load

This output represents the post-fire total fuel load, the consumed total fuel load and the percent total fuel load consumed. The post-fire total fuel load is the sum of the post-fire fuel load for all fuel components, expressed as follows:

Post-burn Total Load (PTL) = Post-burn Duff Load +
Post-burn Litter Load +

Post-burn 1-Hour Load +
Post-burn 10-Hour Load +
Post-burn 100-Hour Load +
Post-burn Sound CWD Load +
Post-burn Rotten CWD Load +
Post-burn Herbaceous Load +
Post-burn Shrub Load +
Post-burn Canopy Load

The consumed total fuel load is the sum of the consumed fuel load for all fuel components, expressed as follows:

Consumed Total Load (CTL) = Post-burn Duff Load +
Post-burn Litter Load +
Post-burn 1-Hour Load +
Post-burn 10-Hour Load +
Post-burn 100-Hour Load +
Post-burn Sound CWD Load +
Post-burn Rotten CWD Load +
Post-burn Herbaceous Load +
Post-burn Shrub Load +
Post-burn Canopy Load

Both consumed and post-burn total fuel loading can be expressed by summing the components listed above. Units for consumed surface load (CTL) and post-fire surface load (PTL) are expressed as tons per acre. Percent consumed surface load is expressed as a percentage as follows:

If CTL = 0 and PTL = 0 then
Percent Consumed Total Load (PCTL) = 0
Else
PCTL = (CTL/(CTL+PTL)) * 100

FRCC Severity

FRCC Severity (FS) synthesizes percent consumption of the surface fuel components along with fire type and canopy cover. This index can be utilized as the Current Severity input to the Fire Regime Condition Class (FRCC) methodology which is spatially implemented by the FRCC Mapping Tool (FRCCmt).

In grass lands (where Canopy Cover is less than 10 percent), Fuel Consumption Index is set to Percent Consumed Surface Load. In forested areas, the Fuel Consumption Index is based on Percent Consumed Surface Load normalized by Fire Type where FS is normalized between 1 and 24 percent for surface fire type, between 25 and 74 percent for passive fires and between 75 and 100 percent for active crown fires. In the locations where there was not any fire, the Fuel Consumption Index is set to 0. The Fire Type raster is an integer grid where fire types map to integer values as shown in Table 4.2.

The synthesis of Percent Consumed Surface Load (PCSL) and Fire type into FRCC Severity (FS) is as follows:

If Unburned (Fire Type = 0)	FS = 0
If Grasslands (Canopy Cover < 10)	FS = round(PCSL)
If Surface Fire (Fire Type = 1)	FS = round(PCSL * 0.24)
If Passive Crown Fire (Fire Type = 2)	FS = round (25.0 + (PCSL * 0.49))
If Active Crown Fire (Fire Type = 3)	FS = round(75.0 + (PCSL * 0.25))

4.3.2 Emissions

The Clean Air Act requires the Environmental Protection Agency (EPA) to set standards for common air pollutants that may impact the health of people, especially the young, the elderly, and those with respiratory illness. WFAT includes output layers for five of these pollutants: PM2.5, PM10, CO, NOx and SO2. It also produces outputs for CH4 and CO2.

Calculating emissions: Flaming and smoldering combustion can be simulated simultaneously in WFAT. For example, flaming combustion in woody fuel may be occurring at the same time that smoldering combustion is occurring in the duff or CWD. By distinguishing fuel weight consumed in the flaming and smoldering phases of combustion, the Burnup model allows emission factors to be applied separately to the fuel consumed in each phase. The emission factor for a particular pollutant is defined as the mass of pollutant produced per mass of fuel consumed (Hardy and others 2001). Emission factors vary by pollutant and type and arrangement of fuel. WFAT applies emission factors for particulate and chemical emissions to the fuel consumed in flaming and smoldering combustion, assuming combustion efficiencies of 0.97 for flaming and 0.67 for smoldering. For example:

Total emission = mass x combustion efficiency x emission factor.

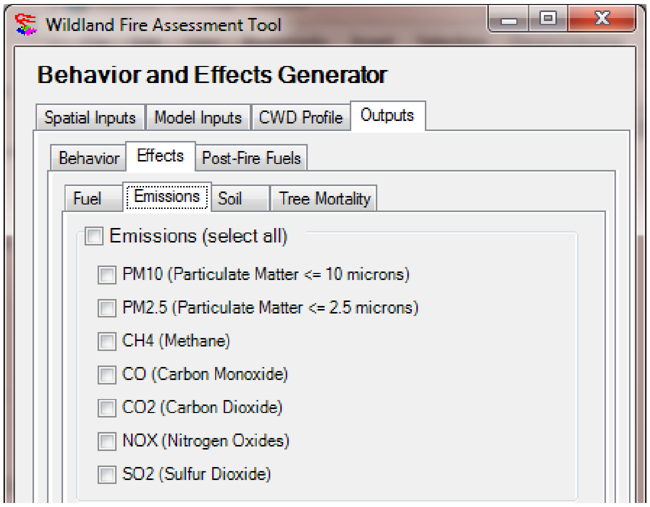


Figure 0-3. WFAT's Outputs > Effects > Emissions tab.

PM10 (Particulate Matter ≤ 10 microns)

The PM10 output layer represents particulate matter consisting of particles less than 10 microns in diameter produced by wildfire (a micron is one millionth of a meter). PM10 is considered an inhalable particle and as such can cause respiratory problems for people. It can also be transported by the wind and can change the nutrient balance and acidity of water and soil where it settles. Units are expressed in lbs/acre.

PM2.5 (Particulate Matter ≤ 2.5 microns)

PM2.5 is a small-diameter pollutant (particles less than 2.5 microns in diameter) found in wild and prescribed fire smoke emissions. It can cause serious health problems, particularly in the very young, the old, and those with heart and lung conditions. Both PM 10 and PM 2.5 are addressed by EPA's National Ambient Air Quality Standards. Because of its increased potential to impact human health, PM 2.5 is often the pollutant of greatest concern from fire. It also causes reduced visibility or haze in many wildland areas (EPA).

The amount of pollutant produced by a fire is determined by the length of the flaming and smoldering combustion phases, by fuel moisture, and by fuel size and arrangement. The PM2.5 layer is expressed as lbs/acre.

> ***Note:*** *Over 90 percent of the mass of particulate matter produced by wildland fire is less than 10 microns in diameter and over 80-90 percent of that is less than 2.5 microns in diameter (Forestry Encyclopedia).*

CH4 (Methane)

Methane is released during forest fires due to incomplete combustion of organic material. Fires can lead to the release of large amounts of methane from soil, especially in high latitude regions. Here, fires melt permafrost, which traps methane in the soil. In addition, warmer soil temperatures after fire events lead to greater microbial activity. Greater microbial activity increases the diffusion of methane from soils to the atmosphere. (EPA) In this layer, methane is expressed as lbs/acre.

CO (Carbon Monoxide)

Carbon monoxide (CO) is produced by the incomplete combustion of fuel, such as wood, and represents the most abundant emission product from wildland fires. Its negative effect on human health depends on the carbon monoxide concentration, the duration of exposure, and the level of physical activity during the exposure. Generally, dilution occurs rapidly enough from the source of the fire that carbon monoxide will not be a problem for local citizens unless a large fire occurs and inversion conditions trap the carbon monoxide near rural communities. Carbon monoxide is always a concern for wildland firefighters however, both on the fire line at prescribed fires and wildfires, and at fire camps (Reinhart and others 2000; Forest Encyclopedia).

CO2 (Carbon Dioxide)

Two products of complete combustion during fires – carbon dioxide (CO2) and water (H2O) – generally make up over 90 percent of the total emissions from wildland fire. Under ideal conditions, complete combustion of one ton of forest fuel requires 3.5 tons of air and yields 1.84 tons of CO2 and 0.54 tons of water (NWCG 1985). Under wildland conditions, however, inefficient combustion produces different yields. Neither carbon dioxide nor water vapor are considered air pollutants in the usual sense, even though carbon dioxide is considered a greenhouse gas and the water vapor will sometimes condense into liquid droplets and form a visible white smoke near the fire. This fog/smoke mixture can dramatically reduce visibility and create hazardous driving conditions. As combustion efficiency decreases, less carbon is converted to CO2 and more carbon is available to form other combustion products, such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), and sulfur oxides (SO2) – all of which are considered pollutants (Forest Encyclopedia).

NOx (Nitrogen Oxides)

Small amounts of nitrogen oxides are produced in wildland fires, primarily from the oxidation of nitrogen compounds present in the fuel. The highest emissions of NOx occur from burning fuel that has a high nitrogen content, but most fuels contain less than 1 percent nitrogen and, of that amount, only about 20 percent is converted to NOx when burned. Nitrogen oxides contribute to fire emissions by reacting with volatile organic compounds in the presence of sunlight to form ozone. (EPA; Forest Encyclopedia)

SO2 (Sulfur Dioxide)

Sulfur dioxide emissions produced by wildland fire are usually in low concentrations because most fuel is low in sulfur compounds, with exceptions being highly organic mucky or peat soils (Mobley 1976). Sulfur dioxide emissions (along with NOx) contribute to the production of acid rain and sulfur dioxide exposure is associated with respiratory illnesses, particularly in at-risk populations that include children, the elderly, and asthmatics. Units in this map layer are expressed as lbs/acre.

4.3.3 Soil

Two variations of the soil heating model were developed in FOFEM in order to simulate soil heating under conditions with burnable duff material and where there is an absence of any burnable duff. In the latter case, soil heating is attributed to the surface fire rather than the slower moving, lower intensity smoldering duff fire.

WFAT assumes the duff depth (in inches) to be $1/10^{th}$ of the duff load (tons/acre). By knowing the depth and density of duff, WFAT computes the total amount of heat that is released when it burns. This heat is released over a period of time, which is determined by the rate of spread of the fire, which in turn is correlated with the moisture of the duff material. The dryer the duff, the faster it will burn. Duff moisture is based on 100-hr fuel moisture in WFAT.

Part of the heat produced by the fire is radiated and convected away at the duff surface, and part flows into the soil. Attempting to separate these values is difficult and highly variable depending on the fire behavior; therefore, WFAT assumes a worse-case scenario with the model and applies all of the heat generated from the burning duff into the soil. It is often observed that not all of the duff material is consumed in the fire, and the remaining unburned duff acts as a soil insulator. In such cases, the model accounts for the amount of heat absorbed by the unburned duff and predicts soil heating based not only on the amount of heat generated from the burning duff, but also from the amount of heat absorbed by the unburned duff layer.

High temperatures deep into the soil profile break down organic material and can change soil chemical and physical composition. Predicting first order fire effects can aid managers in determining possible second order fire effects, such as erosion and nutrient release due to loss of the vegetation layer and changes in soil characteristics.

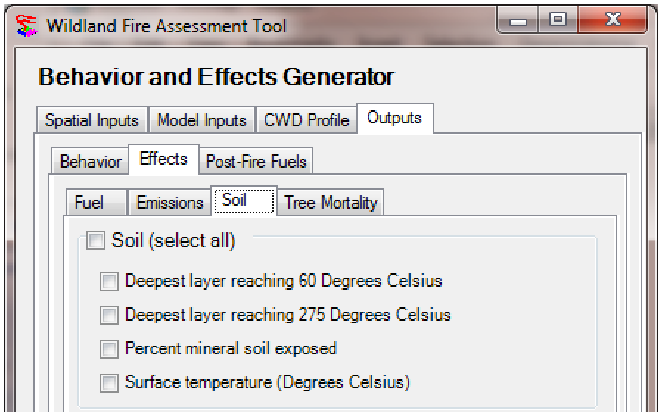


Figure 0-4. WFAT's Outputs > Effects > Soil tab.

Deepest layer reaching 60 Degrees Celsius

This layer represents the depth at which soil temperature reaches 60 degrees Celsius – the temperature at which unprotected plant tissue death begins to occur.

Deepest layer reaching 275 Degrees Celsius

This layer represents the depth at which soil temperature reaches 275 degrees Celsius – the temperature at which hydrophobic soil characteristics begin to break down.

Percent mineral soil exposed

This layer depicts percent mineral soil exposed by fire as a result of duff and litter consumption.

Surface temperature (Degrees Celsius)

Soil surface temperature during a fire can affect vegetation in several ways. High surface temperatures can enhance seed germination and stimulate plant growth in some species, but it can also reduce surface vegetation, which can increase water flow and erosion across the soil surface. Surface temperature alone is not necessarily a good indicator of fire's effects on soil and vegetation. Duration and temperature depth also play a significant role in the effects of soil heating.

4.3.4 Tree Mortality

Each cell in the Tree Mortality layer corresponds to a tree species list which represents a stand of trees. A tree species list includes a list of tree species that occur in a stand with related density (trees/acre), DBH (in), height (ft), canopy base height (ft), and crown class (co-dominant, dominant, emergent, open grown, intermediate, or suppressed). The tree species list is used in WFAT to compute all tree mortality-related fire effects.

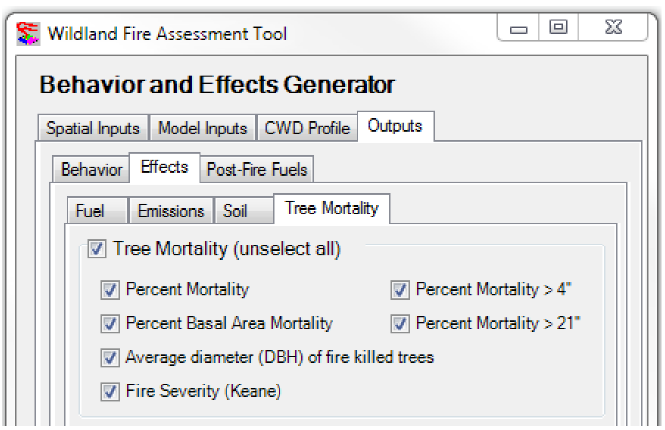


Figure 0-5. WFAT's Outputs > Effects > Tree Mortality tab.

Percent Mortality

Percent tree mortality is the number of dead trees post-fire divided by total number of pre-fire trees in the original stand, expressed as a percent. In WFAT, tree mortality is determined using predicted fireline intensity and mid-flame wind speed, along with species-specific mortality models listed in the tree species list assigned to the pixel.

Percent Basal Area Mortality

Percent basal area mortality is the percentage of basal area of the original pre-fire stand that was killed as a result of the fire. For example, if the original stand had 33.29 ft^2 basal area and 28.92 ft^2 were killed, then percent basal area mortality would be 28.92/33.29*100, or 87%.

Average diameter (DBH) of fire-killed trees

The average diameter of fire-killed trees is calculated for each pixel in the map layer by averaging the diameter (found in the tree species list) of post-fire dead trees. This output can be especially useful when simulating a prescribed fire that has specific size allowances for fire-killed trees. An example might be when your objective is to remove small understory trees while retaining larger overstory trees.

Percent Mortality > 4"

Percent tree mortality greater than 4 inches is the number of dead trees post-fire divided by total number of pre-fire trees in the original stand where we only consider trees whose diameter exceeds 4 inches. This metric is expressed as a percent. In WFAT, tree mortality is determined using predicted fireline intensity and mid-flame wind speed, along with species-specific mortality models listed in the tree species list assigned to the pixel. The intent of this metric is to exclude seedlings and saplings from consideration in the equation.

Percent Mortality > 21"

Percent tree mortality greater than 21 inches is the number of dead trees post-fire divided by total number of pre-fire trees in the original stand where we only consider trees whose diameter exceeds 21 inches. This metric is expressed as a percent. In WFAT, tree mortality is determined using predicted fireline intensity and mid-flame wind speed, along with species-specific mortality models listed in the tree species list assigned to the pixel. The intent of this metric is to only consider more mature medium and large trees in exclude the calculation

Fire Severity (Keane)

The Fire Severity (Keane) index rates fire severity based on percent basal area mortality, percent non-canopy (surface and ground) fuel consumption, and depth of soil heated to 60^{o} C. It scores each variable and then averages the total to produce the index. The thresholds for each score are listed below:

Table 0-7. Keane fire severity index

Percent Basal Area Mortality	0	1-20	20-70	>70
Percent Non-canopy Fuel Consumption	0	1-20	20-50	>50
Depth Soil Heating to 60^{o} C (cm)	0	1-2	2-6	>6
Score:	**0**	**1**	**2**	**3**

4.4 Post-fire fuel outputs

WFAT produces five post-fire fuels layers that are summarized in the following table.

Table 0-8. Summary table of WFAT's post-fire fuels outputs, including layer names, grid names, grid formats, and units.

Post-fire Fuels Outputs			
Layer Name	**Grid Name**	**Grid Format**	**Units**
Post-Fire Fire Behavior Fuel Model	FBFM_POS	Unsigned integer	value
Post-Fire Fuel Loading Model	FLM_POS	Signed integer	value
Post-Fire Canopy Cover	pfcc	Unsigned integer	percent
Post-Fire Canopy Height	pfch	Signed integer	feet
Post-Fire Canopy Based Height	pfcbh	Signed integer	feet
Post-Fire Canopy Bulk Density	pfcbd	Unsigned integer	kg/m3

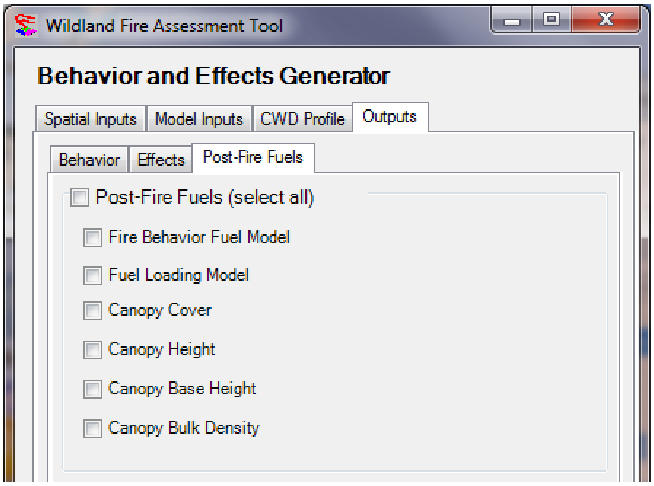


Figure 0-6. WFAT's Outputs > Post-fire Fuels tab.

4.4.1 Fire Behavior Fuel Model

WFAT contains an algorithm for selecting a standard fire behavior fuel model (FBFM) based on the modeled surface fuel characteristics present before and after treatment. The 40 FBFM (Scott and Burgan 2005) are used to create the FBFM output regardless of what was entered for the input settings. A detailed description of how this output is created can be found in Appendix E.

4.4.2 Fuel Loading Model

WFAT uses a key to assign a new fuel loading model (FLM) to each pixel after the simulation based on the post-fire fuel loading values of the surface fuel components.

4.4.3 Canopy Cover

Canopy cover represents the non-overlapping fraction of the vertical projection of tree crowns that covers the plot.

4.4.4 Canopy Height

WFAT estimates plot-level canopy height (CH) as the highest height above the ground at which CBD ≥ 0.012 kg/m3.

4.4.5 Canopy Base Height

Canopy base height is the lowest height above the ground on an individual tree above which there is sufficient canopy fuel to propagate fire vertically (Scott and Reinhardt 2007).

FuelCalc estimates plot-level canopy base height (CBH) as the lowest height above the ground at which CBD ≥ 0.012 kg/m3. This threshold-CBD method works well in most situations but can fail completely in others. For example, a plot with low CBD (due to thinning, for example, or one in a naturally open stand) may not exceed the threshold at any height, even though it is possible that every tree has a crown that extends to the ground. We addressed this issue in FuelCalc by reducing the threshold to 10 percent of the maximum CBD value for CBD less than 0.12 kg/m3. In other words, when plot-level CBD is greater than 0.12 kg.m3, the normal threshold of 0.012 kg/m3 is used; when CBD is less than 0.12, the threshold is 0.1 times the CBD value. This approach ensures that there is always a CBH value produced.

4.4.6 Canopy Bulk Density

Canopy bulk density is the mass of available canopy fuel per unit canopy volume (Scott and Reinhardt 2001) in kilograms per cubic meter.

Installing the Wildland Fire Assessment Tool

***Note**: If you have an earlier version of WFAT installed on your computer, you will first need to uninstall it before proceeding with installation of the current version.*

> ***Tip**: For best results, make sure that you have installed the most recent ArcGIS service packs and patches. Go to www.esri.com to verify that you have the most recent versions already installed on your computer. If you do not, download the newer service packs and patches as directed on the website.*

By default, the WFAT Setup Wizard loads a 32-bit FlamMap module along with the rest of WFAT, regardless of whether the computer has 32-bit or 64-bit architecture. With the 32-bit FlamMap module, we recommended that the input ArcGRIDS be no larger than 4 million pixels. This will keep the landscape file (.lcp) small enough that the 32-bit FlamMap module can load it into RAM without exceeding the 32-bit address space. There are two options for working around this size restriction when working with larger ArcGRIDS:

1. Clip the input grids into smaller pieces that contain less than 4 million pixels.
2. Install WFAT's 64-bit FlamMap module (See Appendix F).

5.1 Tool installation

- Download WFAT from www.niftt.gov on the *Tools and User Documents* page.

> ***Note**: To continue with the download, you will need to have the ability to open zip files on your computer.*

- Click **OK** or **Save** to download .zip files to a convenient location on your computer.
- Go to the file in which you stored the WFAT .zip file and double-click on the file.
- Unzip the files to either the default location (C:\\NIFTT) or to another location of your choice.
- Navigate to the directory where you have saved your extracted WFAT files.
- Click on **setup.exe**.

> ***Note**: If the setup determines that an earlier version of WFAT is already installed on your computer, go to **Start > Control Panel** and select **Add/Remove Programs.** Uninstall the previous version of WFAT and then rerun **setup.exe**.*

- If you already have the proper .NET Framework (2.0) installed on your computer (a message will alert you if you do not), the WFAT zip file contains everything that you will need to install the tool. A series of dialog boxes will now open. If you need to obtain the latest .NET Framework, go through the following steps.

- **Obtaining the latest .NET Framework**

  - If the installer determines that the setup requires a .NET Framework that has not been previously installed on your computer, you will see a dialog box similar to the one displayed below instead of the first WFAT Setup Wizard screen:

Figure 0-1. Dialog box indicating the need to first install .NET Framework for installation to proceed.

  - Click **Yes** and follow all prompts as directed. If the .NET Framework 2.0 has not been previously installed on your computer, the setup will at this point direct you to a website where you will be able to download the appropriate file.

  - You will now need to specify which version of the .NET Framework you would like to install on your computer. Select the x86 version if you have a Pentium (or other 32-bit) computer. Click on **Download x86 version**.

    Tip: *Most users will need to specify the x86 version of .NET Framework 2.0. If you are unsure, contact your system administrator.*

  - A screen similar to the following will appear after your selection has been made. Click on the **Download** button to continue.

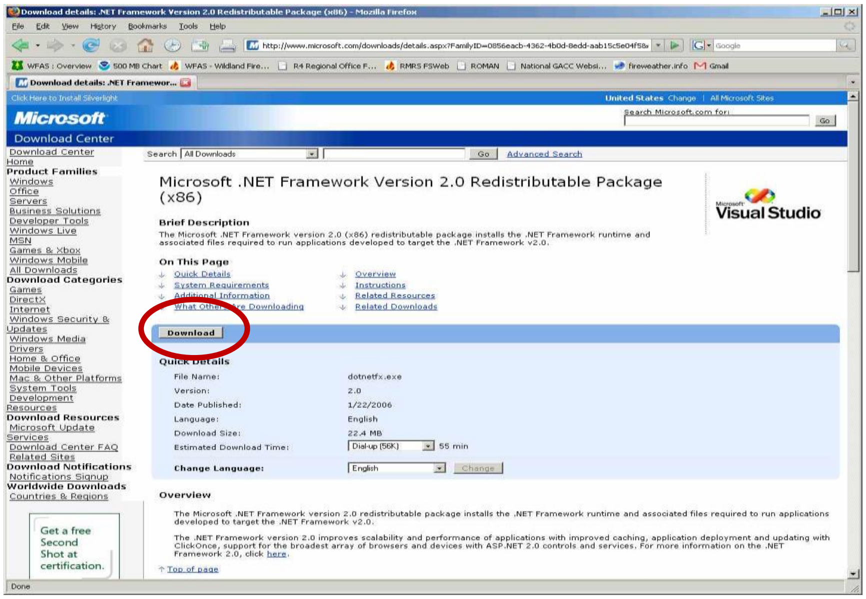


Figure 0-2: Microsoft website showing the download link for the .NET Framework

- Browse to a location of your choice. Download and save the dotnetx.exe file
- The Microsoft .NET framework 2.0 will automatically download, extract, and install.

Finishing the Installation

- Click on the **setup.exe** file to initiate the setup wizard and to continue installation of WFAT. At this point, you may need administrative privileges to continue. Contact your system administrator if you experience problems.
- Follow all instructions as directed by the dialog boxes in the WFAT Setup Wizard. During the installation process, you may see a radio button asking you to specify whether the tool is to be installed for "Everyone" or "Just Me." Select the **Everyone** option.

> ***Note**: With WFAT version 2.0.0 and higher, it is no longer necessary to reboot your computer during the installation process.*

- Click on **Finish** when the WFAT installation is complete.

- Open ArcMap and make sure that the WFAT toolbar  is visible.

> ***Note:** The WFAT toolbar may be "floating." If so, you will need to anchor it in a convenient location.*

5.2 Troubleshooting the tool installation

If the WFAT toolbar does not appear in ArcMap automatically, navigate to *Customize > Toolbars* and check the box to the left of **WFAT**.

If the WFAT toolbar is not available, click on **Customize** at the bottom of the list of all the available toolbars. Again, make sure that the box to the left of **WFAT** is checked (Figure 5-3).

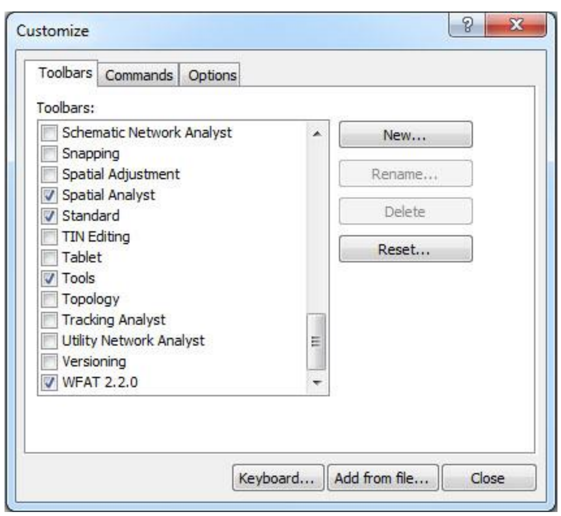


Figure 0-3. Check the box to the left of WFAT.

If the WFAT box is still unavailable in the *Toolbars* list, click on **Add from file** (Figure 5-4).

> ***Note**: To continue this process, you must first log on as an "Administrator." Contact your systems administrator if you experience problems.*

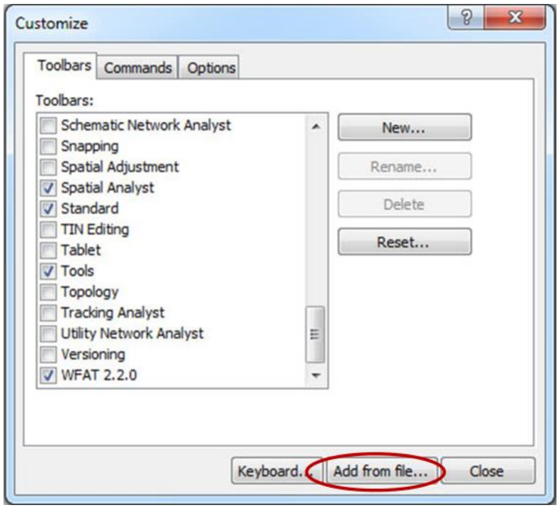


Figure 0-4. Select Add from file...

Navigate to the directory in which you have saved your extracted WFAT files (the default location is *C:\Program Files\NIFTT\Wildland Fire Assessment Tool v2.2.0)*, click on the **bin** folder, and select **WFAT.dll**.

The WFAT toolbar should now be enabled and ready for use.

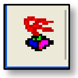
> ***Note**: For all NIFTT tools – including WFAT – to function properly, the Spatial Analyst extension must be installed and activated. Open ArcMap, go to the Customize menu, and select **Extensions**. Make sure that the box to the left of **Spatial Analyst** is checked and click **Close**.*

Please direct any questions on WFAT installation to helpdesk@niftt.gov.

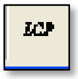
Running the Wildland Fire Assessment Tool

6.1 The Wildland Fire Assessment Tool toolbar

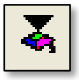
To view the title of each icon on the WFAT toolbar, place your mouse pointer over each without clicking. A brief discussion of each button follows:



Behavior and Effects Generator – Launches the WFAT application. This icon opens a dialog box that allows the WFAT user to select desired inputs and outputs.



Landscape (LCP) File Generator – Used when simulation is not desired. Clicking on this icon allows the creation of an .lcp for later use with FARSITE, FlamMap, or WFAT.



Effects from FARSITE or FlamMap Generator – Typically used to convert ASCII layers generated in FARSITE or FlamMap into ArcGrids for use in WFAT. The tool can also use outputs from FARSITE or FlamMap to generate WFAT fire behavior and effects output layers.

6.2 How to run the Wildland Fire Assessment Tool – an overview

The information presented below includes only the basic steps for running the Wildland Fire Assessment Tool. Please refer to previous chapters for more detailed information.

In addition, both a WFAT Tutorial and WFAT Online Course are available on www.niftt.gov.

6.2.1 Selecting spatial inputs

☐ Obtain and add the appropriate spatial inputs to a new ArcMap project.

The following grids are required spatial inputs. A Tree List grid is required if tree mortality outputs are desired.

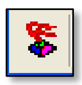
- Elevation
- Aspect
- Slope
- Fire Behavior Fuel Model (FBFM)
- Canopy Cover (CC)
- Canopy Height (CH)
- Canopy Base Height (CBH)
- Canopy Bulk Density (CBD)
- Fire Effects Fuel Model (FEFM)
- Tree List

Aside from the Tree List grid, these data layers can be obtained using the LANDFIRE Data Access Tool, which can be found on www.niftt.gov on the Tools and User Documents page.

The Tree List grid can be requested for your desired LANDFIRE mapping zone by contacting helpdesk@niftt.gov.

***Note**: All spatial layers must be in ESRI Grid format for use as WFAT inputs. These inputs must all have identical coordinate systems, spatial extents, cell resolution, and cell alignment.*

***Tip**: At this point, you may see several "Create pyramids" dialog boxes. Click **No** to speed up processing. If you do not want to see this dialog box again, put a check in the lower left-hand corner to disable it.*

☐ Start WFAT by clicking the *Behavior and Effects Generator*  icon.

☐ Adjust spatial inputs and units as needed.

***Note**: WFAT will automatically enter layers named according to the LANDFIRE Data Access Tool conventions. If layers are not immediately* *inserted into the correct field, you can use the drop-down menu to select the appropriate layer from the ArcMap Table of Contents.*

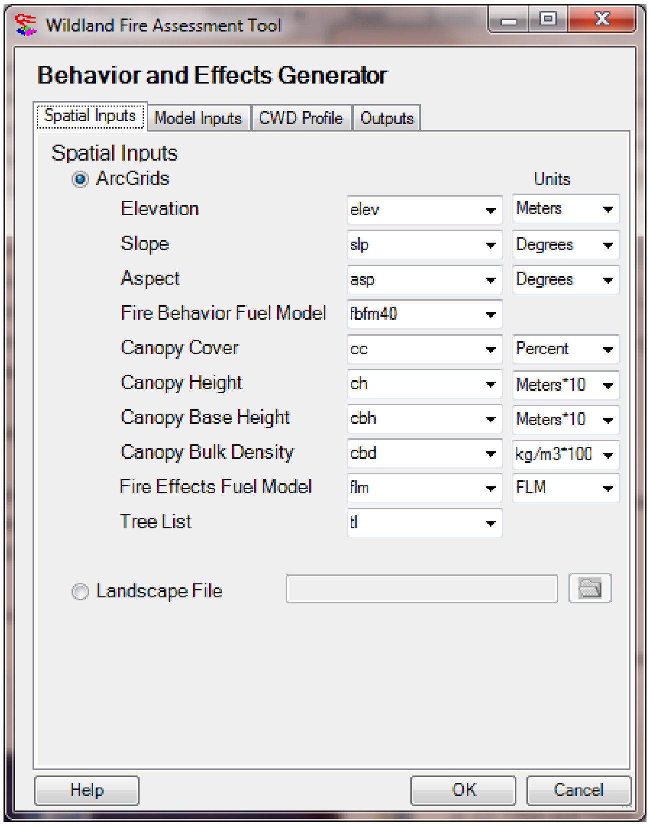


Figure 0-1. WFAT dialog box with Spatial Inputs tab selected.

- If a "Custom" FEFM layer is selected, an additional tab (*Custom FEFM*) will be added to the *Behavior and Effects Generator* dialog box. If using a custom fuelbed characterization, you will need to select field names for each corresponding attribute by using the drop-down menu to the right of each attribute box.

__Note__: If you have selected an FLM or FCCS fuelbed characterization for your run, the Custom FEFM tab will not appear at the top of the dialog box. Only four tabs will be visible.

- As an alternative to specifying each spatial input layer, you can use an already existing landscape file (.lcp). Check the radio button to the left of **Landscape File** and use the browse button to navigate to the .lcp you would like to use for your analysis. You will also need to specify a fire effects fuel model.

6.2.2 Selecting model inputs

- Click on the **Model Inputs** tab.

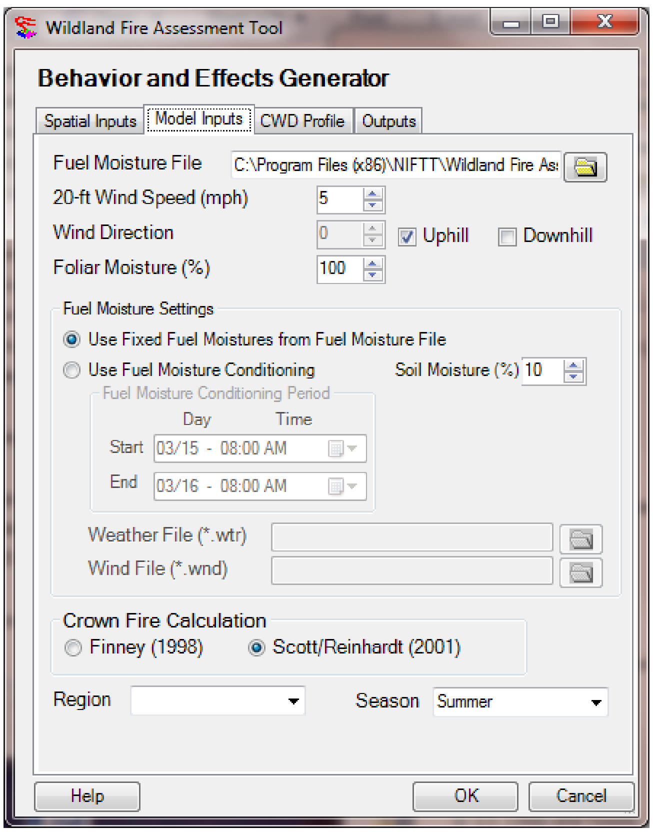


Figure 0-2. WFAT dialog box with Model Inputs tab selected.

Use the browse button to the right of the *Fuel Moisture File* box to navigate to the file you would like to use to specify initial fuel moisture values for each of the fire behavior fuel models.

WFAT is installed with a folder of default fuel moisture files for High, Moderate, Low, and Very Low fuel moisture conditions, as well as default files for FBFM 13 and FBFM 40 data. To use any of these files, navigate to the "Fuel Moisture" folder inside the WFAT installation folder (default is C:\Program Files\NIFTT\Wildland Fire Assessment Tool v2.2.0).

- Enter *Wind Speed*.
- Enter *Wind Direction*.
- Enter the *Foliar Moisture Content*.
- Specify *Fuel Moisture Settings*.
- Enter a *Soil Moisture*.
- If you selected the Fuel Moisture Conditioning option, you will need to select a Weather File (*.wtr) and Wind File (*.wtr) using the browse buttons to the right of the corresponding windows.
- To use the Fuel Moisture Conditioning option, you will need to identify a "Start" and "End" period including both Day and Time *after* selecting your wind and weather files. (These options are available only after selecting the radio button next to "Use Fuel Moisture Conditioning"). The Start and End times must fall within the range provided by your wind and weather files.
- Select a *Crown Fire Calculation* method.
- Select a *Region*.
- Select a *Season*.

6.2.3 Selecting a Coarse Woody Debris (CWD) profile

Coarse wood debris (CWD) refers to down woody material greater than or equal to 3 inches (7.6 cm).

- Click on the **CWD Profile** tab.

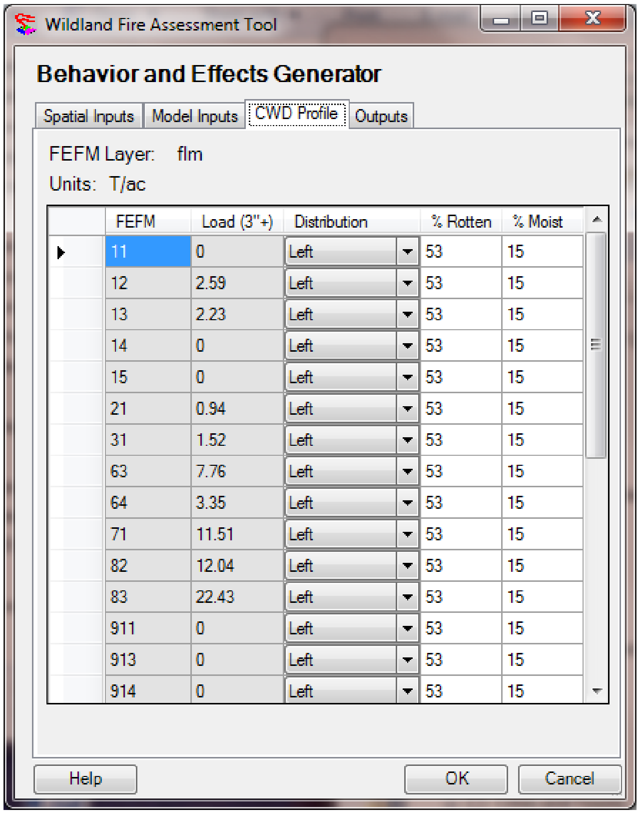


Figure 0-3. Example FEFM layer on CWD Profile tab.

- To edit values, click in the cell within the FEFM that you would like to change.

- The third column, "Distribution," contains a drop-down menu for convenience. Use the menu to select a new log distribution (**Left**, **Center**, **Right**, **Even**, or **End**) for each value you would like to edit.

6.2.4 Selecting model outputs

- Click on the **Outputs** tab.

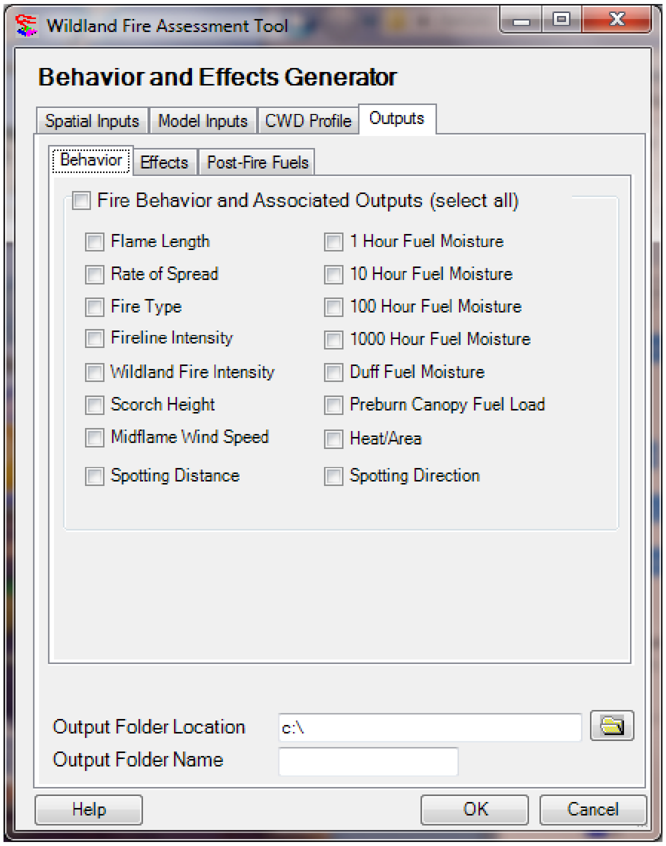


Figure 0-4. WFAT dialog box with Outputs tab selected.

- Select the desired outputs.

  ***Note**: Selecting large numbers of outputs will increase processing time result in large amounts of data.*

- Specify an *Output Folder Location*.

- Specify an *Output Folder Name*.

- Click **OK**.

> ***Note**: It may take up to an hour to process large runs and, during the run, it may appear that ArcMap is not responding. If after several hours WFAT has still not completed processing, close ArcMap and run WFAT with fewer outputs.*

The output layers will appear in your ArcMap Table of Contents and the WFAT user interface will disappear automatically when the run is complete.

- We recommend that users save their ArcMap project as soon as the WFAT run has finished. Saving the ArcMap project will preserve the label and color schemes for each output layer.

> ***Note**: The names of the output layers that appear within ArcMap's Table of Contents are descriptive labels; they are not the ESRI Grid names that will appear in the output folder you specified on the Outputs tab. (See Table 4-1 for the layer names as they will appear in ArcCatalog).*

Generating a Landscape File (.lcp)

The second icon on the WFAT toolbar, the Landscape File Generator, generates a landscape file (.lcp), but does not run FlamMap to simulate fire behavior. This utility was added to WFAT for those who would like to create a landscape file for later use with FlamMap or FARSITE.

7.1 What is a landscape file?

A landscape file is a binary file comprised of a header and a body of short integers for each of the themes it contains. The header contains information on the bounds of the area, the resolution of the cells, and the units of the themes. The .lcp contains the five basic rasterized data themes needed to run FlamMap or FARSITE: elevation, slope, aspect, fuel model, and canopy cover. The .lcp may include optional files for stand height, crown base height, canopy bulk density, coarse woody fuel, and duff loading. Optional parameters not provided in a raster file will be constant across the entire landscape as set in FlamMap's *Inputs* tab of the *Run* dialog box. Because this is the same .lcp format used in FARSITE version 4 and beyond, landscape files generated in either application are interchangeable. To use a WFAT-generated .lcp in FlamMap or FARSITE, the user must ensure that the unit settings in the data layers are the same as those required for WFAT.

7.2 Selecting input layers

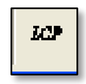
The following spatial layers are required to generate a landscape file:

- Elevation
- Slope
- Aspect
- Fire Behavior Fuel Model
- Canopy Cover
- Canopy Height

- Canopy Base Height
- Canopy Bulk Density
- Fire Effects Fuel Model

7.3 Steps for generating a landscape file

- Load the input layers into ArcMap.
- Click on the **Landscape File Generator** icon located second from the left on the WFAT toolbar.



- Select the appropriate input layers from the drop-down menu located to the right of each layer (Figure 7-1). Clicking on the drop-down menu will display all raster layers that are currently loaded in your ArcMap project.

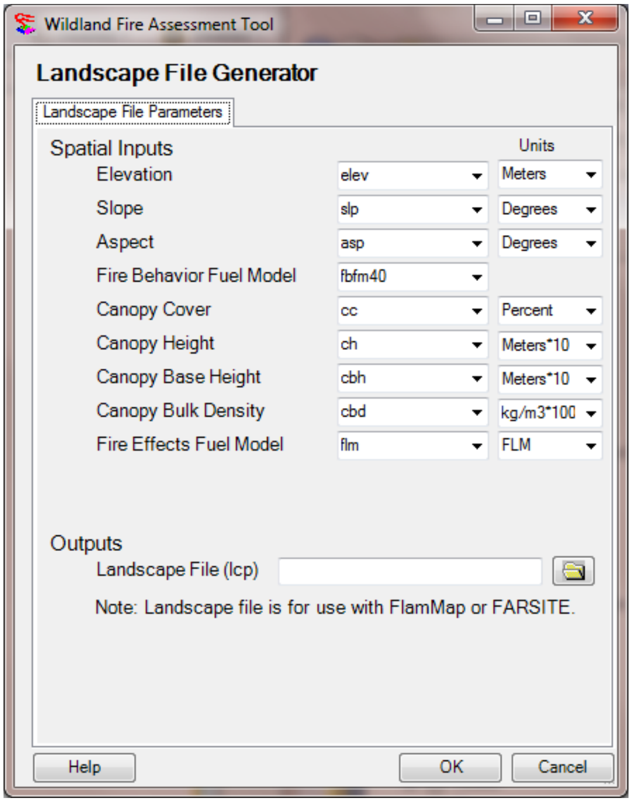


Figure 0-1. Landscape File Generator dialog box.

> ***Note***: *"Slope" and "Aspect" layers are optional inputs. If these layers are not selected by the user, WFAT will automatically derive slope and aspect layers from the elevation layer. However, slope may be calculated incorrectly if your data contains pixels with a value of "-9999," which denotes that those pixels lack data. In addition, the elevation layer will not always be named "elev." In some data sources it will be named "dem" – an abbreviation for Digital Elevation Model.*

- Next, select a Landscape File name and location by using the browse button located to the right of the *Landscape File (lcp)* field.
- Click **OK**.
- A dialog box will notify you after the landscape file (.lcp) and a related param.txt file have been created. Click **OK**.

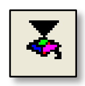
- Verify that the .lcp has been generated by checking for the file in the project folder you specified. Your .lcp is now ready for use in FlamMap or FARSITE.

__Tip__: The only indication that the .lcp has been created is that the "LCP File Creation" dialog box disappears automatically. This is not an error.

Chapter 8: Generating outputs from the Effects from FARSITE or FlamMap Generator

The *Effects from the FARSITE or FlamMap Generator* is typically used to convert ASCII layers generated in FARSITE or FlamMap into ArcGrids for use in WFAT. The tool can also use outputs from FARSITE or FlamMap to generate WFAT fire behavior, fire effects, and post-fire fuels output layers.

> ***Note:*** *To use this feature, you will need to have already run WFAT, FARSITE, or FlamMap so that you have access to an output folder from one of these programs.*

- Add the Tree List and Fire Effects Fuel Model layers for your project into ArcMap.
- Click the **Effects from FARSITE or FlamMap Generator** button: 

8.1 Selecting inputs

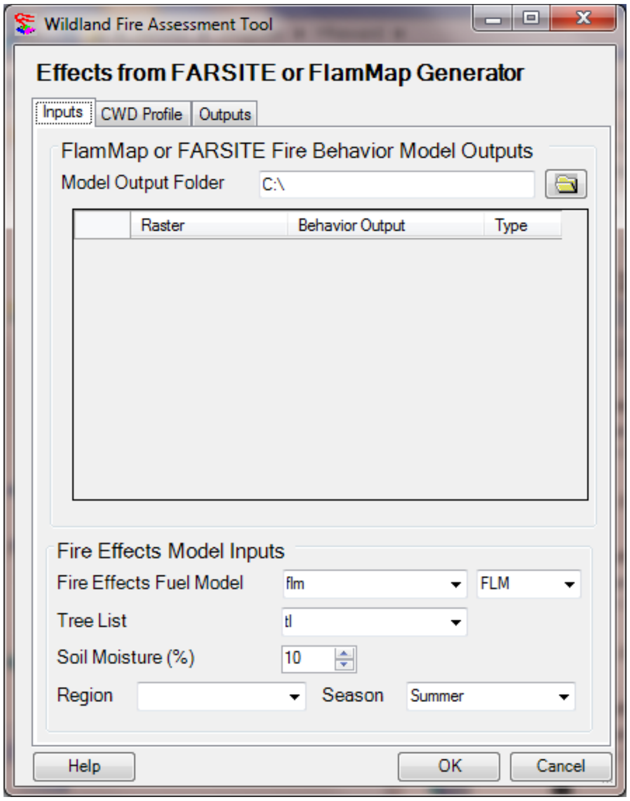


Figure 0-1. Effects from FARSITE or FlamMap Generator dialog box with Inputs tab selected.

- Click on the browse button to the right of the required input folder and navigate to the output folder of a previous WFAT, FARSITE, or FlamMap run.

- Once you have identified and selected an existing output folder containing all required output layers, the box will be automatically populated, as shown in Figure 8-2.

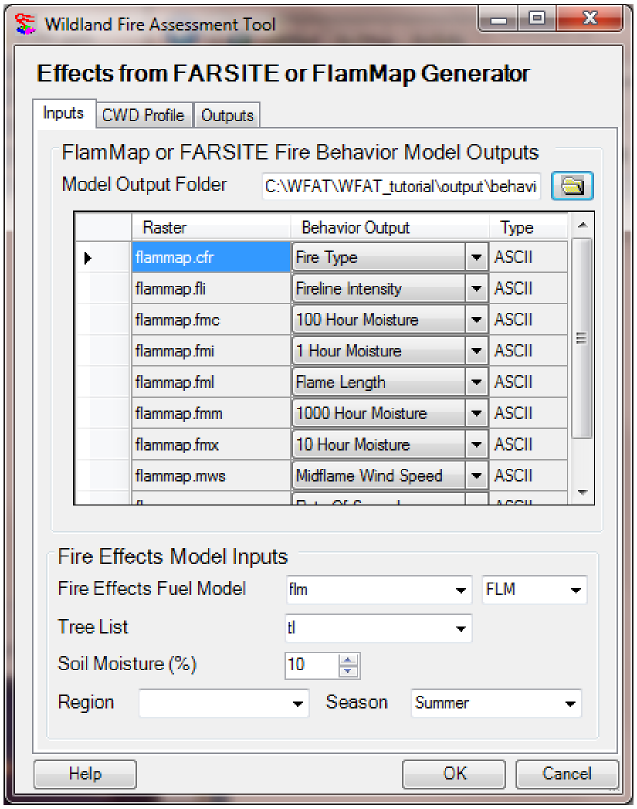


Figure 0-2. Effects from FARSITE or FlamMap Generator dialog box Inputs tab with model output folder selected.

- Select an appropriate Fire Effects Fuel Model (FLM, FCCS, or Custom) layer in the top drop-down box, which lists all layers currently available in the ArcMap Table of Contents.

  If using a custom FEFM, you will also need to complete the required information displayed in the *Custom* tab, which will appear in the dialog box.

- To generate tree mortality, select your **Tree List** input layer from the drop-down box.

- Enter a **Soil Moisture** value.

- Select a **Region**.

- Select a **Season**.

8.2 Selecting a Coarse Woody Debris (CWD) profile

- Click on the *CWD Profile* tab.

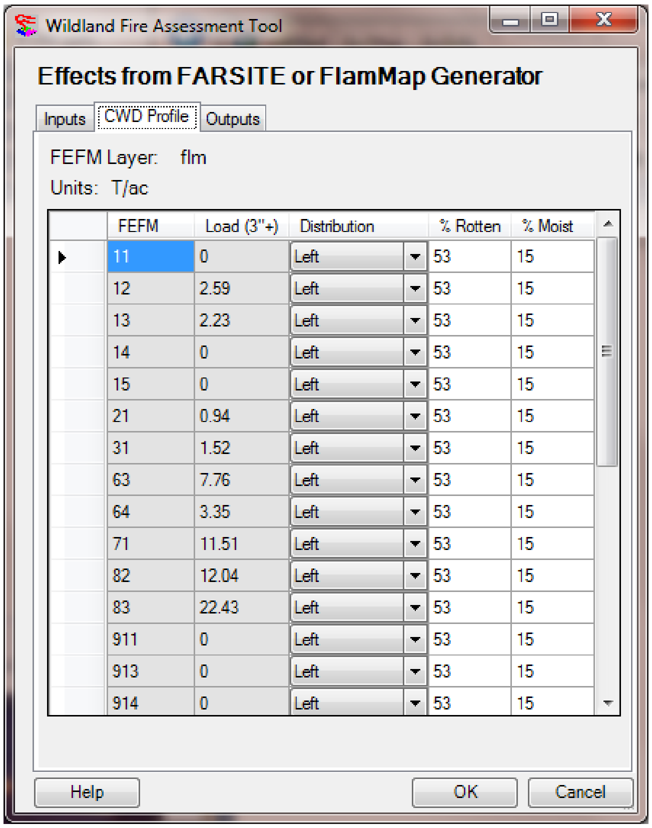


Figure 0-3. Example of a completed CWD Profile tab in the Effects from FARSITE or FlamMap Generator dialog box

> ***Note**: The "Load (3"+)" column displays the total fuel load of the CWD. If an FLM or Custom FEFM is selected, a default "Left" distribution and 53% rot is applied to the load for each FEFM. FCCS fuelbeds include information on the distribution and percent rot of the CWD load and are shown in the dialog box. Any modifications made here will redistribute the load from its original values. (See Section 3.4 for more information on this subject.)*

- Use the *CWD Profile* tab to specify a CWD profile for each value in the FEFM layer. Values include fuel load 3 inches (7.6 cm) or greater in tons per acre, load distribution, percent rotten, and percent moisture. (See Section 3.4 for additional information.)

- To edit values, click in the cell within the FEFM that you would like to change.

- The third column, "Distribution," contains a drop-down menu for convenience. Use the menu to select a new log distribution (**Left**, **Center**, **Right**, **Even**, or **End**) for each value you would like to edit. (See Section 3.4.1 for more information.)

8.3 Selecting outputs

- Click on the *Effects from FARSITE or FlamMap Generator* **Outputs** tab.
-

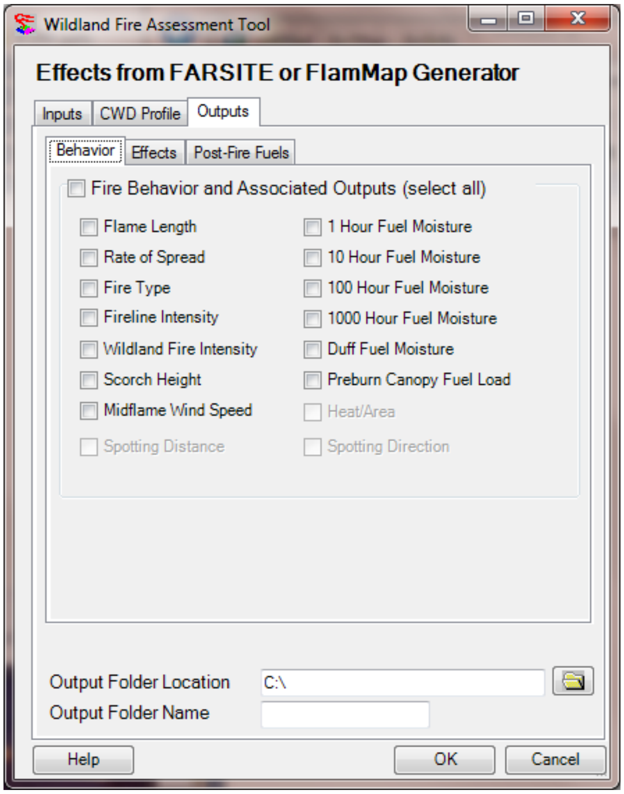


Figure 0-4. Effects from FARSITE or FlamMap Generator dialog box Outputs tab.

- Select the desired outputs.

  Note*: Selecting large numbers of outputs will increase processing time result in large amounts of data.*

- Specify an *Output Folder Location.*

- Specify an *Output Folder Name.*

- Click **OK**.

  Note*: It may take up to an hour to process large runs and, during the run, it may appear that ArcMap is not responding. If after several hours WFAT has still not completed processing, close ArcMap and run WFAT with fewer outputs.*

The output layers will appear in your ArcMap Table of Contents, and the WFAT user interface will disappear automatically when the run is complete.

- We recommend that users save their ArcMap project as soon as the WFAT run has finished. Saving the ArcMap project will preserve the label and color schemes for each output layer.

  Note*: The names of the output layers that appear within ArcMap's Table of Contents are descriptive labels; they are not the ESRI Grid names that will appear in the output folder you specified on the Outputs tab. (See* *Table 4-1* *for the layer names as they will appear in ArcCatalog.)*

Troubleshooting WFAT – Common Errors, Symptoms, and Solutions

9.1 Evaluating input data
9.2 Evaluating input parameters

Perhaps the most common WFAT user issue is that modeled potential fire behavior does not coincide with observed fire behavior. The discrepancy between simulated and observed fire behavior can generally be attributed to WFAT input parameters. These parameters can include fuel input data as well as environmental conditions, such as wind speed and direction.

Fuel data are often derived from vegetation attributes, which can be poor correlates of fuel characteristics. In addition, accurate identification of the input parameters (such as fuel moisture, wind speed, and wind direction) that result in observed fire behavior can also be problematic. For example, it may be difficult (after the fact) to identify the actual 20-ft wind speed and direction that occurred during an active crown fire.

We recommend that users review Stratton (2006) for guidance on evaluating input data and fire behavior outputs as well as for guidance on calibrating models to observed local fire behavior. The discussion of climatology and fire analysis is particularly useful for identifying appropriate environmental parameters for modeling specific fire scenarios.

The following guidelines can be used if you have doubts regarding the accuracy of your output.

9.1 Evaluating input data

1. **Evaluate the Fire Behavior Fuel Model layer**. Do the values seem appropriate for your particular analysis scenario? For example, a fuel model layer developed from observations taken during the green-up period will likely not be suitable if you are trying to simulate fire behavior to reflect conditions during the peak of the fire season. The appropriate fuel model on a given site can vary according to plant phenology, as well as with yearly fluctuation in available moisture. In addition, accurate simulation of expected fire behavior is unlikely if the fuel model has been misclassified. For example, crown fire simulation cannot generally be modeled using the Anderson (1982) Fuel Model 8: Closed Timber

Litter, which is often characterized under common burning conditions by slow-burning ground fires with low flame lengths.

2. **Evaluate the Canopy Base Height layer**. Canopy base height is a critical variable for determining the transition between surface fire and crown fire. Do the values seem reasonable for your analysis area? Simulating crown fire may be troublesome if the values for canopy base height are too high.

3. **Evaluate the Canopy Bulk Density layer.** Canopy bulk density serves as a critical variable for determining the transition from passive to active crown fire. Do the values seem reasonable for your analysis area? Simulating active crown fire may be troublesome if the values for canopy bulk density are too low.

4. **Evaluate the Canopy Cover layer.** Canopy cover and effective mid-flame wind speed are inversely related. Thus, dense canopy cover will substantially decrease mid-flame wind speed, which subsequently reduces flame length, which in turn reduces the likelihood of transition from surface fire to crown fire. Be suspicious of canopy cover values exceeding 70 percent (see Scott and Reinhardt [2005]).

5. **Evaluate the Slope layer**. Typically, slope layers are derived from digital elevation models (DEMs). A poor quality DEM can be recognized by the occurrence of "spikes" or "troughs." Using a poor quality DEM to derive a slope layer will result in unrealistic slope values.

> ***Tip:*** *Many of the errors discussed above can often be detected by simply viewing the layers and zooming-in when necessary.*

9.2 Evaluating input parameters

1. **Consider which crown fire calculation algorithm you used.** Use of the Scott and Reinhardt (2001) algorithm will increase the amount of active crown fire relative to passive crown fire.

2. **Evaluate the surface fuel moisture file used for the simulation**. Do the fuel moisture values truly reflect the scenario that you were trying to simulate? See Stratton (2006) for a detailed discussion on obtaining fuel moisture parameters from local remote automated weather stations (RAWS).

3. **Evaluate the wind speed and direction used for the simulation**. (See Stratton [2006] for information on how to obtain wind speed and direction parameters.) Because WFAT does not currently allow the use of wind vectors, we encourage

users to use the "uphill" option as this will maximize fire behavior. However, using upslope winds does not adequately simulate actual fire weather. Wind vectors, on the other hand, vary wind speed and direction according to topography to provide a more realistic simulation.

4. **Evaluate the canopy fuel moisture used for the simulation**. Many people use the default of 100 percent. This may underestimate the transition to crown fire during cumulative drought conditions or in areas with short-needled conifer species.

5. **Review the environmental parameters used for your WFAT run**. Open the param.txt file located in the output folder you specified for your simulation. Ensure that a mistake was not made when selecting the fuel moisture file, wind speed, wind direction, and/or foliar moisture content. In addition, check to make sure that you selected the correct input layers. For example, unrealistic simulations may result if you inadvertently used the canopy height layer to represent canopy base height.

> ***Note***: *For WFAT to function properly, the analysis area that you select is currently limited to approximately 4 million pixels in size.*

To report a bug, please contact helpdesk@niftt.gov.

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Appendix B: Default Fuel Moisture File (.fms)

Table B-1. Dead fuel moisture content values (in percent) for the dead fuel moisture scenarios.

	Very low	Low	Moderate	High
1-hr	3	6	9	12
10-hr	4	7	10	13
100-hr	5	8	11	14
Live herbaceous	30	60	90	120
Live woody	60	90	120	150

(From Scott and Burgan 2005)

Appendix C: Decision Dependency from FOFEM

This section details the algorithm decision key used by FOFEM to select the most appropriate algorithm for predicting the consumption of the herbaceous, shrub, and duff fuel components. The material in this appendix comes from Reinhardt and others (1997).

Herbaceous Calculations:
- Cover Type
- Season

Shrubs Calculations:
- Cover Type
- Season
- Region

Duff Calculations:
- Region
- Cover Type
- Fuel Category
- Moisture Method

Litter, Crown Branch/Foliage, Down Woody:
These fuel components are always calculated using the same equations, regardless of Cover Type, Season, etc.

Herbaceous

Herbaceous fuel is generally a small component of the total fuel load. However, for completeness, especially in modeling emission production, their consumption is computed by FOFEM. Generally, all the herbaceous fuel is assumed to burn. If the cover type is a grass type, and the season of burn is spring, only 90% of the herbaceous fuel is consumed.

Shrubs

Shrub consumption is modeled with general rules that will eventually be replaced when additional shrub consumption work is available. The general rules can be summarized as follows:

- If the cover type is sagebrush and the season is fall, shrub consumption is 90%; for all other seasons, 50%.
- For other cover types dominated by shrubs (except in the Southeast), shrub consumption is assumed to be 80%.
- For cover types not dominated by shrubs, shrub consumption is set to 60%.
- For the southeastern region, for the pocosin cover type, in spring or winter, shrub consumption is 90%, in summer or fall, 80%.
- For non-pocosin types in the Southeast, Hough's (1968, 1978) research was used to predict shrub consumption: percent consumption = ((3.2484 + 0.4322 * pre-burn litter and duff loading + .6765 * pre-burn shrub and regeneration loading - .0276* duff moisture – (5.0796 / pre-burn litter and duff loading) – litter and duff consumption) / pre-burn shrub and regeneration loading) * 100%.

Duff

A number of different duff consumption algorithms are incorporated into FOFEM5. Separate predictions are made for percent duff consumption and duff depth consumed. These equations, their sources, and the circumstances under which each is used by FOFEM are summarized below.

Equation 2: (Brown and others 1985)
%DR (duff depth reduction, %) = 83.7 - 0.426 EDM (entire duff moisture, %)

Used for predicting percent duff consumption from entire or average duff moisture content in the Interior West and Pacific West. This equation is also the default equation that FOFEM uses when it cannot find another duff consumption algorithm.

Equation 6: (Brown and others 1985)
DR = (duff depth reduction in inches) 0.8811 - 0.0096 EDM + 0.439 DPRE

Used for predicting duff depth consumption from entire or average duff moisture content in the Interior West and Pacific West. This equation is also the default equation that FOFEM uses when it cannot find another duff consumption algorithm.

Equation 10: (Brown and others 1985)
MSE (mineral soil exposure, %) = 167.4 - 31.6 log (EDM)

Used for predicting mineral soil exposure from average duff moisture content in the West. This is also the default equation FOFEM uses for predicting mineral soil exposure.

Equation 14: (Brown and others 1985)
MSE = -8.98 + 0.899 %DR

Used for predicting mineral soil exposure from percent duff reduction – a robust equation used when other information is lacking.

Equation 15: (Reinhardt and others 1991)
RD (residual duff depth in inches) = -0.791 + .004 EDM + 0.8 DPRE + 0.56 PINE (PINE = 1 if long needle type, 0 if otherwise)

Used for predicting residual duff depth from average duff moisture and pre-burn duff depth, this equation was based on data assimilated from many studies and is used where a more site-specific equation is lacking.

Equation 16: (Hough 1978)
W (loading of forest fuel consumed – litter plus duff in tons per acre) = 3.4958 + 0.3833 WPRE (WPRE = pre-burn loading of forest fuel litter plus duff in tons per acre) - 0.0237 EDM - 5.6075/WPRE
%DR = 0 if W ≤ L (pre-burn loading of litter in tons per acres)

= ((W-L)/ (WPRE-L))*100%, if W > L

Used in the Southeast except in pocosin cover types.

Equation 19
%DR = 100% (chaparral)

Equation 20: (Hungerford 1996)
DR = DPRE - 4 (pocosin)

For deep organic soils in the pocosin type, pre-burn duff depth is defined to be the depth above the water table. This depth is set to be 1 inch if moisture conditions are wet, 5 inches if moderate, 14 inches if dry, and 25 inches if very dry. These defaults can be changed by changing the pre-burn duff depth. It is assumed that the duff is consumed to within 4 inches of the water table.

Equation 201: (Hungerford 1996)
%DR (pocosin)

It is assumed that the top 8 inches of the duff are root mat with a bulk density of 0.1, and the muck below has a bulk density of 0.2. The duff loading consumed and percent duff consumption are calculated by assuming that this material burns from the top down to within 4 inches of the water table.

Equation 202: (Hungerford 1996)

$$MSE = 0\% \quad \text{(pocosin)}$$

For deep organic soils in the pocosin type, we assume mineral soil is never exposed.

Appendix D: WFAT Calculated Inputs

This section describes any special calculations that WFAT performs to generate specific outputs. The majority of outputs generated by WFAT come directly from the inputs. Some outputs, however, require additional calculation, which is noted below.

- *Crown Branch Load* = *Crown Fuel Load* * .1
- *Crown Foliage Load* = *Crown Fuel Load* * .9
- *Duff Depth* if FLM is selected
  - *Duff Load* / 10
- *Soil Type* = Coarse Silt (which is common in the West)
- *100-hr Fuel Moisture* is used to calculate the *Duff Moisture*.
- *Duff Moisture* is based on *100-hr Fuel Moisture*
  - If (*100-hr Fuel Moisture* > 6.96) then *Duff Moisture* = ((*100FuelMoisture* * 6.42) - 34.7) rounded
  - Else *Duff Moisture* = 10
- *Duff Moisture* method is always set to "Entire"
- *Moisture Condition* – based off *Duff Moisture*
  - If (*Duff Moisture* ≥ 130) then *MoistureCondition* = Wet
  - Else if (*DuffMoisture* < 130 & *DuffMoisture* ≥75)then *MoistureCondition* = Moderate
  - Else if (*DuffMoisture* ≤ 75 & *DuffMoisture* ≥ 20)then *MoistureCondition* = Dry
  - Else if (*DuffMoisture* < 20) then *MoistureCondition* = VeryDry
- *1000-hr Fuel Moisture* with Fuel Moisture Conditioning (Effects Generator assumes Fuel Moisture Conditioning)

  - Pull *1000-hr Fuel Moisture* are pulled from *1000-hr Fuel Moisture Grid* (with a min of 1)

- *1000-hr Fuel Moisture* without Fuel Moisture Conditioning

  - If FLM is in CWD profile (which it should be) the value comes from the CWD profile (for that FLM)

  - Else *1000-hr Fuel Moisture* = 15

- Cover Group is set based on the FEFM

  - If *FEFM Type = Custom*
    - CoverGroup = NO_CVRGRP ("")

  - Else if *FEFM Type = FLM*

    - If *FLM* = 66, 54, or 15

      - CoverGroup = SHRUB ("SG")

    - Else if FLM = 65, 53, or 14

      - CoverGroup = SAGEBRUSH ("SB")
    - Else

      - CoverGroup = NO_CVRGRP ("")

  - Else if *FEFMType = FCCS*

    - Pull Cover Group from Ctg column in FCCS table

Mapping of FCCS.Ctg values to cover group:
- GG Grass
- SB Sagebrush
- SG Shrub
- PC Pocosin
- PN Ponderosa
- WPH White Pine Hemlock
- RJP Red, Jack Pine
- BBS Balsam, Black, Red, White Spruce

- *Duff Load Post* (tons per acre) - load ground fuels for doing a broadcast burn

    - If *Duff Load Post* <0.45 and ≥0.35
        - Then *Duff Load Post* = 0.45
    - If *Duff Load Post* < 0.35
        - Then *Duff Load Post* = 0.0
- *Lichen* and *Moss* set to 0.0 in WFAT
- Post Load Sound Classes (SC)
    - SC 1 = 3-6 inches
    - SC 2 = 6-9 inches
    - SC 3 = 9-12 inches
    - SC 4 = 12-20 inches
    - SC 5 = 20+ inches
- *10-hr* and *1000-hr Fuel Moisture* must be between 0.01 and 3.0
    - If *10-hr Fuel Moisture* < 0.01
        - *10-hr Fuel Moisture* = 0.01
    - If *1000-hr Fuel Moisture* < 0.01
        - *1000-hr Fuel Moisture* = 0.01
- Percent of *Moss and Lichen Consumed* = 90%
- If *Duff Load Post* > 0.0
    - *Duff Depth Post* = *Duff Load Post*/10
- *Duff Moisture* = 0.1
- *Fire Behavior Fuel Model* = Scott and Burgan 40
- *Climate* = Arid

- *1-hr Surface Area to Volume Ratio* (SAV) = 2000.0
- *Grass SAV* = 2000.0
- *Shrub SAV* = 1500.0
- *Fuel Bed Depth* = 6 inches
- If *Crown Class* = "G", "O", "-9", ""
    - *Crown Class* = "D"
- If *Tree Heigh*t ≤ *Height to crown* (HCB)
    - *HCB* = *Tree Height* -0.1
- *Retention Priorotiy* = 0.5

Appendix E: Fuel Model Selection

Selecting a standard fuel model from fuel load data constitutes a two-step process. The first step is narrowing the range of fuel model choices to a reasonable handful based on fuel type, climate type, and fuel model set. In step two, you select from the narrowed list based on a similarity index of fuelbed characteristics, such as fine fuel load, characteristic surface-area-to-volume ratio, packing ratio, and bulk density. These characteristics can be calculated for both the measured/modeled fuel loads and for the standard fuel models.

E.1 Narrowing the fuel model choices

For any given fuelbed, three pieces of information are used to narrow the list of fuel model choices: major fire-carrying fuel type, climate type, and fuel model set. A set of rules is used to classify the fuelbed into a major fire-carrying fuel type. Climate type and fuel model set are direct inputs from the user.

E.1.1 Fire-carrying fuel type

The FuelCalc method recognizes four of the six fire-carrying fuel types described in Scott and Burgan (2005): grass (GR), grass-shrub (GS), shrub or timber-understory (SH/TU), and timber litter or slash/blowdown (TL/SB). TL and SB fuel types are combined because both consist only of dead fuel. SH and TU fuel types are combined because both consist of a large fraction of dead fuel with a component of live woody or herbaceous fuel. A simple key is used to classify any fuelbed into one of these fuel types. Three fuelbed characteristics must be calculated to use the key:

LiveFraction is the ratio of live fuel load (grass/herbaceous load plus fine live shrub) to the total fine fuel load (which is the live fuel load plus the 1-hour timelag class dead fuel load). LiveFraction is used to determine if the fuelbed should be treated as a dead-fuel-only fuel model or as a fuel model that contains live fuel. LiveFraction theoretically varies between 0.0 (for fuelbeds with no live fuel) and 1.0 (for fuelbeds with only live fuel). In practice, fuelbeds normally have some amount of dead fuel, so the LiveFraction normally approaches 1.0 without reaching it.

HerbFraction is the ratio of the herbaceous load to the total fine fuel load. HerbFraction is used to determine if a fuelbed that has previously been determined to have a live fuel component is a grass-dominated fuelbed. Like LiveFraction, HerbFraction theoretically varies between 0.0 (for fuelbeds with no herbaceous fuel) and 1.0 (for fuelbeds with only herbaceous fuel). In practice, even pure-grass fuelbeds normally have some amount of dead fuel (for example, grass litter), so the HerbFraction normally approaches 1.0 without reaching it. A grass-dominated fuelbed will have a high HerbFraction.

HerbRatio is the ratio of the herbaceous load to the fine live woody load, which varies between 0.0 and 1.0 for all fuelbeds. If the fuelbed has no live woody load, this ratio should be set to 1.0.

Once the above quantities have been computed, the following selection key identifies the fire carrying fuel type. (In the unlikely event that at fuelbed contains no fine fuel load – just 10- and 100-hour timelag class dead particles – then the fuel type is set to TL/SB.)

A. IF *LiveFraction* ≤ 0.20, THEN the live fraction is inconsequential and a fuel model that does not include any live fuel will be selected (FuelType = TL/SB)
B. IF *LiveFraction* > 0.20, THEN the live fraction is significant, and a fuel model that contains a live herbaceous or live woody component will be selected (continue with a. below)
    a. IF *HerbFraction* ≥ 0.75, THEN the fuelbed is dominated by herbaceous fuel and a grass-dominated fuel model will be available for selection (FuelType = GR)
    b. IF *HerbFraction* < 0.75, THEN the fuelbed is not dominated by grass/herbaceous fuel (continue with i. below)
        i. IF *HerbRatio* > 2.0, THEN grass/herbaceous component is dominant and fuel type is GR
        ii. IF *HerbRatio* > 0.25 but ≤ 2.0, THEN both the grass/herbaceous load is enough to require a GS fuel model, but not enough to indicate a GR model, as above (FuelType = GS)
        iii. IF *HerbRatio* ≤ 0.25, THEN the grass component is not enough to indicate a GS fuel model, and any SH or TU fuel model may be appropriate (FuelType=SH/TU)

E.1.2 Climate type

Fuel models appropriate for humid and sub-humid climates have higher extinction moisture contents than fuel models for arid and semi-arid climates. Therefore, a different set of fuel models are available for selection in the different climate types (with some overlap). Depending on the application, climate type may be set by the application (by variant in FVS-FFE, for example) or the user will need to indicate the climate type separately (for example, in FuelCalc). Therefore, two climate types are available: arid to semi-arid climates (low extinction moisture content) and humid to sub-humid climates (high extinction moisture content).

E.2 Selecting a fuel model from the narrowed list

Once the list of potential fuel models has been narrowed from Step 1, the next step is to compute a similarity index comparing characteristics of the subject fuelbed to characteristics of each of the fuel models in the narrowed list.

E.2.1 Similarity index

The similarity index is the weighted average of three separate fuelbed similarity factors: characteristic surface-area-to-volume ratio (SAV; σ), fuelbed bulk density (ρ), and load (L) of live and dead fuel less than 6 mm (0.25 in) in diameter. Bulk density and SAV are weighted equally; fine fuel load receives twice the weight of SAV and bulk density. Each of these individual factors is the square of the difference between the fuelbed characteristic and the fuel model characteristic, normalized by dividing by the standard deviation of the characteristic across all 53 standard fuel models. The proposed similarity index is therefore defined as follows:

$$Similarity = 0.25 * \left(\frac{\sigma_{fuelbed} - \sigma_{fm}}{409.0}\right)^2 + 0.25 * \left(\frac{\rho_{fuelbed} - \rho_{fm}}{0.4030}\right)^2 + 0.50 * \left(\frac{Wf_{fuelbed} - Wf_{fm}}{3.073}\right)^2$$

Where:
$\sigma_{fuelbed}$ is the SAV of the subject fuelbed
σ_{fm} is the SAV of the subject standard fuel model
409.0 is the standard deviation of SAV of the 53 standard fuel models
$\rho_{fuelbed}$ is the bulk density of the subject fuelbed
ρ_{fm} is the bulk density of the subject standard fuel model
0.4030 is the standard deviation of the bulk density of the 53 standard fuel models
$Wf_{fuelbed}$ is the fine fuel load of the subject fuelbed
Wf_{fm} is the fine fuel load of the subject standard fuel model
3.073 is the standard deviation of the fine fuel load of the 53 standard fuel models

For each subject fuelbed, the similarity index is computed for each of the standard fuel models on the narrowed list from Step 1.

E.2.2 Selecting a standard fuel model

The single best standard fuel model for the subject fuelbed is the one with the lowest similarity index. An index value of 0.0 indicates that all three fuel characteristics of the subject fuelbed exactly match one of the standard fuel models.

Appendix F: Running the Wildland Fire Assessment Tool with the FlamMap Module x64

F.1 Prerequisites for installing the 64-bit FlamMap module

In order to install the 64-bit FlamMap module, the computer it is being installed on must be a 64-bit computer that is running a 64-bit Windows operating system. One way to tell if your computer is running a 64-bit operating system is to check your computer's properties. To bring up your computer properties dialog box, run Windows Explorer and right click on **Computer**, then select **Properties** from the context menu.

Figure F-1. The Windows 7 Computer Properties dialog box showing that the computer has a 64 bit operating system.

Under Windows 7 and Vista, check the *System* > *System Type* property to determine whether your computer is running a 64-bit operating system. Another important piece of information on the Computer Properties dialog box can be found in *System* > *Installed Memory (RAM),* which will indicate how many gigabytes of RAM are installed on the computer.

F.2 64-bit FlamMap module installation instructions

Before installing WFAT's 64-bit FlamMap module, WFAT must first be installed. To verify that WFAT has been installed, go to **Start > Control Panel > Uninstall a Program**, as shown below.

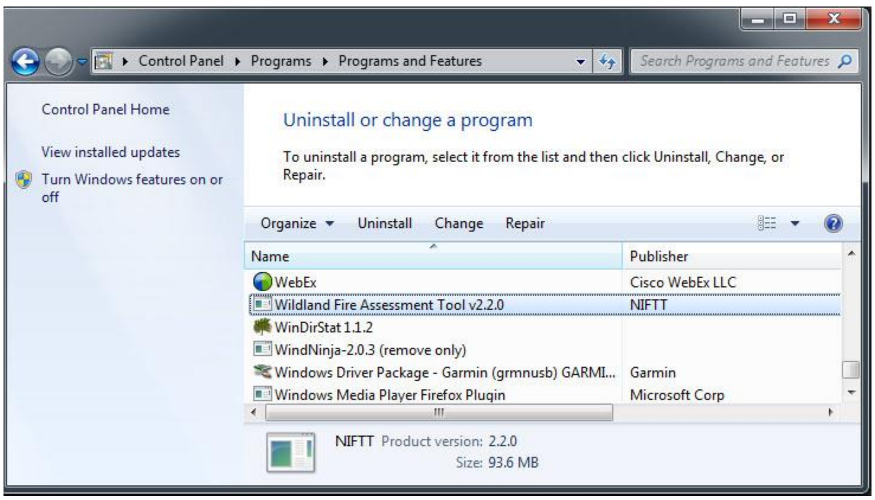

Figure F-2. Wildland Fire Assessment Tool v2.2.0 is installed.

While verifying that WFAT has been installed, it also necessary to verify that the WFAT FlamMap Module x64 has not been previously installed.

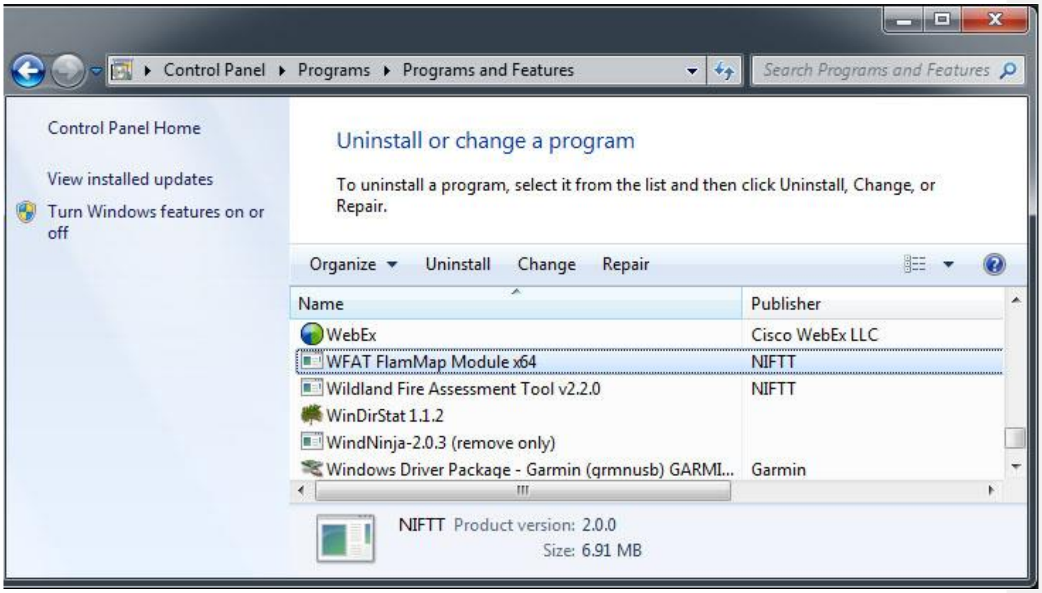

Figure F-3. WFAT FlamMap Module x64 has already been installed previously, so it will need to be uninstalled prior to running the WFAT FlamMap Module x64 install that's included with WFAT v 2.2.0.

After WFAT has been installed, navigate with Windows Explorer to the folder in which WFAT was installed. By default, on a 64-bit windows operating system, this will be *C:\Program Files (x86)\NIFTT\Wildland Fire Assessment Tool v2.2.0*. Within the install folder, navigate to the *Flammap Module x64 Install* folder, where you will find an installation package called *FlamMapModule_x64_Setup.msi***.** Double-click on the .msi file to launch the FlamMap Module x64 installer. As the WFAT FlamMap Module x64 Setup Wizard runs, follow the instructions, clicking **Next** until the WFAT FlamMap Module x64 Setup Wizard allows you to select the installation folder. Enter the same path that WFAT was installed to (for example, *C:\Program Files (x86)\NIFTT\Wildland Fire Assessment Tool v2.2.0*). The default on a 64-bit windows operating system is *C:\Program Files (x86)\NIFTT\Wildland Fire Assessment Tool v2.2.0.*

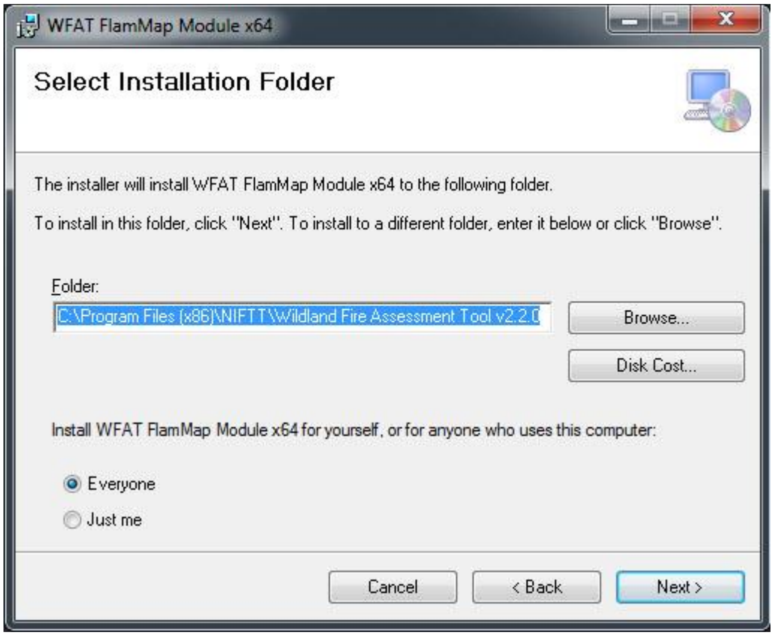

Figure F-4. Specifying the folder where WFAT was installed when selecting the installation folder for the WFAT FlamMap Module x64.

Continue clicking **Next** until the Setup Wizard indicates that the installation is complete and then click **Close** to exit the Setup Wizard.

F.3 Maximum size of input ArcGRIDs

The maximum size of input ArcGRIDs that WFAT can process when running the FlamMap Module x64 is directly related to how much RAM the computer has. One option for increasing the size of ArcGRIDS that WFAT can process without increasing RAM is increasing the amount of Virtual Memory. To set the amount of virtual memory available on the computer, bring up your computer properties dialog box from Windows Explorer (see Section F-1). On the left, right-click on **Computer** and then select **Properties** from the context menu.

Figure F-5. The Windows 7 computer properties dialog box showing that the computer has a 64-bit operating system.

Click on **Advanced system settings** on the left to launch the *System Properties* dialog box. Click on the **Advanced** tab.

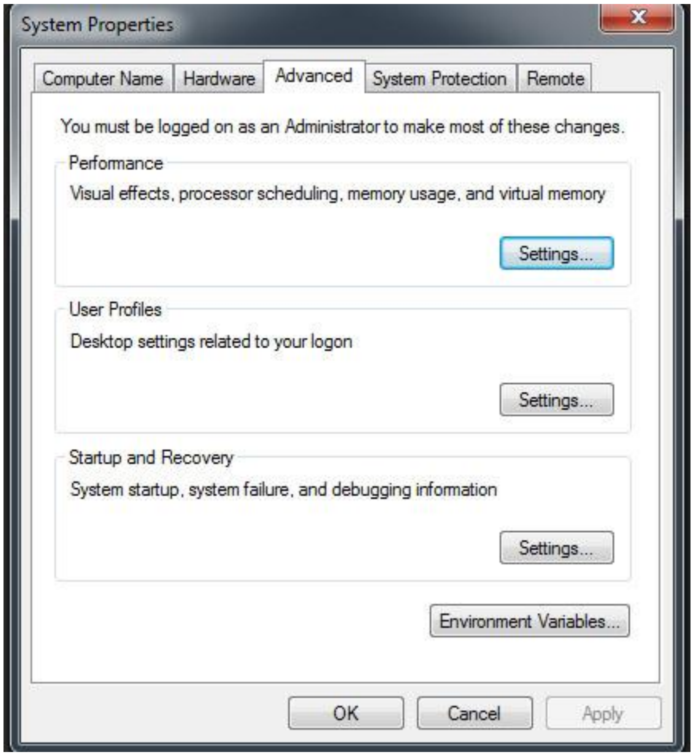

Figure F-6. The *System Properties* dialog box.

In the *Performance* section of the *Advanced* tab, clicking the **Settings** button will bring up the *Performance Options* dialog box, where you will select the **Advanced** tab.

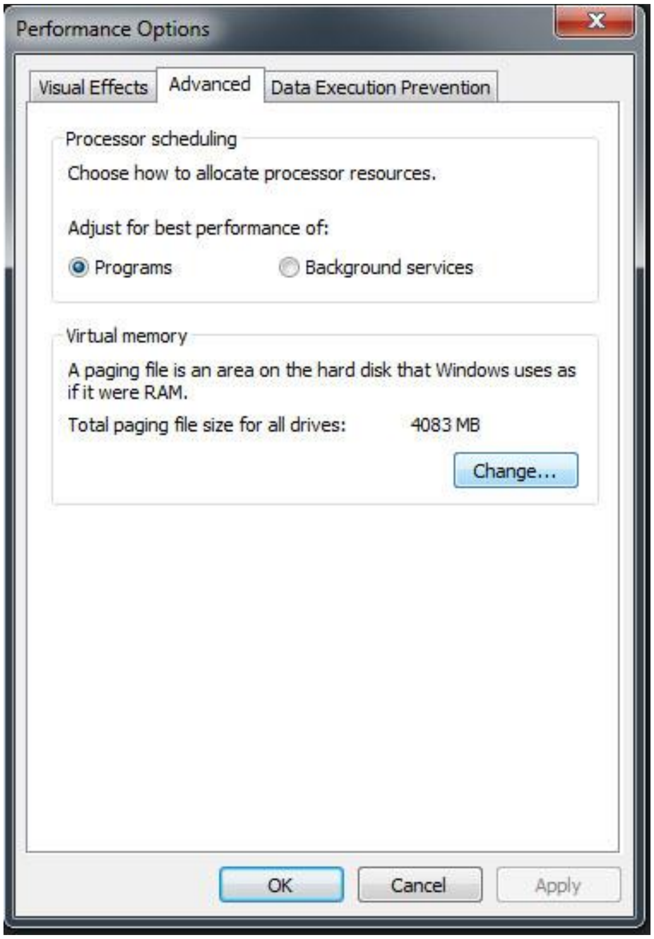

Figure F-7. The *Performance Options* dialog box's *Advanced* tab.

Click on the **Change** button in the *Virtual Memory* section to bring up the *Virtual Memory* dialog box.

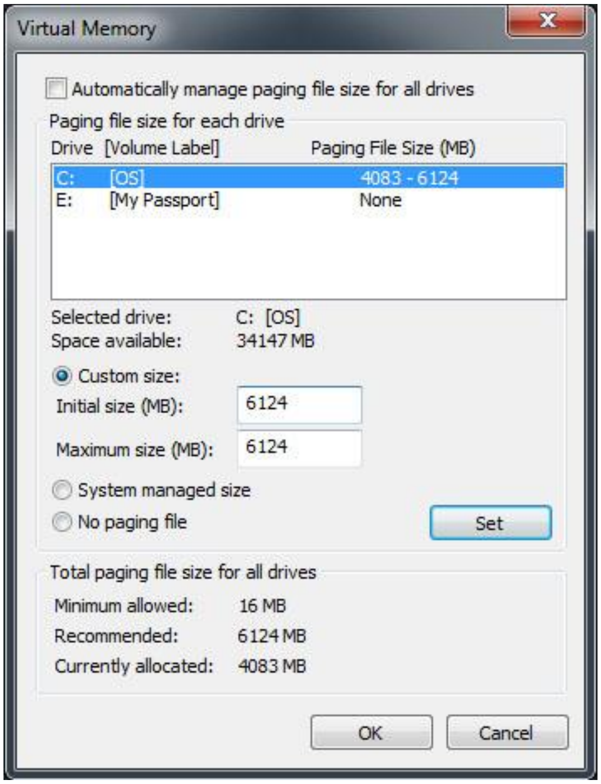

Figure F-8. The *Virtual Memory* dialog box.

Set the *Initial size* and *Maximum size* to the *Recommended* amount of virtual memory. Click **Set** and then **OK**. You will need to restart your computer for the new virtual memory settings to take effect.

F.4 Running WFAT with FlamMap Module x64

Once the FlamMap Module x64 has been installed with WFAT, it will be utilized when WFAT is generating the fire behavior outputs. In order to run the FlamMap Module x64, WFAT launches it in a 64-bit sub-process. This will be evident by the DOS window that appears (Figure F-9).

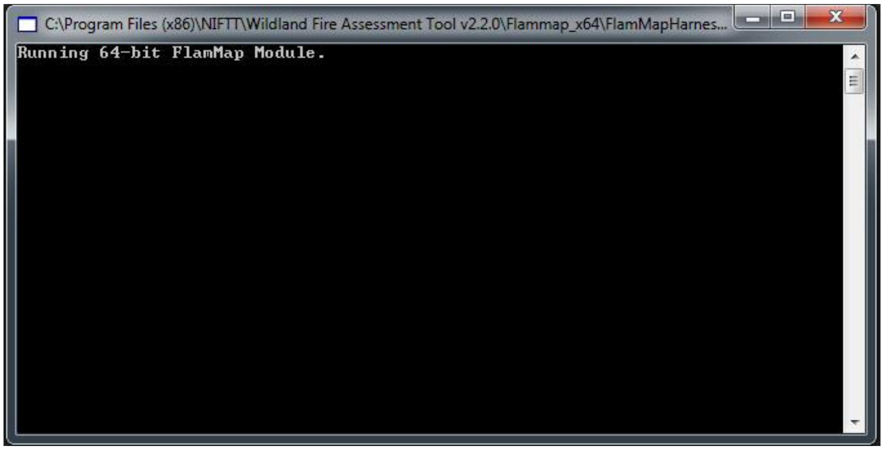

Figure F-9. WFAT running the FlamMap Module x64 in a 64-bit process.

When WFAT is running the FlamMap Module x64 on large data sets (millions of acres), we recommend that you monitor your computer's RAM usage, which can be done using the Task Manager. The Task Manager can be launched by pressing **<ctl><alt><del>**. The Task Manager's *Performance* tab has displays showing the computer's current and recent physical memory usage.

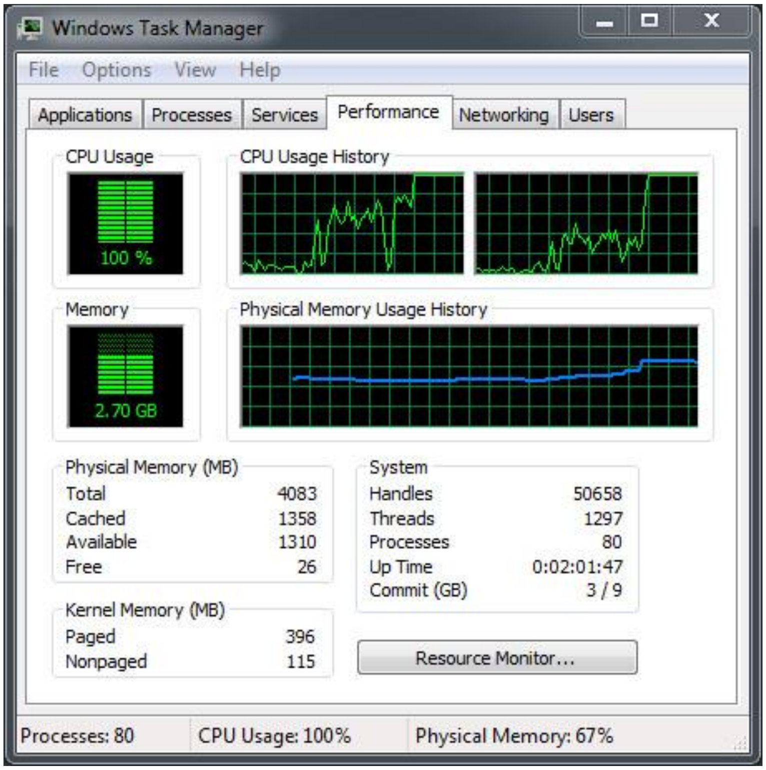

Figure F-10. Using the Task Manager to monitor RAM usage while WFAT is running the FlamMap Module x64.

In Windows 7 and Vista, the CPU Meter gadget can also be used to monitor RAM usage. The meter on the left records current CPU usage averaged for all the CPU cores. The meter on the right records the current RAM usage.

Figure F-11. The CPU Meter gadget. The meter on the right shows current RAM usage at 68 percent.