# FOFEM 6.3

## FIRST ORDER FIRE EFFECTS MODEL

## USER GUIDE

July 2016

FIRE AND AVIATION MANAGEMENT
ROCKY MOUNTAIN RESEARCH STATION
FIRE MODELING INSTITUTE

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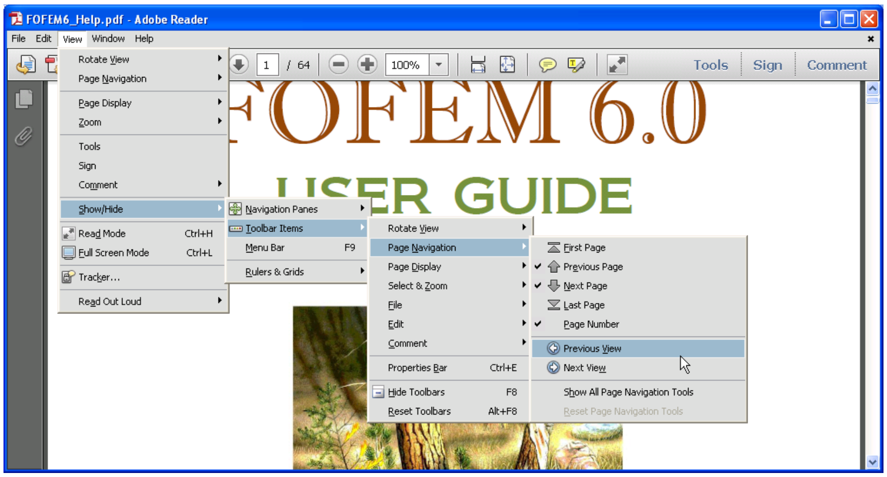
# Instructions for Setting up Adobe Reader

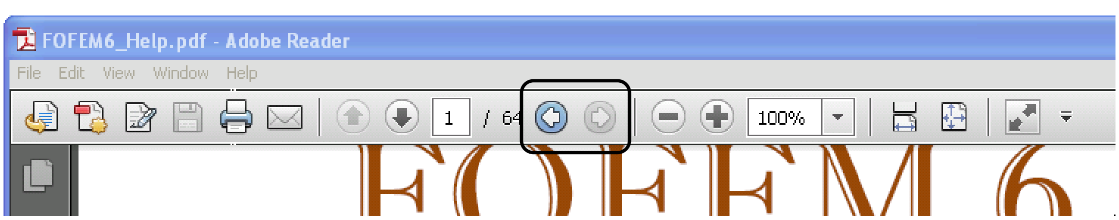
Using the **Previous View** and **Next View** buttons in Adobe Reader (and Adobe Acrobat) will make it easier to navigate the FOFEM Help; however, they are not added to the Reader toolbar by default.

1) To turn on the **Previous View** button select: *View > Show/Hide > Toolbar Items > Page Navigation > Previous View.*




2) To turn on the **Next View** button select: *View > Show/Hide > Toolbar Items > Page Navigation > Next View.*


3) When you are done the **Previous View** and **Next View** buttons will be on the Reader toolbar.



# Introduction

FOFEM - A First Order Fire Effects Model - is a computer program that was developed to meet needs of resource managers, planners, and analysts in predicting and planning for fire effects.

Quantitative predictions of fire effects are needed for planning prescribed fires that best accomplish resource needs, for impact assessment, and for long-range planning and policy development. We have developed the computer program FOFEM to meet this information need.

Much fire effects research has been conducted, but the results of this research have tended to be empirical, and thus limited in applicability to situations similar to those under which the research was conducted. Additionally, fire effects research results have not previously been assembled in a common format that is easily accessed and used, but rather have been scattered in a variety of journals and publications.

In developing FOFEM, we have searched the fire effects literature for predictive algorithms useful to managers. These algorithms have been screened to evaluate their predictions over a range of conditions. We also determined the conditions under which each is best suited to use by examining the documentation of these algorithms. Thus, a major internal component of FOFEM is a decision key that selects the best available algorithm for the conditions specified by a user.

In addition to selecting appropriate algorithms for users, we have also attempted to make these algorithms simple to apply; this has been done by incorporating the algorithms into an easy-to-use computer program.  Realistic default values, documented in detail in this guide, have been provided for many inputs, minimizing the data required. These defaults were derived from a variety of research studies. Any of these default values can be overridden by the user, allowing the use of this program at different levels of resolution and knowledge.

We anticipate that FOFEM will be useful in a variety of situations. Examples include: setting acceptable upper and lower fuel moistures for conducting prescribed burns; determining the number of acres that may be burned on a given day without exceeding particulate emission limits; assessing effects of wildfire; developing timber salvage guidelines following wildfire; and comparing expected outcomes of alternative actions.

A new version…

FOFEM6 replaces its two predecessors; FOFEM4 an IBM-PC DOS version developed in the early 1990s and FOFEM5 an IBM-PC Windows version developed circa 2000.

FOFEM6 is functionally equal to FOFEM5 but sporting a much improved GUI, graphs and a few other updates please see:  Updates

# Overview

First order fire effects are those that concern the direct or indirect or immediate consequences of fire. First order fire effects form an important basis for prediction secondary effects such as tree regeneration plant succession, and changes in site productivity, but these long-term effects generally involve interaction with many variables (for example, weather, animal use, insects, and disease) and are not predicted by this program. Currently, FOFEM provides quantitative fire effects information for tree mortality, fuel consumption mineral soil exposure, smoke and soil heating.

FOFEM is national in scope. It uses four geographical regions: Pacific West, Interior West, North East, and South East. Forest cover types provide an additional level of resolution within each region. Geographic regions and cover types are used both as part of the algorithm selection key, and also as a key to default input values.

## System Requirements

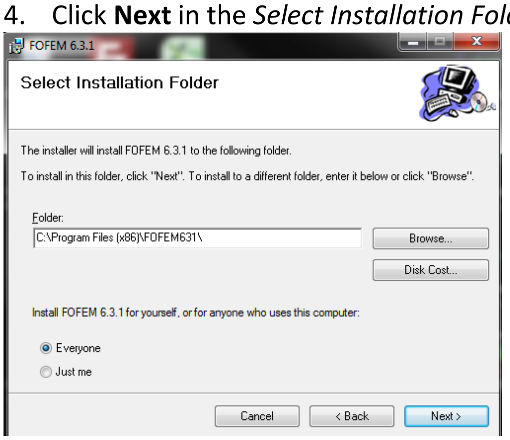
FOFEM6 will run on any IBM compatible PC using Windows XP, 7, 8 or 10.

## Installation

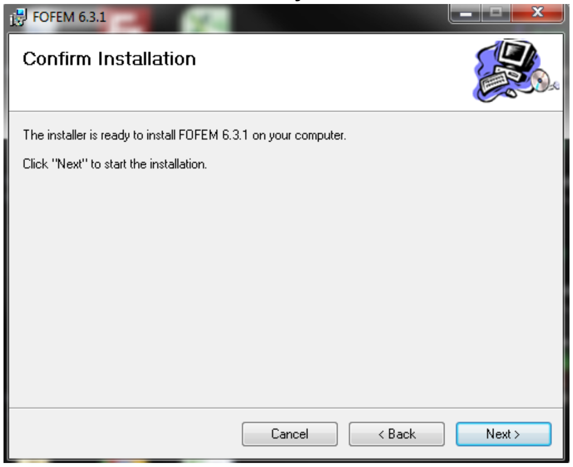
The FOFEM installation package can be downloaded from the Science Applications page on the Missoula Fire Sciences Lab website: [www.firelab.org](http://www.firelab.org).

1. Download the installer package to a folder of your choice and unzip the contents of the file.
2. In Windows Explorer or My Computer navigate to the folder of unzipped FOFEM installation files. Double-click *Setup.exe*.
3. Click **Next** in the *Setup Wizard* window.

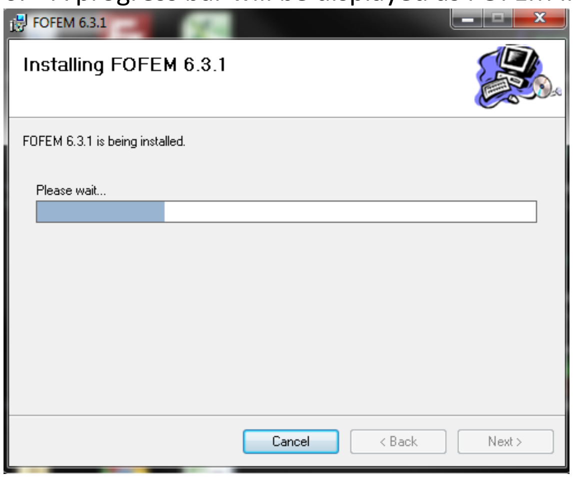

4. Click **Next** in the *Select Installation Folder* window.



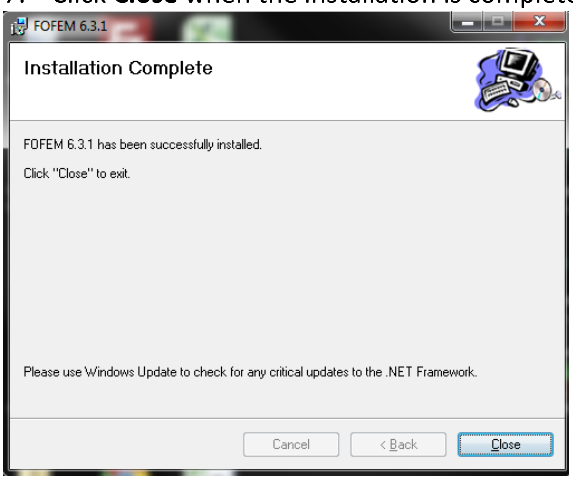
5. Click **Next** in the *Confirm Installation* window.




6. A progress bar will be displayed as FOFEM in being installed.




7. Click **Close** when the installation is complete.



Files will be placed in two folders:

C:\Program Files\FOFEM631 – program executable files

C:\Users\Username\AppData\Local\FOFEM6.3.1 – reference files and user files.

These files are added to the user folder when FOFEM is run the first time:

- *fofem.ini* – Initialization file.
- *Path-FOFEM.bat* – Batch file to set the path to the FOFEM install folder. Used when running FOFEM from the command line.
- *FOF_SPP.DAT* – Links to species codes, mortality equations, bark thickness equations, region and crown coefficient. Space delimited.
- *FOF_NVCS.CSV* – Default fuel loading for NVCS types. Comma delimited.
- *FOF_FCCS.CSV* - Default fuel loading for FCCS fuelbeds. Comma delimited.
- *FOF_FLM.CSV* - Default fuel loading for FLM classes. Comma delimited.
- *FOF_SAF.CSV* - Default fuel loading for SAF/SRM types. Comma delimited.
- *fofem.prj* – Project file of saved settings.
- *Emission_Factors.csv* – Not currently enabled. Emissions factors. Comma delimited.
- *FFI_Sample.Tre* – Example FFI export file that includes tree data for mortality simulations.
- *FFI_Sample.FFI* - Example FFI export file that includes fuels data for consumption, emissions and soil heating simulations.

A good place to get started is Getting Started.

## Features

- Graphics: Graphs are available for each of the major fire effects categories: tree mortality, fuel consumption, smoke, and soil heating. The graphs can be viewed in their respective graph windows and also be saved to file, printed or copied into the system clipboard.
- Reports: reports are available for fuel consumption, emissions, soil heating and tree mortality.
- Files: FOFEM provides a variety of options for saving data to files; include graphs, reports and other calculated outputs.
- Fuel Types: FOFEM provides default fuel loadings for SAF/SRM cover types; NVCS cover types and FCCS and FLM types.
- Batch Processing: Multiple plots can be processed using input text files. See Batch Processing

  *NOTE: FOFEM can also be used to run batch files from the system command line circumventing the GUI completely.*

## Modeling Approach

In developing the decision key to select algorithms, we were guided not only by the conditions under which an algorithm was developed, but also by a need to develop a model without sharp discontinuities or inconsistencies. This made algorithm selections in some cases a judgment call and it also led to the exclusion of some algorithms that may have performed well but in very restricted situations, or that require inputs not easily available to managers. Details about algorithms and their sources are documented in the Scientific Content sections of this guide.

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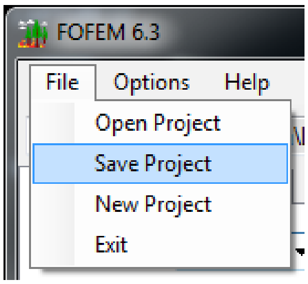
Modifications were funded by USDA Forest Service, Research and Development program. Development support was provided by the USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Lab and Fire Modeling Institute; and USDA Forest Service, Fire and Aviation Management

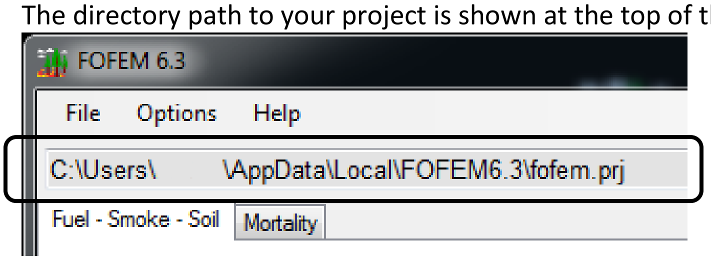
We would like to thank Larry Gangi, Jeff Jones, Jim Reardon, Sharon Hood and Tom Waldrop for their help with FOFEM6. We add them to the list of previous FOFEM contributors: Jim Brown, Wendel Hann, Dan Jimenez, Scott Mincemoyer, Kevin Ryan, Melanie Miller, Gaylon Campbell, Roger Hungerford, and Deb Tirmenstein. Courtney Couch provided the artwork used on the FOFEM splash screen.

# Getting Started

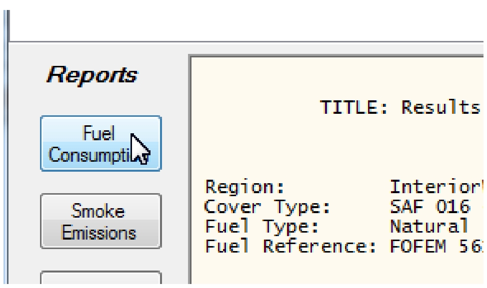
When you start FOFEM for the first time it will open using the default project file (with a PRJ extension), which is stored in your user folder *(C:\Users*\username*AppData**Local**FOFEM6.3*). You can choose a different project folder by selecting **File>Save Project** and navigating to a different directory. At any time during a FOFEM session you can save all of your settings to a file by selecting **File>Save Project**. Any number of project files can be saved.



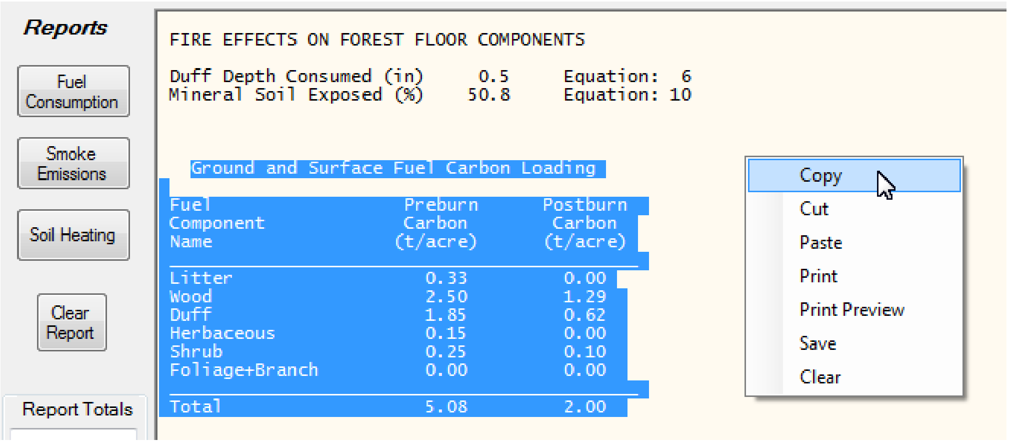

The directory path to your project is shown at the top of the FOFEM user interface.



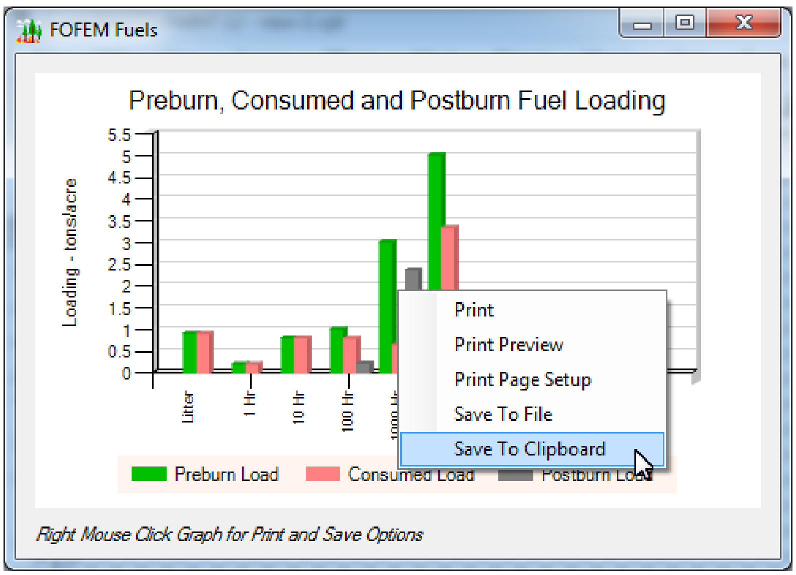

To create a report or graph make the desired settings for cover type, fuel moisture, etc. then click the desired button located on the right or left side of the user interface.



Report text can be moved into electronic documents using Copy/Paste commands. To copy report text, highlight the desired text, right-click in the report window and select **Copy**. Then open your document and use the paste command to move the selected text. You can also print reports.




Graphs can also be copied or printed using right-click commands.




## Setting a Work Folder

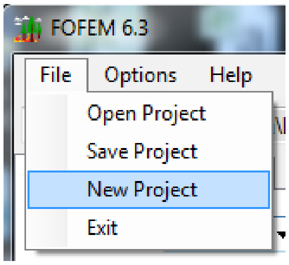
Your work folder is the folder that contains your active project file. When you start FOFEM your work folder using the last project file you were working with. The work folder path and project file name are always shown at the top of the user interface. The suggested work folder path is: *C:\Users*\username*\AppData\Local\FOFEM6.3*.

There are two ways to set your work folder, under the main menu option Project:

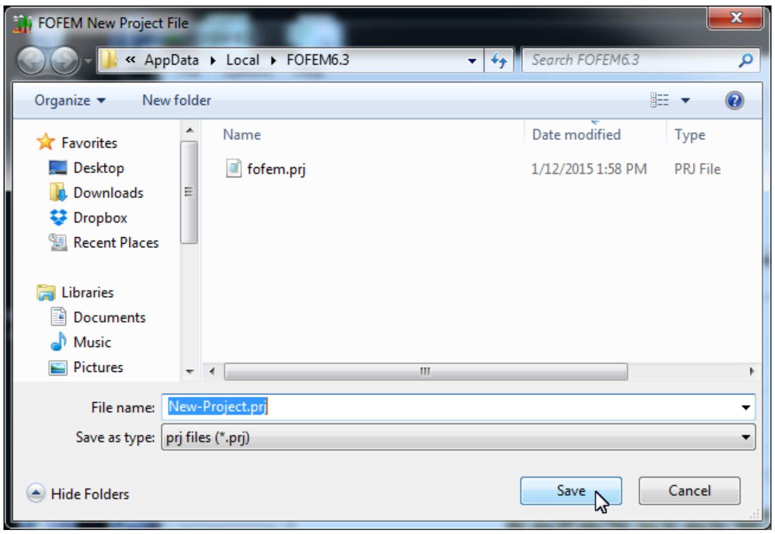
1. **Open Project** - opens a project file
2. **New Project** - creates a new project file

If you move to a different folder when doing one of the above you will change your work folder.

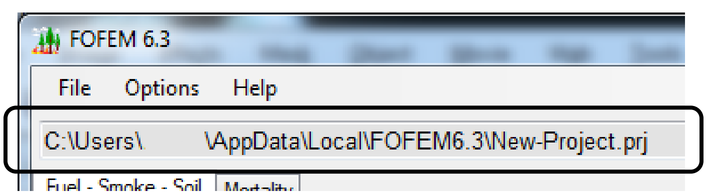
Select **File>New Project** from the main menu.




Select a project name and directory for your new project and click **Save**.




The project name and file path will be displayed at the top of the user interface.

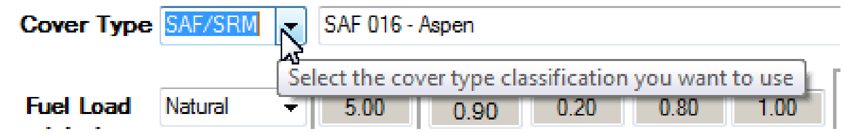



## General Rule

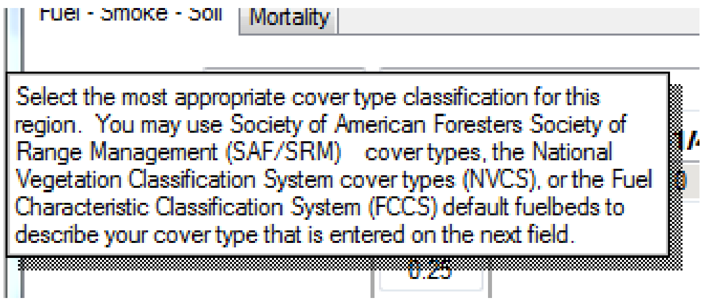
You should always check all of your screen settings before creating any report or graph. Whenever you make a change to a screen setting it can affect other screen settings or values, for example changing *Moisture* regime effects percent moisture for four fuel components. Some user entered values may also change or remain the same as other settings are changed and adjusted. This document attempts to explain the rules, but the easiest rule to remember is the one mentioned above – always review all of your screen settings before you create a reports or graphs.

## Getting Help

FOFEM has a variety of ways for you to get help. Most of the controls on the main window have a small Tool Tip textbox that will appear when you move and hold the cursor over them.



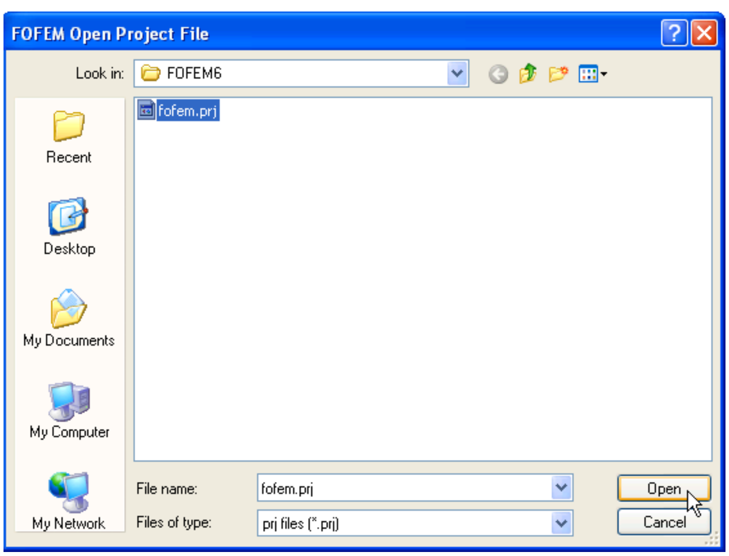

The F1 function key can also be used to give you more detailed help. Mouse click on the screen control you are interested in (for example, in the *Cover Type* field.), hit the F1 key and a small dialog box will pop up with the help text in it.




This document is the third source of help. Aside from just explaining how to use FOFEM it contains other content such as modeling approach, scientific content, and references.

## Open & Save File Window

Whenever you save or open a file in FOFEM you'll be using a window like the one shown below, the only difference being the title and the file type(s). The example shown below is for opening a project file, which uses the file PRJ extension. The window allows you to navigate to folders, create folders, etc., it also selectively shows you particular files types.

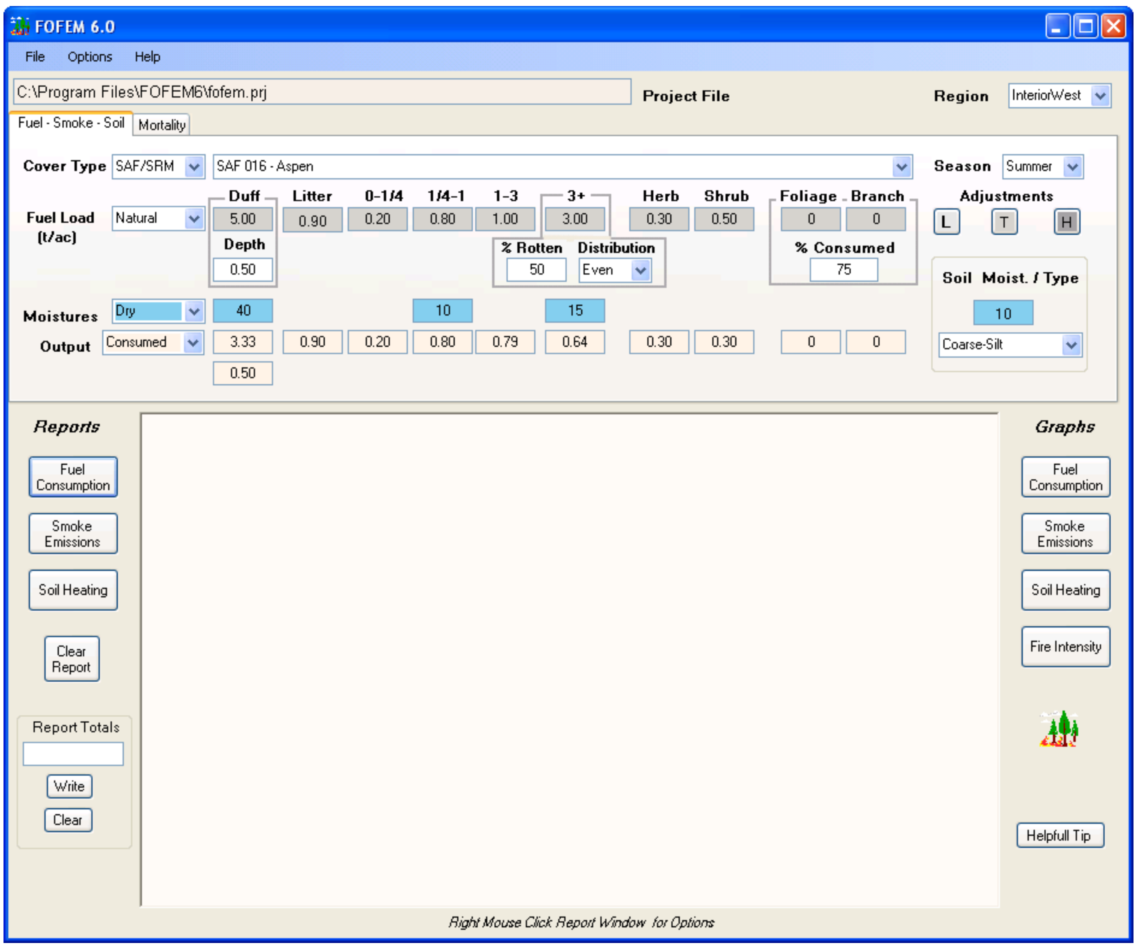


# Main FOFEM Window

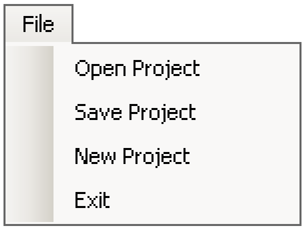
## Main Window

The FOFEM window has three sections:

1. The upper section contains the main menu and FOFEM header dropdown list. See Main Menu - File, Main Menu – Options, and FOFEM Header
2. The middle section contains the Fuel-Smoke-Soil Tab and Mortality Tab. Click on the tab for the model you wish to run, the screen shot below has the former tab selected.
3. The bottom section contains buttons for creating reports and graphs, and a large text area where the reports are placed. Graphs are opened in a separate window and can be copied, saved or printed.



### Main Menu - File




A project file is a snapshot of all the FOFEM screen settings captured directly from the screen and saved to a file. This is done by using the **Save Project** menu item. By saving your settings in a project file you can restore them at any time by using the **Open Project** menu item. Any number of project files can be saved. Your active (current) project file is always shown in the **Project File** field. The folder that contains you active project file is you Work folder. The Work folder is your default folder for opening and saving files.

**Open Project**: Open a project file. The Work folder will get set to the folder where the project file is located. If you go to a different folder to open a project file, it will become your new Work folder and it will be shown in the Project File field.

**Save Project**: Save will only save your screen settings to a project file, it will not change your Work folder setting. However you can save project files to any folder you choose.

**New Project**: Save the screen setting to a project file and in addition place the project file's folder and name in the Project File field

**Exit**: Exit FOFEM. Make sure you save any of you work of project file before you exit.

### Main Menu – Options

**Batch Processing**: Run FOFEM models using input files with multiple plots. See Batch Processing for details.

**Save Burnup Emission File**: The Burnup model in FOFEM can produce a smoke emissions file, which can be exported to a spreadsheet for graphing. The file is a text file and shows emissions across time. Before using this option you will need to check the Smoke Analysis Type check button. See Sample Burnup Output Files

**Create Sample Burnup Input File**: See notes above for menu item Run Burnup from Input File. See Sample Burnup Input File

**Run Burnup from Input File**: This option lets you run Burnup from an input text file to create two output files. Output files show predicted fuel consumption and smoke emissions. You can create a sample input file by using the Create Sample Burnup Input File menu item below. For more details see Running Burnup from an input File

*NOTE: This option can also be run from a command line prompt. The input and output file formats are the same as those mentioned above. To run this option, at the command line prompt type the following:*

*>> FOF_GUI Burnup inputfile outputfile outputEmission outputErrors*

*Following the program name the key word 'Burnup' is used, followed by the four files names. Depending on the folder you are attempting to run from you may have to set a system PATH variable to the FOFEM executable file in its install folder.*

**Create Sample Soil Input Files**: Create sample files for the Duff model and the Zero Duff model. Two types of files are created based on duff loading. If there is no duff the sample file will have a *.exp* extension and will run the no-duff soil heating model. If duff load is greater than 0 the example file will have a *.duf* extension and will run the duff soil heating model. See Running Soil Heating from Main Menu for more details.

**Run Soil from Input File**: This option lets you create a soil heating graph and report using a text file as input. The Graph window will appear first, use the View menu item to switch over to the Report window. You can create sample input files for templates using the Create Sample Soil Input Files menu item below. The samples files contain comments to explain the file contents. See Running Soil Heating from Main Menu for more details

**Save Soil Temp Points File**: Creates a text file containing a table of temperature values. This file can be used with other graphing software. Before using this option you will need check the Soil Analysis Type check button and create a soil graph. For more details see Output Graphing File

**Settings:** This window allows you to change units for emissions and change other simulation settings. These settings are not saved in the project file.

*NOTE: If non-default settings are desired they must be set every time FOFEM Is opened.*

**Emissions Output Unit** – Set units in the Smoke Emissions report. Available units are *lbs/ac* (default), *Tons/acre* or *g/m²*

**Duff Heat Production Source** – Set heat content of burning duff.

| Production Source | Heat of combustion (Mj/kg) | Note |
|---|---|---|
| PeatLow | 15 | Used in previous versions of FOFEM |
| PeatHigh | 20 | |
| DuffLow | 25 | |
| DuffHigh | 30 | |

Values based on: *Frandsen, W.H. 1991. Heat evolved from Smoldering Peat. Int. J. Wildland Fire l(3): 197-204*

**Heat Efficiency** – The proportion of heat intensity that is directed to the soil for determining soil heating. There are the components that *Duff*, *W/L* (woody fuels and litter) and *H/S* (herb and shrub). Default values provided next to each field are the values used in previous versions of FOFEM.

**Duff Reduction Equations** – When the box is checked FOFEM calculates the amount of duff consumed using equation 6 (% duff consumption) instead of equation 2 (duff depth consumed). See Scientific Content-Fuel Consumption-Duff Consumption for more information.

# FOFEM Header

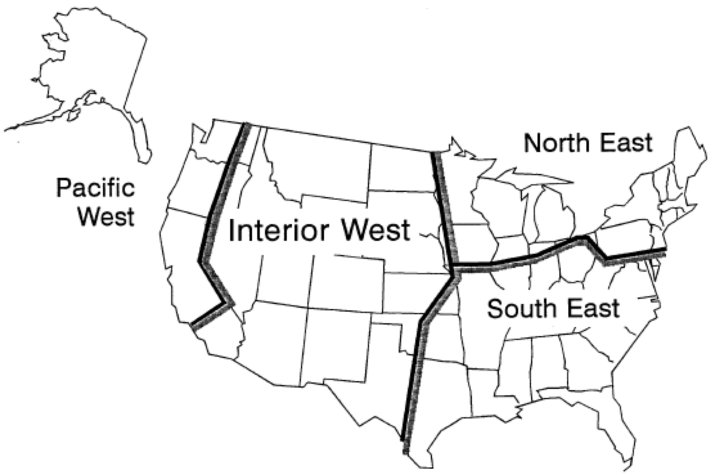
## Project File

The Project window displays the active (current) project file.

The window also lets you know what your Work folder is by showing the full folder path.


### Region

The region you select will determine the availability of cover types and tree species, and which consumption and mortality equations are used.



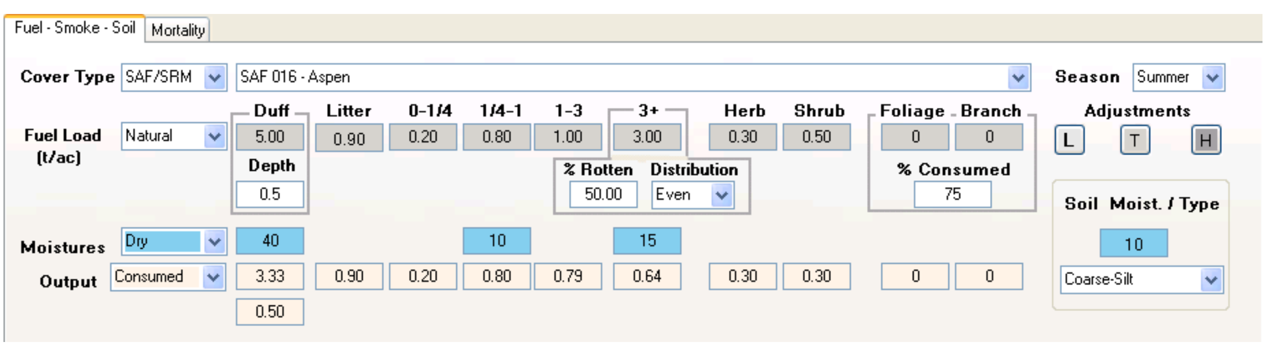

Select a region that is appropriate for you project.

1. Interior West
2. Pacific West
3. North East
4. South East

## Fuel-Smoke-Soil Tab

This tab located on the main FOFEM window contains all of the inputs needed to calculate fuel consumption, smoke/emissions and soil heating outputs.

### Settings




**Cover Type**: The smaller dropdown list field contains the Cover Type Classification and the larger dropdown list field contains the fuelbed code and name.

*NOTE: Only cover types that are relevant to the Region you have selected will be loaded.*

**Season**: For setting the of the burn: Spring, Summer, Fall, Winter. The selection of some FOFEM model equation is dependent on the season selection. See Decision Dependency.

**Fuel Load**: The dropdown list on the left let you set the whether the fuels were Natural or Slash. The selection modifies of the fuel loading of the fuel components to the right. Depending on the cover classification you have selected, not all cover types will have adjustments. See Cover Type Classification.

**Duff, Litter, 0-1/4, … Branch**: These are the individual fuel loadings for the cover type you have selected are placed in this row of textboxes. The values can be individually adjusted with a right mouse click in the textbox. The shading of each textbox reflects how it has been adjusted. For reference see the shading of the adjustment buttons on the far right hand side of the row. A white textbox indicates that a **User** value has been entered.

**Adjustments**: Clicking these buttons will adjust fuel loadings for each of the fuel components. The number of buttons shown is dependent upon the selected cover classification. The single letter on each button indicates the adjustment - **L**ight, **T**ypical and **H**eavy

**Depth**: duff depth, this value is based on the selected cover type and is editable by the user.

**% Rotten**: the amount of 3+ inch fuel that is rotten.

**Distribution**: 3+ inch log loading distribution, see the Distribution table.

**% Consumed**: the amount of Foliage and Branch fuels that you want to be consumed will be based on this percentage.

*NOTE: the entered percent is directly applied to the foliage, but only 50 percent is applied to branch. That is ….for decimal percentage N, then Consumed foliage = foliage load * N, Consumed Branch = branch load * ( N * 0.50 )*

**Moistures**: default moisture regimes are available in the dropdown: Wet, Moderate, Dry, Very Dry. The values are user editable by highlighting the value in the textbox and typing in a new value. See Moisture Regime.

*NOTE: When the duff moisture is set to its lower limit (10%) all of the duff will be consumed regardless of what FOFEM's assigned duff equation predicts. This is helpful when doing soil simulations, in that it will force all of the duff to be consumed, allowing the fire's heat to reach the soil; otherwise any remaining duff will act as an insulator.*

*NOTE: Litter, 0 -> ¼ and 1->3 inch fuel moistures needed to calculate consumption are computed by FOFEM based on the ¼ -> 1 moisture value.*

**Output**: select the calculated values you want shown in the textboxes at the right: Consumed, Post, Consumed %. This setting does not affect the reports or graphs.

**Soil Moist / Type**: this setting modifies heat transfer through the soil and can be set to these soil families: Loamy Skeletal, Fine-Silt, Fine, Coarse-Silt, Coarse-Loamy. Soil moisture is user editable by highlighting the value in the textbox and typing in a new value. If you aren't interesting in soil heating outputs then these settings are not used for simulating consumption or emissions.

## Cover Type Classification

Set this box according to the cover type classifications you want to use.

You have four choices.

1. SAF/SRM – Society of American Foresters/Society for Range Management
2. NVCS – National Vegetation Classification System
3. FCCS – Fuel Characteristic Classification System
4. FLM – Fuel Loading Models

Selecting FCCS or FLM cover type will cause the low (L) and high (H) fuel load adjustment buttons to disappear because these classes do not have adjustment codes associated with them.

*NOTE: FCCS coarse woody fuel loadings, unlike other classes are stored (see fof_fccs.csv file), in three separate size classes (3–9 in., 9–20 in., and >20 in., plus sound, and rotten). When the Cover Type classification is set to FCCS FOFEM shows one total 3+ loading on the user interface along with a calculated rotten percentage and a "Fixed' log load distribution but when fuel consumption is calculated the individual size classes are used behind the scenes. If you do choose to change an FCCS fuel load, percent rotten or log load distribution, FOFEM will simply resort to normal operation, using the percent rotten and log load distributing as shown on the screen. NOTE: The list of FCCS fuelbeds and associated component fuel loads was current as of 9/2012. For more information about FCCS see http://www.fs.fed.us/pnw/fera/fccs/.*

*NOTE: For more information about FLMs see:*

*Lutes, DC; Keane, RE; Caratti, JF. (2009). A surface fuel classification for estimating fire effects. International Journal of Wildland Fire 18: 802-814*

*Sikkink, Pamela G.; Lutes, Duncan C.; Keane, Robert E. 2009. Field guide for identifying fuel loading models. Gen. Tech. Rep. RMRS-GTR-225. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 33 p.*

## Outputs

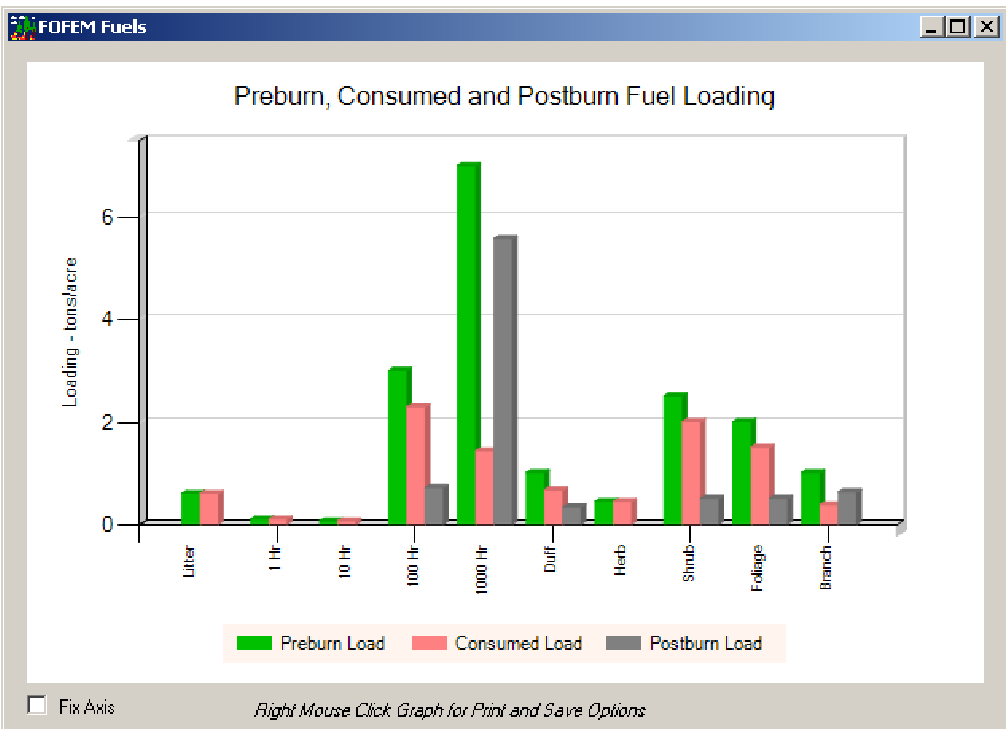
The bottom half of the Fuel – Smoke – Soil window is where you produce reports and graphs.

To create a **Report** click any one of the buttons on the left and a report will be placed in the Report window. Each time a button is clicked a new report is added to the end of the report, scroll down in the text window to see it. You can use a right mouse click to Copy, Cut, Paste, Print, Save or Clear.

**Report Totals**: This box allows you to report results from multiple FOFEM simulations in an easier to read table format. To save simulation results type a name in the textbox and click one of the report buttons. Repeat to save successive reports. When you have completed all the simulation you want to compare click the **Write** button and the results will be placed into the report. Hit the **Clear** button to clear all of the stored totals.

To create a **Graph** click the buttons on the right side and a window will pop up with the graph. You can leave the graph windows open and watch them change as you modify your inputs on the main window.

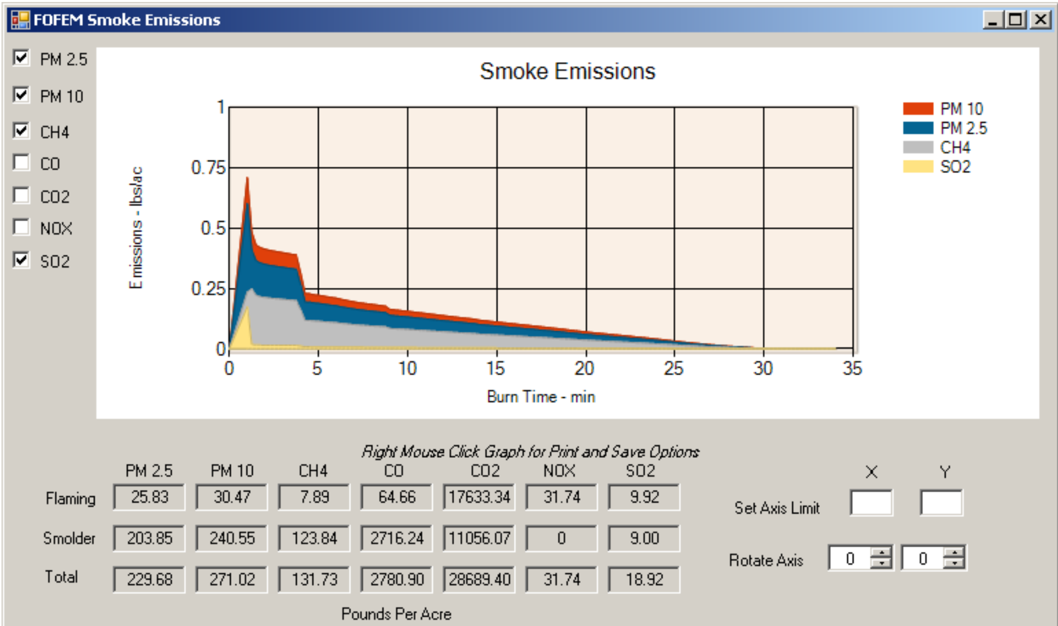
### Fuel Consumption Graph




The graph shows the pre-burn load, the amount consumed and the post-burn load amount.

**Fix Axis**: The graph will readjust the Y axis whenever you change an input on the main window. You can prevent this from occurring by clicking this checkbox. This can be handy if you are trying to compare outputs. Clicking the box will freeze the scale of the Y axis. Uncheck the box and the FOFEM will set the axis automatically.

## Smoke Emissions Graph

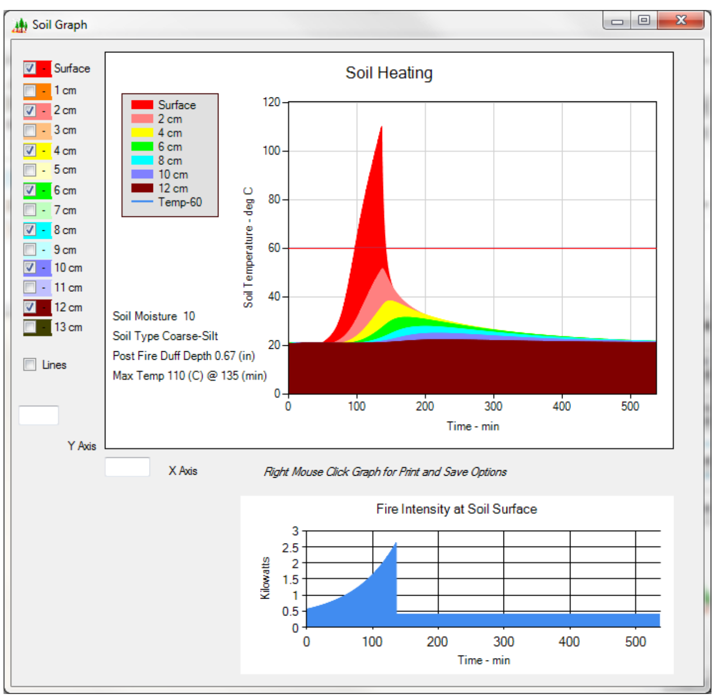



The graph displays the rate which components are being emitted. By selecting the checkboxes on the left you can show one or more of the emission components.

**Set Axis Limit**: To limit the X or Y axis, enter a number in the textbox and hit the return key. If no values are entered FOFEM will automatically set them

**Rotate Axis**: The graph can also be rotated on either or both axis using the up/down boxes.

## Soil Heating Graph



The graph shows soil temperatures (Celsius) for each layer across time (minutes), with each layer representing one centimeter. By selecting the checkboxes on the left you can show one or more of the soil layers (each layer is one centimeter in thickness). The intensity graph at the bottom displays intensity at the soil surface over time. When there is duff present the intensity comes entirely from the burning duff. When there is no duff present then intensity is simulated as a proportion of the total woody fuel, litter, herb and shrub combustion intensity.

**Post Fire Duff Depth**: Specifies the amount of duff depth that is remaining after a simulated fire.

**Max Temp xx @ min xx**: The maximum temperature and the time in minutes that it was reached. This number represents the layer closest to the surface that is selected (checked) in the layer checkboxes.

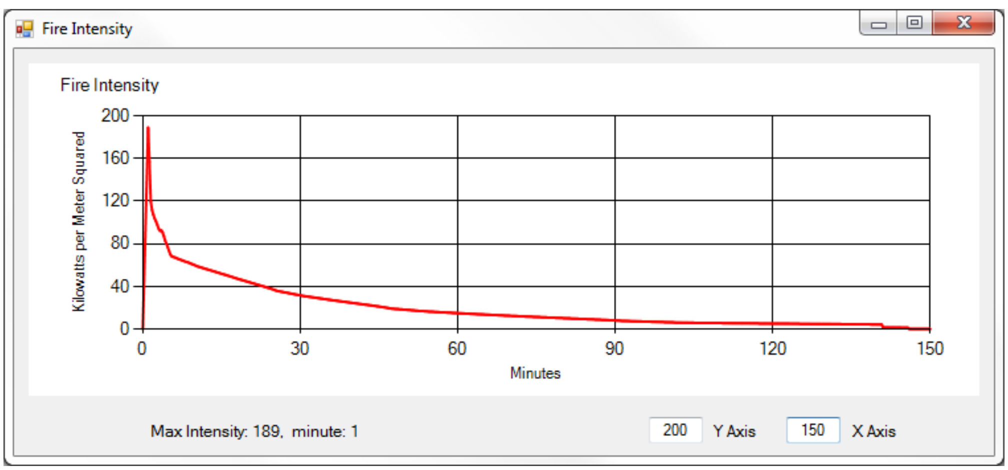
**Lines**: Selecting this checkbox will show the graph in line form.

**Y Axis, X Axis**: Used to limit the axis enter a number and hit the return key, otherwise FOFEM will automatically set them.

*NOTE: when doing soil heating simulations you should be aware that the amount of duff consumed is an important factor and that some duff reduction equations may never allow complete combustion of duff. However, FOFEM allows you to force duff consumption of 100 percent – please see notes related to moisture and duff.*

### Fire Intensity Graph

The values used to produce this graph come directly from the Burnup model.




**X Axis, Y Axis**: to limit the axis enter a number and hit the return key, otherwise FOFEM will automatically set them. In the above example a user value of 25 was entered.

### Fuel Consumption Report

The top section of this report shows the input settings that you have selected for Region, Cover Type, etc. The next section of the report shows each fuel components. For the 3+ inch fuel loading each individual size class is shown as well as total, the size classes are broken up according the Log Distribution setting you selected on the main window. If you adjusted any of the fuel loadings you will see the characters “u”, “+”, or “-“ to designate the type of adjustment as noted at the bottom of the report.

The equation number 999 indicates that the Burnup model was used to compute the consumption values.

TITLE: Results of FOFEM model execution on date: 10/1/2012

FUEL CONSUMPTION CALCULATIONS

Region: PacificWest
Cover Type: SRM 210 - Bitterbrush
Fuel Type: Natural
Fuel Reference: PMS-830

FUEL CONSUMPTION TABLE

| Fuel Component Name | Preburn Load (t/acre) | | Consumed Load (t/acre) | Postburn Load (t/acre) | Percent Reduced (%) | Equation Reference Number | Moist. (%) |
|---|---|---|---|---|---|---|---|
| Litter | 0.60 | u | 0.60 | 0.00 | 100.0 | 999 | |
| Wood (0-1/4 inch) | 0.15 | + | 0.15 | 0.00 | 100.0 | 999 | |
| Wood (1/4-1 inch) | 0.06 | | 0.06 | 0.00 | 100.0 | 999 | 10.0 |
| Wood (1-3 inch) | 3.00 | u | 2.29 | 0.71 | 76.5 | 999 | |
| Wood (3+ inch) Sound | 3.50 | u | 0.49 | 3.01 | 14.0 | 999 | 15.0 |
| 3->6 | 0.88 | | 0.28 | 0.59 | 32.4 | | |
| 6->9 | 0.88 | | 0.12 | 0.76 | 13.6 | | |
| 9->20 | 0.88 | | 0.06 | 0.81 | 7.2 | | |
| 20-> | 0.88 | | 0.03 | 0.85 | 2.9 | | |
| Wood (3+ inch) Rotten | 3.50 | u | 0.94 | 2.56 | 26.8 | 999 | 15.0 |
| 3->6 | 0.88 | | 0.46 | 0.42 | 52.5 | | |
| 6->9 | 0.88 | | 0.26 | 0.61 | 30.1 | | |
| 9->20 | 0.88 | | 0.15 | 0.73 | 17.1 | | |
| 20-> | 0.88 | | 0.07 | 0.81 | 7.6 | | |
| Duff | 1.00 | u | 0.67 | 0.33 | 66.7 | 2 | 40.0 |
| Herbaceous | 0.44 | | 0.44 | 0.00 | 100.0 | 22 | |
| Shrubs | 1.25 | - | 1.00 | 0.25 | 80.0 | 231 | |
| Crown foliage | 2.00 | u | 1.50 | 0.50 | 75.0 | 37 | |
| Crown branchwood | 1.00 | u | 0.38 | 0.63 | 37.5 | 38 | |
| Total Fuels | 16.50 | | 8.52 | 7.98 | 51.6 | | |

'u' Preburn Load is User adjusted
'+' Preburn Load is Heavy/Abundant
'-' Preburn Load is Light/Sparse

The bottom section of the report contains the fire effects on the forest floor and carbon loadings.

FIRE EFFECTS ON FOREST FLOOR
Mineral Soil Exposed (%) 50.8 Equation: 10

Ground and Surface Fuel Carbon Loading

| Fuel Component Name | Preburn Carbon (T/ac) | Postburn Carbon (T/ac) |
|---|---|---|
| Litter | 0.44 | 0.00 |
| Wood | 5.30 | 1.38 |
| Duff | 9.25 | 3.08 |
| Herbaceous | 0.08 | 0.00 |
| Shrub | 0.13 | 0.05 |
| Foliage+Branch | 5.60 | 2.00 |
| Total | 20.80 | 6.52 |

## Smoke Emission Report

Emission amounts for each component are shown for flaming and smoldering in pounds per acre.

*NOTE: $NO_X$ emissions are only generated during the flaming period of fuel consumption.*

```
         TITLE: Results of FOFEM model execution on date: 10/1/2012

                  FUEL EMISSIONS CALCULATIONS

Region:         PacificWest
Cover Type:     SRM 210 - Bitterbrush
Fuel Type:      Natural
Fuel Reference: PMS-830


                   Emissions  -- lbs/acre
                  flaming      smoldering      total
--------------------------------------------------------------
PM 10                  24            243          267
PM 2.5                 21            206          227
CH 4                    6            125          131
CO                     52           2745         2797
CO 2                14115          11173        25288
NOX                    25              0           25
SO2                     8              9           17
--------------------------------------------------------------


                                Consumption     Duration
                                   tons/acre    hour:min:sec
                        Flaming:        3.97       00:01:00
                        Smoldering:     4.55       00:34:00
                        Total:          8.52
Unit Average Combustion Efficiency:     0.81
```

## Soil Heating Report

Soil Layer Maximum Temperature: the table shows the maximum temperatures that were reached at each layer.

```
                          Soil Heat Report

Region:         InteriorWest
Cover Type:     SAF 213 - Grand Fir
Fuel Type:      Natural
Fuel Reference: FOFEM 071
Duff Depth.....: Pre-Fire:   3.56 cm.,   Post-Fire:   0.73 cm.

                       Soil Layer Maximum Temperature

Depth (cm)     0    1    2    3    4    5    6    7    8    9   10   11   12   13
Temp (C)     223  173  129   99   73   68   63   57   52   46   40   33   27   21
Time (min)   165  176  209  221  223  227  238  248  257  265  272  277  280    1

Max Depth Having 60 degrees: 6
Max Depth Having 275 degrees: - None -
```

**Depth**: Layers are in one centimeter increments starting with the surface being 0

**Temp**: The maximum temperature (Celsius) that the layer reached

**Time**: How many minutes it took to reach the layer’s maximum temperature

*NOTE: The number 1 means that no heat from the fire reached the layer as shown at the 13 cm layer.*

**Max Depth Having 60/275 degrees**: the deepest layers to reach 60 and 275 degrees. This example shows that the deepest layer to reach 60 degrees was 7 cm. This example also shows that there were no layers reaching 275 degrees, including the surface, so the word “None” is shown.

### Summary Report

Summary reports provide an quick way to compare simulation results at various prescriptions. The example summary report shows totals taken from two smoke emissions reports (because emissions are closely tied to consumption a fuel consumption summary report is included with the emissions summary report).

Report Totals:

Fuel Consumption Summary - (T/ac)

| Id | Litter | Wood 0->1/4 | Wood 1/4->1 | Wood 1->3 | Wood 3+ | Duff | Herb | Shrub | Crown Folge | Crown Brnch |
|---|---|---|---|---|---|---|---|---|---|---|
| VeryDry | 1.20 | 0.56 | 0.75 | 2.30 | 4.64 | 18.80 | 0.15 | 0.15 | 1.20 | 6.00 |
| Dry | 1.20 | 0.56 | 0.75 | 2.30 | 4.23 | 16.67 | 0.15 | 0.15 | 1.20 | 6.00 |

Report Totals:

Smoke Emission Summary (lb/ac)

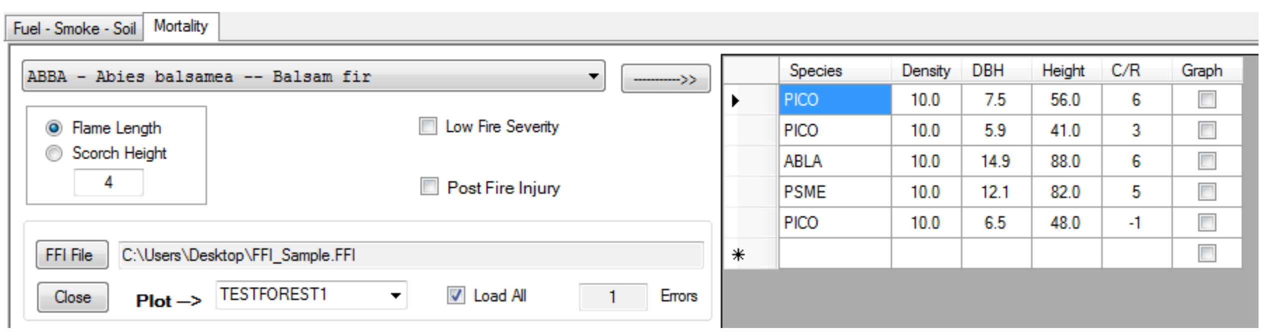
| Id | PM10 | PM2.5 | CH4 | CO | CO2 | NOX | SO2 |
|---|---|---|---|---|---|---|---|
| VeryDry | 1465.3 | 1241.8 | 739.6 | 16015.1 | 98174.8 | 60.3 | 71.5 |
| Dry | 1331.2 | 1128.1 | 670.6 | 14502.8 | 91907.5 | 60.1 | 66.4 |

The example was created simply by running two emissions reports and naming each based on the moisture regime setting selected. The first report was run with the title “VeryDry” entered in the **Summaries** field on the user interface. The second emissions report was titled “Dry”. The summary report was produced by clicking the **Write** button.

## Mortality Tab

### Settings – “Pre-fire”

The “Pre-fire” report and graph are used when you want to simulated mortality before a fire has taken place, for example, when determining a burn prescription for a prescribed fire. All input fields are required.




The **Mortality** tab shown above is located on the main window next to the **Fuel – Smoke – Soil** tab. All of the settings needed to do a report or graph are on this tab.

**Species:** Make a selection from the species dropdown list and use the arrow button to populate the species textbox in the data grid.

*NOTE: Only the species available for the selected region are available in the dropdown list. You can also type the species code directly into this box.*

**Density:** Trees per acre

**DBH:** Diameter breast height in inches

**Height**: Height in feet

**C/R**: Crown ratio/10. Valid values: 1 – 10.

**Graph**: Select the checkbox for one or more species to be graphed

**Flame Length / Scorch Height**: Enter the value in feet and check the appropriate radio button.

**Low Fire Severity**: Check this box for a low fire severity condition (currently only used for aspen mortality).

**Post Fire Injury**: Check this box if you want to do post fire injury mortality

*NOTE: See Settings – "Post Fire" for instructions using the post-fire mortality simulation.*

**FFI File**: This button allows you to import tree data exported from the FFI software. The imported plots will be shown in the **Plot-->** dropdown list. Select the desired plot and the tree information will be loaded directly into the tree data grid. Tree records missing required data will not be displayed. The count of records with missing data is displayed in the **Errors** field. Check the **Load All** checkbox to see all records. Missing data will be displayed as *-1* in the data grid. Click **Close** to erase records in the data grid.

*NOTE: See the FFI user guide for information about exporting data.*

To delete a row from the data grid, highlight the row by clicking the gray area to the left of the Species column then hit the **Delete** key on your keyboard.

If desired, save your settings to a project file.

## Mortality Report – "Pre-fire"

This report includes five tables and summarized mortality information.

TITLE: Results of FOFEM model execution on date: 10/2/2012

TREE MORTALITY MODULE:
REGION: PacificWest

FLAME LENGTH (FT): 4.00
Scorch Height: 23.76

ORIGINAL STAND DENSITY AS INPUT TO FOFEM

| Species Code | Diameter classes (in) 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| ABAM | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| PIPO | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 |
| TOTALS | 0 | 0 | 0 | 0 | 10 | 1 | 0 | 0 | 0 | 0 |

DBH classes (in): 2: 0-2, 4: 3-4, 6: 5-6, 8: 7-8, 10: 9-10and so on...

POSTFIRE STAND DENSITY (TREES/ACRE)

| Species Code | Diameter classes (in) 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| ABAM | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| PIPO | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 |
| TOTALS | 0 | 0 | 0 | 0 | 9 | 1 | 0 | 0 | 0 | 0 |

DBH classes (in): 2: 0-2, 4: 3-4, 6: 5-6, 8: 7-8, 10: 9-10and so on...

TREES PER ACRE KILLED BY THE FIRE

| Species Code | Diameter classes (in) 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| ABAM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PIPO | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| TOTALS | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

DBH classes (in): 2: 0-2, 4: 3-4, 6: 5-6, 8: 7-8, 10: 9-10and so on...

PROBABILITY OF MORTALITY FOR EACH SPECIES/DIAMETER ENTRY

| Species Code | Diameter (inch) | Number Trees | Prob Mort | Mortality Equation Number | Name |
|---|---|---|---|---|---|
| ABAM | 11 | 1 | 0.35 | 1 | Other - based on conifer species |
| PIPO | 10 | 10 | 0.06 | 19 | Ponderosa pine and Jeffery pine |

AVERAGE MORTALITY PROBS BY FLAME LENGTH BY SPECIES/DIAMETER ENTRY

| Species Code | Tree DBH | Flame Length (feet) 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ABAM | 11 | 0.35 | 0.35 | 0.62 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 |
| PIPO | 10 | 0.06 | 0.06 | 0.61 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| AVERAGES | 10 | 0.21 | 0.21 | 0.61 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |

STAND TREE MORTALITY
Percent mortality: 21
Number of trees killed by the fire: 1
Average tree diameter (DBH) of fire killed trees: 10.0
Percent mortality for trees 4+ in DBH: 21
Total prefire number of trees: 11

| Stand Basal Area: | sq/ft | Percent |
|---|---|---|
| Prefire Live: | 6.11 | 100 |
| Postfire Live: | 5.54 | 91 |
| Postfire Killed: | 0.57 | 9 |

| Stand Canopy Cover: | Percent |
|---|---|
| Prefire Live: | 3 |
| Postfire Live: | 3 |
| Change: | 0 |

**Original Stand Density**: The pre-fire stand data reported by species and diameter class.

**Post-fire Stand Density**: The post-fire stand data reported by species and diameter class.

**Tree Killed by Fire**: The trees killed by the simulated fire reported by species and diameter class.

**Probability of Mortality**: This table shows the probability of mortality of the trees included in the simulation and the **Mortality Equation Number** and **Mortality Equation Name** used to predict the mortality.

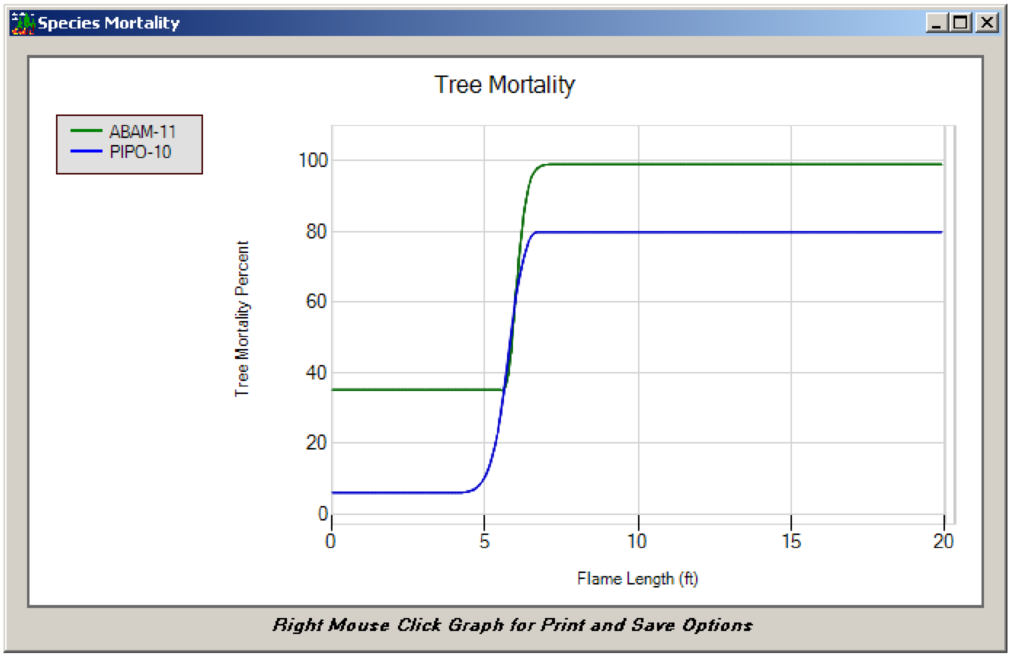
> *NOTE: Not all tree species have species specific mortality equations so review the equations used for the species in your simulation. See* *Estimating Tree Mortality - "Pre-fire"*

**Average Mortality Probability by Species /Diameter**: The table shows the probability of mortality at a variety of crown scorch or flame lengths (as set on the **Mortality** tab) for the species/DBH combinations entered in the data grid.

**Stand Tree Mortality**: Summary information for the simulation.

### Mortality Graph - "Pre-fire"

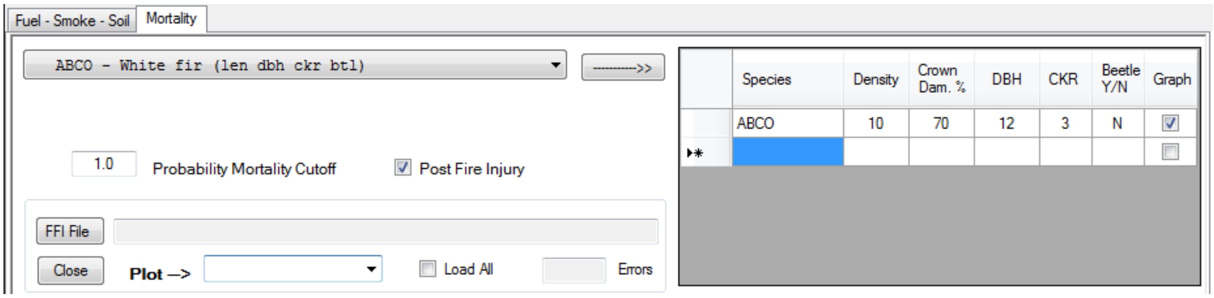
The mortality graph shows all of the species where the *Graph* box is checked in the species grid. The X axis variable graphed as Flame Length or Crown Scorch as set by the user on the **Mortality** tab.



## Settings – "Post Fire"

The "Post-fire" report and graph are used to simulate tree mortality using information sampled from individual trees after a fire has occurred. All input fields are required.

> *NOTE: Post fire injury simulation is not currently available in the FOFEM batch mode. FOFEM does not support FFI data import for post-fire mortality simulation.*




**Species**: Make a selection from the species dropdown list and use the arrow button to populate the species textbox or you can type a valid code directly into the **Species** field.

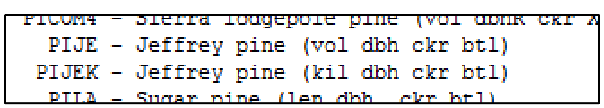
> *NOTE: Only the species available for the selected region are available in the dropdown list, and not all regions currently have species available for them.*

**Density**: Enter the tree density in trees per acre

**Crown Dam %**: This is a value from 0 to 100 based on either percent crown length scorched, percent crown volume scorched or percent crown with bud kill.

If the first variable in parenthesis following the species name in the species selection window is `len` then input the percent crown length scorched in the **Crown Scorch** field. If the first variable in parenthesis in `vol` then input the percent crown volume scorched. If the first variable in parenthesis in `kil` then input the percent crown volume killed (percent buds killed). For example, in the screen shot above the species ABCO is selected so the crown scorch should be based on scorch length.

> *NOTE: Crown volume killed is used only in post-fire mortality equations for ponderosa pine and Jeffrey pine. When selecting these species on the **Mortality** tab you will see two sets of equations. Species symbols that end in "k" require percent crown killed in the **Crown Scorch** field and the species symbols that don't end in "k" require percent crown volume scorched in the **Crown Scorch** field. For example, the equation linked to PIJEK uses percent crown killed and the equation linked to PIJE use percent volume scorched.*




**DBH:** Diameter at breast height in inches.

**Cambium Kill Rating**: Cambium Kill Rating (CKR) is a value from 0 to 4 and is the number of dead cambium samples found at the tree's base based on 4 samples evenly spaced around the tree bole.

*CKR* is used in all post-fire mortality predictions

**Beetle Y/N**: Y= the tree was attacked by beetles; N= the tree was not attacked by beetles. See the individual mortality equations in the Mortality Equations –"Post-fire" section for more information about beetle species used in the models.

If the fourth variable in parenthesis following the species name in the species selection window is `X` then beetle attack is not used in the mortality equation and the Beetle field in the data grid must be set to "X". If the fourth variable in parenthesis is `btl` then enter "Y" or "N" in the Beetle field in the data grid.

**Graph**: Use these checkboxes to indicate the species that you want to graph

**Probability Mortality Cutoff**: Enter a value between 0 and 1. This value determines how the **STAND TREE MORTALITY…** section of the mortality report is formatted. Trees with probability of mortality values greater than or equal to the entered cutoff are predicted to die. Trees with probability of mortality values less than the cutoff are predicted to live.

**FFI File**: This function is not available when using the Post-Fire equations.

## Mortality Report - "Post-fire"

Post-fire injury reports differ somewhat from pre-fire reports. Below is an example showing the probability section of a post-fire report.

TITLE: Results of FOFEM model execution on date: 10/2/2012

TREE POST FIRE MORTALITY MODULE:
REGION: PacificWest
Probability Mortality Cutoff: 0.7

ORIGINAL STAND DENSITY AS INPUT TO FOFEM

| Species | Diameter classes (in) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Code | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| ABCO | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 |
| TOTALS | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 |

DBH classes (in): 2: 0-2, 4: 3-4, 6: 5-6, 8: 7-8, 10: 9-10and so on...

ORIGINAL STAND DENSITY AS INPUT TO FOFEM

| Species | Diameter classes (in) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Code | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40+ |
| ABCO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTALS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DBH classes (in): 2: 0-2, 4: 3-4, 6: 5-6, 8: 7-8, 10: 9-10and so on...

TREES PER ACRE KILLED BY THE FIRE

| Species | Diameter classes (in) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Code | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| ABCO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTALS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DBH classes (in): 2: 0-2, 4: 3-4, 6: 5-6, 8: 7-8, 10: 9-10and so on...

TREES PER ACRE KILLED BY THE FIRE

| Species | Diameter classes (in) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Code | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40+ |
| ABCO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTALS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DBH classes (in): 2: 0-2, 4: 3-4, 6: 5-6, 8: 7-8, 10: 9-10and so on...

PROBABILITY OF MORTALITY FOR EACH SPECIES/DIAMETER ENTRY

| Species Code | Crwn Scrh | Dia (in) | Camb Kill | Btle Atck | Num Trs | Prob Mort | Mortality Equation Id | Name |
|---|---|---|---|---|---|---|---|---|
| ABCO | 70 | 12 | 3 | N | 10 | 0.38 | WF | White fir |

AVERAGE MORTALITY PROBS BY CROWN SCORCH BY SPECIES/DIAMETER ENTRY

| Species | Tree | Cam | Btl | Crown Scorch Percent | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | DBH | Kil | Atk | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| ABCO | 12 | 3 | N | 0.07 | 0.07 | 0.08 | 0.10 | 0.14 | 0.22 | 0.38 | 0.64 | 0.88 | 0.97 |
| AVERAGES | 12 | | | 0.07 | 0.07 | 0.08 | 0.10 | 0.14 | 0.22 | 0.38 | 0.64 | 0.88 | 0.97 |

STAND TREE MORTALITY
Percent mortality: 0
Number of trees killed by the fire: 0
Average tree diameter (DBH) of fire killed trees: 0.0
Total prefire number of trees: 10

| Stand Basal Area: | sq/ft | Percent |
|---|---|---|
| Prefire Live: | 7.85 | 100 |
| Postfire Live: | 7.85 | 100 |
| Postfire Killed: | 0.00 | 0 |

This report includes five tables and summarized mortality information.

**Original Stand Density**: The pre-fire stand data reported by species and diameter class. The second table is a continuation of the first so large DBH trees can be included.

**Post-fire Stand Density**: The post-fire stand data reported by species and diameter class. There are two tables with the second table is a continuation of the first so large DBH trees can be included.

**Tree Killed by Fire**: The trees killed by the simulated fire reported by species and diameter class.

**Probability of Mortality**: This table reports the data entered in the data grid, the probability of mortality of the trees included in the simulation and the **Mortality Equation ID** and **Mortality Equation Name** used to predict the mortality.

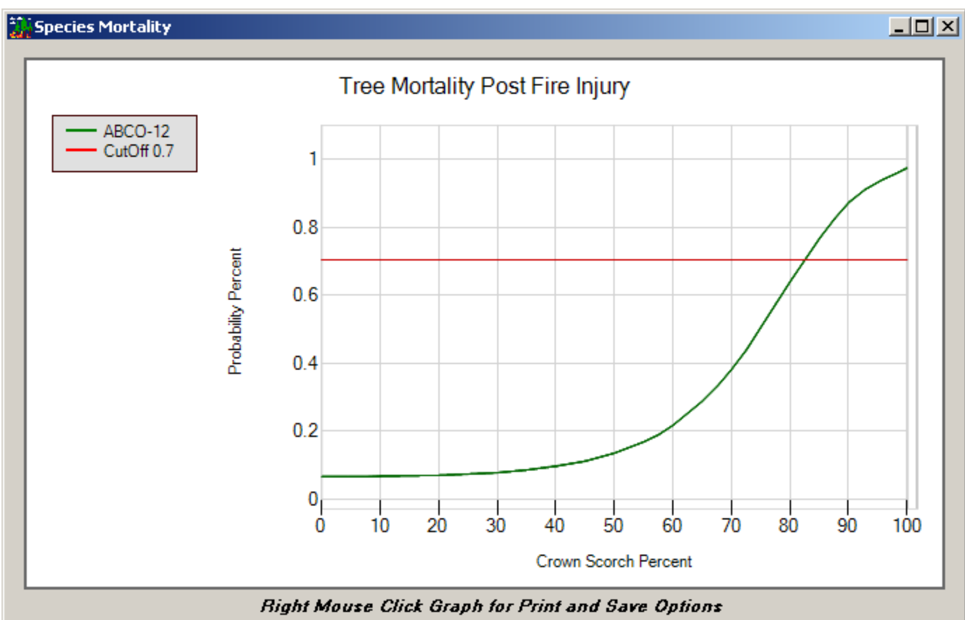
*NOTE: Not all tree species have species specific mortality equations so review the equations used for the species in your simulation. See* *Estimating Tree Mortality - "Post-fire"*

**Average Mortality Probability by Species /Diameter**: The table shows the probability of mortality at different levels of crown scorch for the species/DBH combinations entered in the data grid.

**Stand Tree Mortality**: Summary information for the simulation.

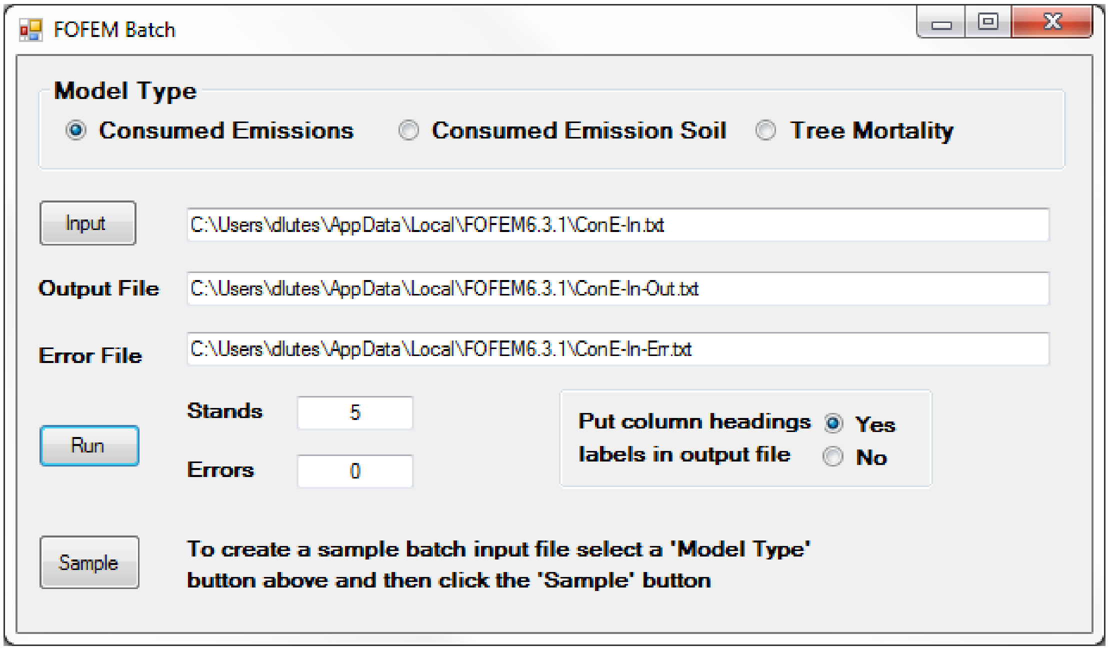
## Graph – "Post-fire"

Predicted probability of mortality is shown by crown scorch. The horizontal red line marks the mortality probability cutoff value you entered. All trees with calculated probability of mortality values greater than the entered cutoff are predicted to die. All trees less than the entered cutoff are predicted to live.



# Batch Processing

FOFEM contains a batch mode for processing multiple plots using input files. Each one of the four FOFEM models is available. Batch files can be processed in either one of two ways: 1) Using the user interface or 2) From a system command line prompt. Each procedure is explained below.




### Batch runs using the user interface

1. Open the FOFEM Batch File Dialog Box from the main menu **Options->Batch Processing**
2. Select a **Model Type** by clicking the radio button immediately preceding the model name: Consumed Emissions, Consumed Emission Soil or Tree Mortality.
3. Select a batch input file by clicking the **Input** button.
4. Set the **Output File** name. A default file name will be shown based on the selected input file name, you can use the default path and file name or edit it. The **Error File** name will be generated by the program based on the input file name.
5. Click **Yes** or **No** to put column heading labels into your output file. You have the option of putting a single row of column labels to the top of your output file. The labels are abbreviations for each column of output data and are helpful if you are going to import the data into a spreadsheet or database.
6. Click **Run** to process.

The number of stands/plots run from the input file will be displayed in the **Stands** field.

The number of errors encountered in the input field will be displayed in the **Errors** field and the error messages will be placed in the error file.

*NOTE: You can create a sample input file by selecting a Model Type and then clicking the **Sample** button. The sample file includes comments and notes about inputs and other features you might* *choose to use. For example, placing the #Emission-File text switch in the file will cause FOFEM to generate individual emission files for each plot of data listed in the batch file.*

The output file is in comma delimited format. The column headers are defined in the Batch Output File section.

### Batch runs using the system command line prompt

The FOFEM6 batch command line option was designed to allow the program to be run in situations where a user interface is not relevant or not allowed by the system or application that it is running under. All of the program's output, including errors, will be written to text files (the program will attempt to pop up a Windows dialog box if it detects any command line program arguments). A sample input file can be created in the FOFEM Batch window as described in the previous section of the user guide.

When running FOFEM in a command window (DOS window) you need to set a system *PATH* variable in order for the system to find the FOFEM executable in its installation folder. Setting the Path variable will allow you to run FOFEM in batch mode from any directory (e.g., your working directory: *C:\Users...FOFEM6.3.1*).

Running *Path-FOFEM.bat* file – found in the *C:\Users …FOFEM6.3* .1 folder - will automatically set the *Path* variable. To run the file, simply double-click on the filename in Windows Explorer or My Computer.

Optionally, you can open a command window and type the *Path* variable at the prompt:

> *set path=%path%;C:\Program Files (x86)*\FOFEMFolder

where FOFEMFolder is the name of your FOFEM installation folder in the *C:\Programs Files (x86)* folder (e.g., *FOFEM631*).

At the command prompt type *FOF_GUI ?* to display the DOS options for running FOFEM.

> *NOTE: The* Emissions_Factors.csv *file must be in the same folder as the* Infile.

1. Open a command window and at the command prompt enter the string to run FOFEM using the following syntax:

   > *> FOF_GUI C | S | M infile outfile runfile errorfile [H]*

   Select one of the following as the first argument:

   *C* = Consumed/Emissions model

   *S* = Consumed/Emissions/Soil model

   *M* = Mortality model

   Set input and output file names:

   *Infile* = standard batch input file for the selected model type to be run

   > *NOTE: Only the* infile *is an input file, the other three files are created when the program is run.*

   *outfile* = batch output file created by program, contains calculation values

   *runfile* = upon completion this file is created and contains number plots processed, number of errors, and file names

   *errorfile* = any error or warning messages

*H* = is an optional argument, when present column heading labels will be placed in the *outfile*

2. When program is complete, you should check the error file to see if any errors were encountered, the run file also contains the number of errors.

### Example FOFEM Command Line Text

In the example screen shot below the first command sets the *Path* variable and the second runs FOFEM using a Consumed/Emissions input file. The input file is named *ConE-In.txt*, the output files that are created when FOFEM runs are *ConE-out.txt*, *ConE-run.txt and ConE-err.txt*. The *H* option is used to add headers in the ConE-Out.txt file. After FOFEM executes the output files can be open with a text editor.

```
C:\Users\ ...\FOFEM6.3>set path=%path%;c:\program files (x86)\fofem63

C:\Users\ ...\FOFEM6.3>FOF_GUI C ConE-in.txt ConE-out.txt ConE-run.txt ConE-err.txt H
```

### Batch - Consumed Emission Soil

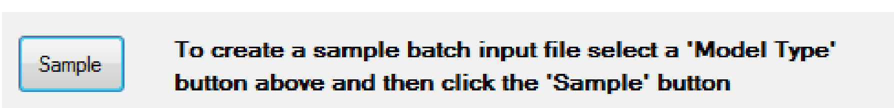
<u>Batch Input file - Consumed Emission Soil</u>

Batch input files use a comma delimited format. Numerical fields can be an integer or a floating point number. Text fields must be contained within double quote marks (e.g., “Spring”, “Entire”). In addition, comment lines can be created by placing a “#” in column one. Blank input lines found in the input file will be ignored.

> *NOTE: In FOFEM batch input files lines that are comments begin with a “#” followed by a space and then the comment text. Lines that are switches begin “#”, followed immediately by the name of the switch. For example:* # FOFEM example file *is a comment.* #1k-SizeClass *is a switch. See* *[Example Batch Parameter File](#)*

No output record will be created for any input record that contains any errors. If an unusually large number of error messages occur while you are processing a file you should check the input file format and also make sure that you have selected the proper Model Type for the input file you are using. Model Type is selected at the top of the FOFEM Batch window. The options are: *Consumed Emissions*, *Consumed Emission Soil* and *Tree Mortality*.

There is a button on the FOFEM Batch dialog box for creating sample batch input files. The sample files are specific to each Model Type and contain comments and column headings to aid you in formatting your own files.




Each row of input data represents one plot and will produce one row of output. All columns shown in the Batch File Description table below are numeric unless specified as text.

**Batch File Description table**
For *Consumed Emissions* and *Consumed Emission Soil* Model Types

| Column No. | Field Name | Description |
|---|---|---|
| 1 | Plot Id | Text or numeric, this field can be entered with or without delimiting double quote marks. Do not use embedded blank characters, for example use "Ridge-1" instead of "Ridge 1" |
| 2 | Litter | Litter fuel load (T/ac) |
| 3 | 1 Hour | Loading of 0 – ¼ in. fuels (T/ac) |
| 4 | 10 Hour | Loading of the ¼ - 1 in. fuels (T/ac) |
| 5 | 100 Hour | Loading of the 1 – 3 in. fuels (T/ac) |
| 6 | 100 Hour Moisture | Moisture of the 100 hour fuels; range: 3 - 298% |
| 7 | 1000 Hour[1] | Loading of the greater than 3 in. fuels (T/ac) |
| 8 | 1000 Hour Moisture | Moisture of the 1000 hour fuels; range: 1 - 300% |
| 9 | 1000 Hour Percent Rotten | Percent of 1000 hour load that is rotten, expresses as a whole number; range 0 - 100% |
| 10 | 1000 Hour Weight Distribution[2] | Defines how the 1000 hour fuel is distributed into size classes; "Even", "Right", "Left", "End", "Center" |
| 11 | Duff | Duff Loading; range 0 - 356.79 T/ac. *NOTE: if duff loading is 0 then duff depth must be 0* |
| 12 | Duff Moisture | Duff moisture; range 10 - 197.2% |
| 13 | Duff Depth | Duff Depth, inches; range 0 – 999 in. *NOTE: if duff depth is 0 then duff loading must be 0* |
| 14 | Duff Moisture Method[3] | The method used to measure duff moisture; "Entire", "Lower", "NFDR", "Adj_NFDR" |
| 15 | Herbaceous | Herbaceous fuel load (T/ac) |
| 16 | Shrub | Shrub fuel load (T/ac) |
| 17 | Crown Foliage | Crown Foliage fuel load (T/ac) |
| 18 | Crown Branch | Crown Branch fuel load (T/ac) |
| 19 | Percent of Crown Burn | Percent of crown that will burn, expressed as a whole number; range 1 – 100% |
| 20 | Region | "InteriorWest", "PacificWest", "NorthEast", "SouthEast" |
| 21 | Cover Group | See the Setting Cover Groups section below |
| 22 | Season | "Spring", "Summer", "Fall", "Winter" |
| 23 | Fuel Category | "Natural", "Piles", "Slash" |
| 24[4] | Soil Family | "Loamy-Skeletal", "Fine-Silt", "Fine", "Coarse-Silt", "Coarse-Loamy" Use "NA" to indicate none available, in which case no soil heating will be calculated for the record |
| 25[4] | Soil Moisture | Soil Moisture; range 0 – 25% |

[1] 1000 hour fuels can be entered as a total or as individual size class amounts. See Entering Individual Size Classes

[2] Size class distributions.

| Size Class | 3 – 6 in. | 6 – 9 in. | 9 – 20 in. | 20+ in. |
|---|---|---|---|---|
| Even | 25% | 25% | 25% | 25% |
| Right | 7% | 16% | 27% | 50% |
| Left | 50% | 27% | 16% | 7% |
| End | 35% | 15% | 15% | 35% |
| Center | 15% | 35% | 35% | 15% |

[3] If you do not have duff fuel, enter zeros for load and depth, a minimum moisture amount of 10 and "Entire" for Duff Moisture Method. Even when there is no duff fuel the Burnup model still requires duff moisture to work.

[4] Input files running the Soil Model Type require fields 24 & 25.

[5] Moisture Regime defaults are based on western systems:

| Regime | Duff | 10-hr | 3+ in | Soil |
|---|---|---|---|---|
| Wet | 130 | 22 | 40 | 25 |
| Moderate | 75 | 16 | 30 | 15 |
| Dry | 40 | 10 | 15 | 10 |
| Very Dry | 20 | 6 | 10 | 5 |

*Setting Cover Groups*

FOFEM batch was designed to accommodate a wide variety of users and their data (with/without cover type and various cover type classifications). Accordingly it has been setup to use a cover group code rather than what would be a rather extensive list of cover types from multiple cover type classifications.

Cover Group is used to determine appropriate consumption formulas for herbaceous, shrub and duff fuel loading, in turn fuel consumption is used to compute smoke emission amounts and simulate soil heating.

| Type | Short code | Long code |
|---|---|---|
| Grass | GG | GrassGroup |
| Shrub | SG | ShrubGroup |
| Sagebrush | SB | Sagebrush |
| Ponderosa pine | PN | Ponderosa |
| Pocosin | PC | Pocosin |
| Balsam, Black, Red, White Spruce | BBS | BalBRWSpr |
| Red, Jack Pine | RJP | RedJacPin |
| White Pine Hemlock | WPH | WhiPinHem |

If you cannot determine a Cover Group use the double quote marks ("") to indicate none and consumption will be calculated using the general consumption algorithm.

*NOTE: For more details concerning how cover groups are used to determine consumption see Cover Groups, Decision Dependency, Duff Consumption, Herbaceous Consumption and Shrub Consumption*

*Switches*

The *Consumed Emissions* and *Consumed Emission Soil* batch input files have three optional switches:

#Emission-File EmFile: This switch creates an emission file for each plot. The required switch argument ('EmFile') will be used as the prefix for the emissions output files. The files are saved in the same folder as the other output files and will have .emi extensions.

#BurnUpFile Burnup.txt: This switch specifies the name of the Burnup parameter file. Do not specify a path. Place the parameter file in the same folder as the input file.

#1k-SizeClass: This switch specifies down woody fuels greater than 3 inches in diameter (1000-hour fuels) are entered in size classes. Replace columns 7 thru 10 described in Batch File Description table with the nine columns in the table below. Then enter Duff in column 16 followed by the remaining data described in the Batch File Description table (i.e., duff, duff moisture, duff depth…).

| Column No. | Description |
|---|---|
| 7 | 3 – 5.9 in. sound (T/ac) |
| 8 | 6 – 8.9 in. sound (T/ac) |
| 9 | 9 – 19.9 in. sound (T/ac) |
| 10 | 20 + in. sound (T/ac) |
| 11 | 3 – 5.9 in. rotten (T/ac) |
| 12 | 6 – 8.9 in. rotten (T/ac) |
| 13 | 9 – 19.9 in. s rotten (T/ac) |
| 14 | 20 + in. rotten (T/ac) |
| 15 | 1000 Hour fuel moisture (%) |

Batch Output File - Consumed Emission Soil

Each fuel component shows post and consumed amounts in tons per acre.

Emissions are shown for Flaming and Smoldering in pounds per acre.

| Column No. | Field name | Description |
|---|---|---|
| 1 | Std | Stand/plot Id from input file |
| | LitPre | Pre fire loading (T/ac) |
| 2 | LitCon | Consumed loading (T/ac) |
| 3 | LittPos | Post fire loading (T/ac) |
| | DW1Pre | Pre fire 1-hour loading (T/ac) |
| 4 | DW1Con | Consumed 1-hour loading (T/ac) |
| 5 | DW1Post | Post fire 1-hour loading (T/ac) |
| | DW10Pre | Pre fire 10-hour loading (T/ac) |
| 6 | DW10Con | Consumed 10-hour loading (T/ac) |
| 7 | DW10Post | Post fire 10-hour loading (T/ac) |

| | | |
|---|---|---|
| | DW100Pre | Pre fire 100-hour loading (T/ac) |
| 8 | DW100Con | Consumed 100-hour loading (T/ac) |
| 9 | DW100Post | Post fire loading (T/ac) |
| | DW1kSndPre | Pre fire 1000 hour sound loading (T/ac) |
| 10 | DW1kSndCon | Consumed 1000 hour sound loading (T/ac) |
| 11 | DW1kSndPost | Post fire 1000 hour sound loading (T/ac) |
| | DW1kRotPre | Pre fire 1000 hour rotten loading (T/ac) |
| 12 | DW1kRotCon | Consumed 1000 hour rotten loading (T/ac) |
| 13 | DW1kRotPost | Post fire 1000 hour rotten loading (T/ac) |
| | DufPre | Pre fire duff loading (T/ac) |
| 14 | DufCon | Consumed duff loading (T/ac) |
| 15 | DufPos | Post fire duff loading (T/ac) |
| | HerPre | Pre fire herb loading (T/ac) |
| 16 | HerCon | Consumed herb loading (T/ac) |
| 17 | HerPost | Post fire herb loading (T/ac) |
| | ShrPre | Pre fire shrub loading (T/ac) |
| 18 | ShrCon | Consumed shrub loading (T/ac) |
| 19 | ShrPost | Post fire shrub loading (T/ac) |
| | FolPre | Pre fire crown foliage loading (T/ac) |
| 20 | FolCon | Consumed crown foliage loading (T/ac) |
| 21 | FolPost | Post fire crown foliage loading (T/ac) |
| | BraPre | Pre fire crown branch loading (T/ac) |
| 22 | BraCon | Consumed crown branch loading (T/ac) |
| 23 | BraPost | Post fire crown branch loading (T/ac) |
| 24 | MSEPer | Post fire mineral soil exposed (%) |
| | DufDepPre | Pre fire duff depth (in.) |
| 25 | DufDepCon | Consumed duff depth (in.) |
| 26 | DufDepPost | Post fire duff depth (in.) |
| 27 | PM10F | $PM_{10}$ flaming emissions (lb/ac) |
| 28 | PM10S | $PM_{10}$ smoldering emissions (lb/ac) |
| 29 | PM25F | $PM_{2.5}$ flaming emissions (lb/ac) |
| 30 | PM25S | $PM_{2.5}$ smoldering emissions (lb/ac) |
| 31 | CH4F | $CH_4$ flaming emissions (lb/ac) |
| 32 | CH4S | $CH_4$ smoldering emissions (lb/ac) |
| 33 | COF | CO flaming emissions (lb/ac) |
| 34 | COS | CO smoldering emissions (lb/ac) |
| 35 | CO2F | $CO_2$ flaming emissions (lb/ac) |
| 36 | CO2S | $CO_2$ smoldering emissions (lb/ac) |
| 37 | NOXF | $NO_x$ flaming emissions (lb/ac) |
| 38 | NOXS | $NO_x$ smoldering emissions (lb/ac) |
| 39 | SO2F | $SO_2$ flaming emissions (lb/ac) |
| 40 | SO2S | $SO_2$ smoldering emissions (lb/ac) |
| 41 | FlaDur | Total flame time (seconds) |
| 42 | SmoDur | Total smoldering time (seconds) |
| 43 | FlaCon | Total flame consumed amount (T/ac) |
| 44 | SmoCon | Total flame consumed amount (T/ac) |

| | | |
|---|---|---|
| 45[1] | Lay0 | Layer 0 maximum temperature at soil surface (C) |
| 46[1] | Lay2 | Layer 2 maximum temperature at 2 cm (C) |
| 47[1] | Lay4 | Layer 4 maximum temperature at 4 cm(C) |
| 48[1] | Lay6 | Layer 6 maximum temperature at 6 cm (C) |
| 49[1] | Lay60d | Deepest layer reaching 60 degrees C (cm)<br>“-1” means no layer reached that temperature |
| 50[1] | Lay275d | Deepest layer reaching 275 degrees C (cm)<br>“-1” means no layer reached that temperature |

[1] When Model Type = Consumed-Emissions-Soil these additional columns of output will be added.

## Batch - Tree Mortality

<u>Batch Input File – Tree Mortality</u>

Input files use a comma delimited format. Numerical fields can be entered as integer or floating point numbers. Text fields must be contained in double quote marks (e.g., “PINPON”, “Low”). Comment lines can be inserted by placing a “#” in column 1, blank lines are also allowed.

Any input records containing errors will not be included in mortality predictions for the stand. If an unusual large number of error messages occur while you are processing a file you should check the input file format and also make sure that you have selected the proper **Model Type** for the input file you are using.

There is an option on the Batch dialog box for creating sample batch input files. The sample files contain comments and column headings to aid you in formatting your own files.

**Mortality Batch File Description table**

| Column No. | Field Name | Description |
|---|---|---|
| 1 | Stand Id | Text or numeric. This field can be entered with or without delimiting double quote marks. Do not use embedded blank characters, for example use "Ridge-1" instead of “Ridge 1” |
| 2 | Tree Species | NRCS tree species code. See the fof_spp.dat file for a complete list of valid codes. The file can be found in the FOFEM install directory, be careful not alter file in any way. Enclose in double quotes. |
| 3 | Stand Density | Trees per acre |
| 4 | DBH | Diameter Breast Height (in.) |
| 5 | Tree Height | Tree Height (ft) |
| 6 | Crown Ratio | Crown Ratio; range 1 - 10 |
| 7 | Flame Length or Scorch Height | You can enter a flame length or a scorch height (ft) |
| 8 | Col 7 Identifier | Text. Enter “F” to specify you are using Flame Length in Column 7 or “S” for scorch height. |
| 9 | Fire Severity | Text, "Low" for low or leave blank "" |

Batch Output File – Mortality

One output record is created for each stand.

| Column No. | Field Name | Description |
|---|---|---|
| 1 | Std | Stand/plot Id from input file |
| 2 | DenPre | Total number of pre-fire trees (trees/acre) |
| 3 | DenPost | Total number of post fire trees (trees/acre) |
| 4 | DenKld | Total number of trees killed (trees/acre) |
| 5 | BAPre | Total basal area of pre-fire trees ($ft^2$) |
| 6 | BAPost | Total basal area post fire ($ft^2$) |
| 7 | BAKld | Total basal area of the killed trees ($ft^2$) |
| 8 | CCPre | Total crown cover of pre-fire trees (%) |
| 9 | CCPost | Total crown cover of post fire trees (%) |
| 10 | CCDiff | Total crown cover change (%) |
| 11 | DBHKldAvg | Arithmetic mean DBH of killed trees (in.) |
| 12 | MortAvgPct4 | Average percent mortality for trees where DBH $\geq$4 inches (%) |
| 13 | MortAvgPct | Average percent morality for all trees (%) |

*NOTE: Batch processing is currently not available for the post-fire injury tree mortality option.*

## Batch Burnup Parameter File

This file allows you to set specific input parameters for the Burnup model that FOFEM uses to simulate fuel consumption. The parameters in this file will be used instead of the default parameters used in FOFEM. See the example file below.

To use a Batch Burnup Parameter File you place the *#Burnup File* switch and file name at the top of a batch input file. The following sample file can be used as is.

*NOTE: In FOFEM batch input files lines that are comments begin with a "#" followed by a space and then the comment text. Lines that are switches begin "#", followed immediately by the name of the switch. For example:* # FOFEM example file *is a comment.* #MAX_TIMES *is a switch.*

Example Batch Parameter File

```
# Sample Burnup input Parameter File
# This file is used in conjunction with the Batch input
# file command switch #BurnUpFile
#
# maximum number iterations burnup does, default 3000
# valid 1 -> 100000
#MAX_TIMES 3
# intensity of the igniting surface fire,
# kW/m2 sq m, 40.0 -> 1.0e5, burnup var - fi  default 50.0
#INTENSITY 0.0
# residence time of the ignition surface fire, seconds
# default = 60.0, fofem's burnup input file uses 30.0
# burnup var = ti,   limits 10.0 -> 200.0
#IG_TIME 60
# windspeed at top of fuelbed meters/second
# burnup var = u, default 0, limits 0.0 -> 5.0,
#WINDSPEED 0.0
```

```
# fuel depth, meters,
# burnup var = d, defualt 0.3, limits 0.1 -> 5.0
#DEPTH  0.3
# ambient air temperature, degrees Celsius
# burnup var = tamb, default 27,
# if ( tamb-273 < tam1 || tamb-273 > tam2)
# const double tam1 = -40.0,  tam2 = 40.0;
#AMBIENT_TEMP  27.0
# fire environment minumum dimension paramter
# default 1.83
#R0  1.83
# fire environment increment temp parater
# default 0.40
#DR  0.4
# time step for integration of burning rates.
# TIMESTEP * MAX_TIMES gives max simulation period default 15
#TIMESTEP 15
# Sigma - Surface area to volume ratio
#SURat_Lit          8200.0
#SURat_DW1          1480.0
#SURat_DW10          394.0
#SURat_DW100         105.0
#SURat_DWk_3_6        39.4
#SURat_DWk_6_9        21.9
#SURat_DWk_9_20       12.7
#SURat_DWk_20         5.91
```

# Scientific Content – Soil Heating

The soil heating component is a product of many years of work by several different researchers. This model is intended to give a view of soil heating based on point-based surface fuel and soil conditions. However, fire practitioners and researchers understand that fire is non-uniform and often erratic in behavior. As a consequence of this variability, it is difficult to attempt to predict soil heating on a unit scale when in reality most fire patterns are mosaic. We strongly encourage the user to experiment with a variety of model input values in order to best predict and understand varying fire regimes. For example, run a number of simulations of various sampled fuelbeds and assume the simulated effects are distributed spatially with the same frequency as the distribution of the fuelbeds.

The degree and depth of mineral soil heating over time is simulated using a model developed at the Rocky Mountain Research Station Fire Sciences Laboratory in a joint effort with Dr. Gaylon S. Campbell and staff at Washington State University. This model assumes that soil temperature gradients in the horizontal direction are small compared to those in the vertical direction and the model predicts the downward heat flow into the soil using a one-dimensional model. This model has broad applicability due to its ability to predict soil temperature depth profiles over a wide range of soil moistures, densities and mineralogy.

Before the Campbell soil heating model is initiated the FOFEM model uses two alternative approaches to simulate the amount of heat delivered to the soil surface. The *non-duff model* assumes radiant heating (simulated in the Burnup model) from the flaming combustion of the woody, litter, herbaceous and shrub fuelbed components heats the soil surface. Alternatively, the *duff model* assumes radiant and conductive heat from only the burning duff/organic soil horizons heats the soil surface.

The energy at the soil surface resulting from surface fires (non-duff model) is often of moderate to high intensity but of short duration. In contrast to flaming combustion, smoldering (duff model) is commonly characterized by lower energy intensities and longer durations. After ignition, the continued smoldering of the duff/organic soil horizons is no longer dependent on the surface fire environment but is a function of soil moisture, mineral content and bulk density. Total heat at the soil surface is often greater than resulting from surface fires because of the long duration and relatively close proximity of the smoldering combustion front and the mineral soil surface (Neary et al, 2005).

In FOFEM, the transfer of heat from the surface into and within the mineral soil is accomplished using the 1-dimensional Campbell model and is a function of soil moisture and soil properties. The soil heating model is more sensitive to the amount and the duration of heat released during burning and the soil moisture content and is less sensitive to other characteristics such as soil family type or texture.

The soil heating component of FOFEM has been designed in a way that makes it easy for the user to change key variables like duff depth, moisture content, and soil family directly on the user interface. There is also an option for the user to run the soil heating model from input files changing more specific inputs to the soil heating model.

## Assumptions for the duff soil heating model

The duff model simulates soil heating resulting from the transfer of heat from the duff smoldering combustion zone into the mineral soil. The total energy reaching the mineral soil surface is a function of the heat energy content of the duff soil material, moisture content and the duration of smoldering and is the product of duff consumed (kg $m^{-2}$) and the energy content of duff fuels). Duff consumption is calculated using the appropriate duff consumption equation based on the selected region, fuel/vegetation type and duff moisture. Duff moisture can be directly input or the user may choose one of the fuel moisture regimes from the FOFEM interface (very dry to wet).

FOFEM uses total duff load consumed and duff moisture in the logic provided by Albini (1994) to determine the intensity of consuming duff at each time step assuming heat from burning peat = 20 MJ/kg (Frandsen 1987):

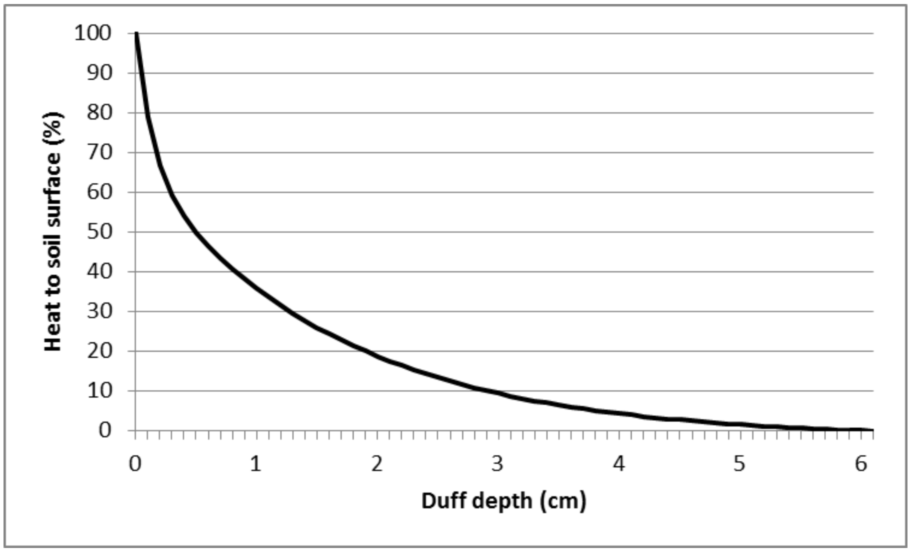
$$I_d = (7.5x10^{-4}) – (2.7x10^{-4}R_M);$$

where $I_d$ is the intensity of the burning duff (kg $s^{-1}$ $m^{-2}$) and $R_M$ is the gravimetric soil moisture (Frandsen 1991b). In FOFEM, duff burning rate is not influenced by wind or burning surface fuels.

It is commonly observed that not all heat from smoldering is directed downward into the soil. The amount of heat from smoldering transferred to the soil is dependent on a several factors. During smoldering the remaining unburned duff between the combustion zone and the soil surface acts as an efficient insulator. The proportion of heat directed to the soil surface is calculated with the equation:

$$H = 1.6996 + (32.7652 * EXP(-7.4601*D_d)) + (68.9349 * EXP(-0.6077*D_d))$$

Where H is the percent of total heat of combustion that is directed to the soil surface, $D_d$ is duff depth measured in cm. This equation does not account for soil moisture which is a variable that may significantly influence the conductivity of heat in duff.




Duff smoldering is commonly observed many hours after flaming combustion has ended. The long duration of smoldering is a major factoring influencing heat transfer into the soil and subsequent fire effects. FOFEM predicts the duration of smoldering as a function of duff thickness, moisture and mineral content (Frandsen 1991).

### Assumptions for non-duff soil heating model

When no duff/ or organic soil horizon is present then soil heating is driven by the radiant energy from flaming combustion of litter, woody fuels, herbs and shrubs. Burning duration of litter and woody fuels is determined in Burnup. Herb and shrub fuels burn at a rate of 10 t $ac^{-1}$ $min^{-1}$. The non-duff model assumes only a portion of the consumption intensity is delivered to the soil surface. These values were developed after comparing simulated outputs to results from field data.

| Component | Proportion of intensity directed to soil surface |
|---|---|
| Woody debris and litter | 15% |
| Herbaceous and shrubs | 10% |

### Running Soil Heating from Main Menu

The soil heating component of FOFEM gives the option to run the Duff or Non-Duff model from a soil heating input file.

From the main FOFEM menu:

- **Options > Create Sample Soil Input File.** This selection creates a soil heating input file for the "duff" or the "non-duff" input files.
- **Options > Run Soil from an Input File**. This selection will run an existing soil heat input file. The input file extensions are; *.exp* and *.duf* for the non-duff and duff models, respectively

The simplest method to produce an input file is to use the *Create Sample Soil Input File (.exp, .duf)* option from the menu. Some input values in the data files result from the user selections on the FOFEM GUI interface. This file can then be edited to make the desired changes.

## Duff Model Input File Input File Description

**Section 1**
This section may be used to document user changes to the input file.

- **# -** The line starting with a pound sign (#) followed by a space is a comment. You can enter an entire line(s) as a comment as long as you start it with a pound sign in column one.

**Section 2**
This section defines the duff fuel parameters.

- **Duff weight (Tons/Acre)** is the preburn duff loading. Default values are used for the selected fuel types or the user may enter other values.

- **Duff depth (inches)** is the duff layer thickness. Default values are used for the selected fuel types of the user can enter other values.

- **Duff consumed (%)** is the percent duff consumed 0 -100% (integer values). Consumption is estimated from the default fuel type duff consumption equation or the user may enter other values.

- **Duff moisture content (%)** is the gravimetric moisture content (%) and is typically obtained by oven drying. Moisture values vary from 10 % or less for extremely dry conditions to 75 to 130 % for wet conditions. Values of 10% or less will result in 100% duff consumption for all fuel types.

**Section 3**
This section defines the various soil properties. Soil bulk density, soil particle density and thermal conductivity are determined from the soil family type (Table 3). Two parameters of most immediate interest to users are:

- **Soil starting water content (g/cm$^3$) -** is the volumetric soil moisture content. It can be estimated as function of bulk density ( g/cm^3) and the mass of water (g)

- **Soil starting temperature (C$^0$)-** The temperature of mineral soil at the start of the soil heating simulation is assumed to be uniform throughout the depth profile used for predictions.

Other parameters in this section have been determined by laboratory work. These default values for each soil family type should not be modified.

**Section 4**
This section of the input file begins with the word ‘layers’ on a single line starting column 1.

Each of the values on this line represents a depth (centimeters) that the model will predict temperature at. Note: the user must specify 13 depths.

<u>Example Duff soil input file</u>

**Section 1**

```
# Duff Model - Example Inputs File
# Use this file type when duff is present
# Lines that start with a # are comments.
# Warning: extreme or missing values in this file can
# cause unexpected results.
# These inputs represent the current GUI settings.
# However if no duff is present a fictitious amount will be used.
# And the soil type = Coarse-Silt
```

**Section 2**

```
Duff-Model
duff-weight           5.0   pre-burn weight - (T/ac)
duff-depth           0.50   duff depth - (in)
duff-consumed        66.7   percent consumed, whole integer 0 -> 100
duff-moisture        40.0   very dry 20, dry 40, moderate 75, wet 130
```

**Section 3**

```
bulk-density         1230000   soil bulk density - (g/m3)
particle-density     2350000   soil particle density - (g/m3)
extrap-water         0.16   extrapolated water cont. at -1 (J/kg)
thermal-conduct      2.53   thermal conductivity of mineral fraction
Vries-shape          0.103   de Vries shape factor
water-content        0.218   water content for liquid recirculation
cop-power            3.43   power for recirculation function
time-step            10      time step - (sec)
start-water          0.10   starting soil water content, Wet 0.25, Mod 0.15, Dry 10, V-
Dry 5,  m3/m3
start-temp           21.0   starting soil temperature (C)
```

**Section 4**

```
# Specifiy exactly 13 depths (cm)
layers   1 2 3 4 5 6 7 8 9 10 11 12 13
```

## Non-Duff Model Input File Description

**Section 1**

This section can be used to document changes to the input file.

- **# -** The line starting with a pound sign (#) followed by a space is a comment. You can enter an entire line(s) as a comment as long as you start it with a pound sign in column one.

**Section 2**

This section defines the various soil properties. Soil bulk density, soil particle density and thermal conductivity are determined from the soil family type. In this section, two parameters of interest to most users are:

- **Soil starting water content ($g/cm^3$) -** is volumetric mineral soil moisture. It can be estimated as function of bulk density (g/cm^3) and the mass of water (g). It is assumed to be uniform throughout the soil depths at the beginning of the heating simulation.

- **Soil starting temperature ($C^0$) -** The mineral soil is assumed to be at a uniform temperature throughout the depth profile used for temperature predictions.

Other parameters in this section have been determined by laboratory work and at this time the default values for each soil family type should be used. (See tables 1 -3 for soil parameters)

**Section 3**
This section of the input file begins with the word ‘layers’ on a single line starting column 1.

Each of the values on this line represents a depth (centimeters) that the model will predict temperature at. Note: the user must specify 13 depths.

**Section 4**
This section defines the proportion of radiant energy generated by flaming combustion of the surface fuels that is transferred to the soil.

- **Efficiency WL and Efficiency HS (%)** - The user can define the percent of heat transferred downward into the bare soil by the Wood/Litter and Herb/shrub loads. In general, estimates of the energy reaching the soil surface from flaming combustion range from 5 to 25 %.
- **FI- interval (sec) -** The user may modify the duration of surface heating by changing the ‘fi-interval’ value.

**Section 5**

- **Fire intensity (kW/m^2) -** Values in the two columns of this section are fire intensity estimates. The estimates are calculated in FOFEM from the Wood/Litter and Herb/Shrub loadings of the selected fuel type. These estimates are modified by the WL and HS efficiency values before they are input into the model.

<u>Example Non-duff soil input file</u>

**Section 1**
```
# Non-Duff Model - Example Input File
# Use this file type when there is an absence of duff
# Lines that start with a # are comments.
# Warning: extreme or missing values in this file can
# cause unexpected results.
# These inputs represent the current GUI settings.
# However the fire intensity values below may not be
# totally accurate if there is duff present on the plot
# Values represent soil type = Coarse-Silt
```

**Section 2**
```
NonDuff-Model
bulk-density          1230000   soil bulk density - (g/m3)
particle-density      2350000   soil particle density - (g/m3)
extrap-water          0.16   extrapolated water cont. at -1 (J/kg)
thermal-conduct       2.53   thermal conductivity of mineral fraction
Vries-shape           0.103   de Vries shape factor
water-content         0.218   water content for liquid recirculation
cop-power             3.43   power for recirculation function
time-step             10      time step - (sec)
start-water           0.10   starting soil water content, Wet 0.25, Mod 0.15, Dry 0.10, V-Dry
0.05,  m3/m3
start-temp            21.0   starting soil temperature (C)
```

**Section 3**
```
# Specifiy exactly 13 depths - (cm)
layers   1  2  3 4  5  6  7  8  9  10  11  12  13

# Specify fire intensity (Kw/m2) for Wood/Liter and Herb/Shrub
efficiency-WL    15    percent of Wood and Liter fire intensity applied to soil surface
efficiency-HS    10    percent of Herbaceous and Shrub fire intensity applied
to soil surface
```

```
fi-interval       15    time between fire intensity values listed in arrays
below - (sec)
```

**Section 4**

```
# Fire intensity (kW/m2) arrays for Wood/Liter and Herb/Shurb
# specify total fire intensity (above efficiency percents will be applied to these values)
# values must start on the line immediately after 'fire-intensity'
fire-intensity
    22     10
    43     21
    65     31
    86     42
    35      0
    26      0
    23      0
    21      0
    19      0
    18      0
    17      0
    17      0
    16      0
    15      0
    14      0
```

## Soil Family Description

- **Loamy-Skeletal**: Rock fragments make up 35% or more by volume; enough fine earth to fill interstices larger than 1 mm; the fraction finer than 2 mm is loamy as defined for the loamy particle-size class.
- **Fine-Silty:** By weight, <15% of the particles are fine sand (diameter 0.25-0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; 18 – 34% clay in the fine-earth fraction.
- **Fine:** A clayey particle-size class that has 35 – 59% clay in the fine-earth fraction.
- **Coarse-Silty**: By weight, <15% of the particles are fine sand (diameter 0.25-0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; <18% clay in the fine-earth fraction.
- **Coarse-Loamy**: By weight, 15% or more of the particles are fine sand (diameter 0.25-0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; <18% clay in the fine-earth fraction.

Descriptions of soil types used in the development of the soil heating model (Campbell, et al. 1995)

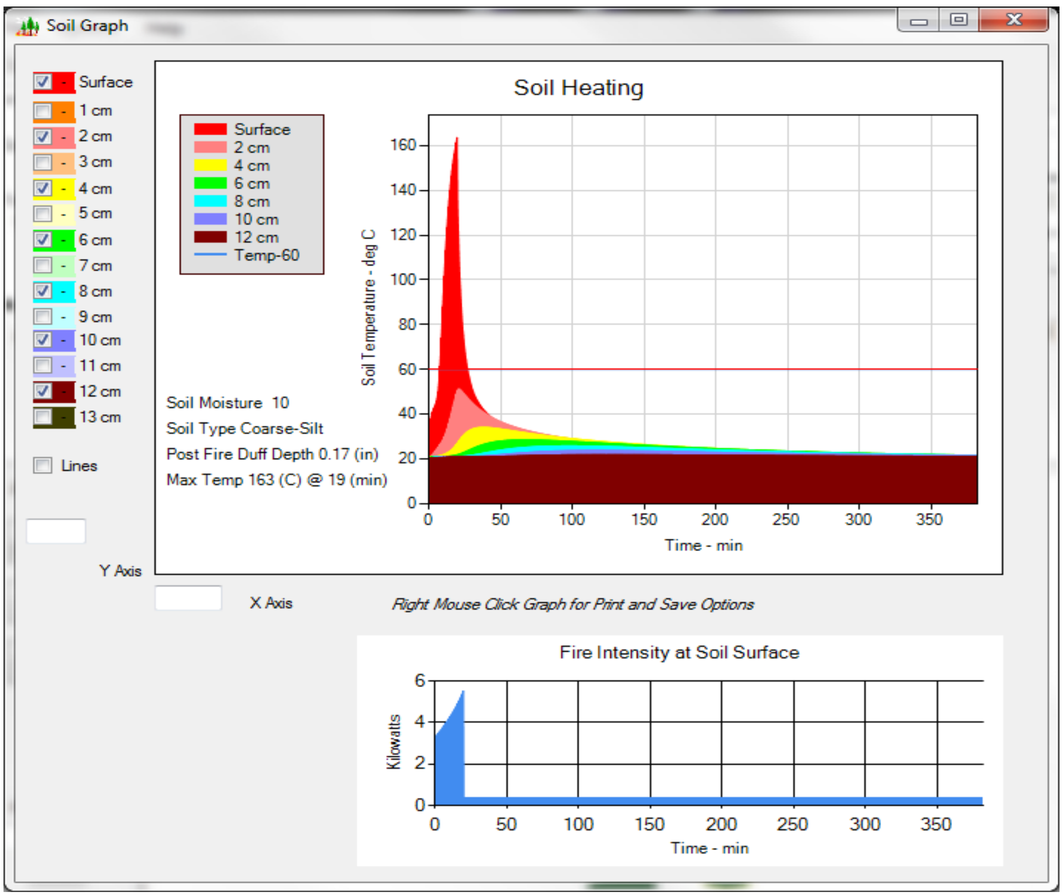
| Soil Name | Soil Family Type | Soil Class | Location |
|---|---|---|---|
| Quincy sand | Sand | Mixed mesic Xeric Torripsamment | Hanford, WA |
| Boldercreek | Loamy-skeletal | Mixed frigid Typic vitrandept | Wallace, ID |
| Palouse B | Fine-silty | Mixed mesic  Pachic Ultic Haploxeroll | Whitman Co. WA |
| Volkmar | Silt loam | Aeric Cryaquept | Delta, AK |

## Soil Simulation Outputs

The results of each soil heating simulation can be output in either graphical or report form.

### Soil Heating Graph

The graphical format plots temperature in Celsius (C) verses time in minutes and allows for scaling adjustments along the x and y-axis. The graph displays temperature at each depth and highlights temperatures that exceed 60 degrees C; this temperature is typically considered the lethal tissue temperature for living organisms. The graphical output also includes the starting soil moisture, soil type, post fire duff depth and maximum temperature reached at the soil surface. Intensity is shown in the bottom graph. Right-click either graph to save or print the image.



Soil Heating Report

Users can also view the output of each soil heating simulation in report form. This option is useful for comparing different soil heating scenarios using the Summary Report functionality.

```
                                    Soil Heat Report

 Region:         InteriorWest
 Cover Type:     SAF 016 - Aspen
 Fuel Type:      Natural
 Fuel Reference: FOFEM 561
 Duff Depth.....: Pre-Fire:   1.27 cm.,  Post-Fire:   0.42 cm.

                        Soil Layer Maximum Temperature

Depth (cm)     0    1    2    3    4    5    6    7    8    9   10   11   12   13
Temp (C)     163   66   51   40   34   30   28   27   25   24   23   22   21   21
Time (min)    19   19   20   27   37   51   66   83   97  107  115  120  123    0

Max Depth Having 60 degrees: 1
Max Depth Having 275 degrees: - None -
```

## Output Graphing File

FOFEM can create an output text file that can be used as input for other graphing programs, for example Excel or SPSS. To save the soil points to a file select **Options > Save Soil Temp Points File**.

Below is a small part of an output file. The grid of values that represents the current graph displayed in the FOFEM graph window. Accordingly you must create a soil graph before you attempt to save the points to a file.

| Time | Surface | Layer 1 | Layer 3 | Layer 4 | Layer 5 | Layer 6 | Layer 7 | Layer 8 | Layer 9 |
|---|---|---|---|---|---|---|---|---|---|
| min. | | | | | cm | | | | |
| 0.3 | 31.4 | 21.6 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 |
| 0.7 | 34.3 | 22.3 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 |
| 1.0 | 36.4 | 23.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 |
| 1.3 | 37.9 | 23.9 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 |
| … | … | … | … | … | … | … | … | … | … |

Column 1 is decimal minutes since ignition, column 2 is the temperature (C) of surface layer at the specified time, column 3 is the temperate at 1 cm depth and subsequent columns show soil temperature at the specified depth. The temperature of 21°C represents the ambient temperature that is used in this example.

## Soil Heating Citations and Sources

Albini, F.A. 1994. Program Burnup: A simulation model of the burning of large woody natural fuels. Unpublished report on file at the Missoula Fire Sciences Lab.

Campbell, G.S. Simulation of soil heating under smoldering duff fires. Unpublished report on file at the Missoula Fire Sciences Lab.

Campbell, G.S., J.D. Jungbauer, Jr., S. Shiozawa, and R.D. Hungerford. 1993. A one-parameter equation for water sorption isotherms of soils. Soil Science 156(5): 302-305.

Campbell, G.S., J.D. Jungbauer, Jr., W.R. Bidlake, and R.D. Hungerford. 1994. Predicting the effect of temperature on soil thermal conductivity. Soil Science 158(5): 307-313.

Campbell, G.S., J.D. Jungbauer, Jr., K.L. Bristow, and R.D. Hungerford. 1995. Soil temperature and water content beneath a surface fire. Soil Science 159(6): 363-374.

Fransden, W.H. 1987. The Influence of Moisture and Mineral Soil on the Combustion Limits Of Smoldering Duff. Can. J. For. Res. 17: 1540-1544.

Frandsen, W.H. 1991. Heat Evolved From Smoldering Peat. Int. J. Wildland Fire 1(3): 197-204.

Frandsen, W.H. 1991. Burning Rate of Smoldering Peat. 1991. Northwest Science. Vol. 65, No. 4. pp 166-172.

Hungerford, R.D., M.G. Harrington, W.H. Frandsen, K.C. Ryan, and G.J. Niehoff. 1991. Influence of fire on factors that affect soil productivity. U.S. Forest Service Intermountain Research Station General Technical Report INT-280.

Nary, Daniel G.; Ryan, Kevin C.; DeBano, Leonard F., eds. 2005. (revised 2008). Wildland fire in ecosystems: effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42-vol.4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250 p.

# Scientific Content - Computing Bark Thickness

The longleaf pine the bark thickness equation comes from: Wang, GG; Wangen, S; Reinhardt, E; Waldrop, TA, Outcalt, KW; Walker, JL; Brockway, DG; Haywood, JD; Hiers, JK. 2007. Modify FOFEM for use in the Coastal Plain Region of the Southeastern US. JFSP Program Report: 05-4-3-06. Available at: http://www.firescience.gov/projects/05-4-3-06/project/05-4-3-06_final_report.pdf

Longleaf SBT = 0.435 + ( 0.031 * DBH)

Where SBT is single bark thickness (cm) and DBH is diameter breast height (cm).

The remaining FOFEM bark thickness equations are from the equations and sources listed in the Forest Vegetation Simulator with modifications made using descriptions in: North American Trees by R.J. Preston, Jr.; A Natural History of Western Trees and A Natural History of Trees of Eastern and Central North America by D. C. Peattie and The Audubon Society Field Guide to North American Trees, Western and Eastern regions by E. L. Little. In the FOFEM model, spruce spp. mortality is constricted by factors other than bark thickness to be at least 80 percent, thus the FOFEM bark thickness equations for the spruces are the least researched.

Single bark thickness (SBT) is assumed to have a linear relationship to diameter breast height (DBH), both measured in inches, in the form SBT=v(DBH); where v is a species specific bark thickness coefficient from table 1. Species specific bark thickness indices can be found in the “Brk” column of the FOF_SPP.DAT file typically located in C:\Users*username*\AppData\Local\FOFEM.

Table 1. FOFEM bark thickness indices and coefficients.

| Bark thickness index FOF_SPP.DAT | Bark thickness coefficient | Bark thickness index FOF_SPP. DAT | Bark thickness coefficient |
|---|---|---|---|
| 1 | 0.019 | 21 | 0.042 |
| 2 | 0.022 | 22 | 0.043 |
| 3 | 0.024 | 23 | 0.044 |
| 4 | 0.025 | 24 | 0.045 |
| 5 | 0.026 | 25 | 0.046 |
| 6 | 0.027 | 26 | 0.047 |
| 7 | 0.028 | 27 | 0.048 |
| 8 | 0.029 | 28 | 0.049 |
| 9 | 0.03 | 29 | 0.05 |
| 10 | 0.031 | 30 | 0.052 |
| 11 | 0.032 | 31 | 0.055 |
| 12 | 0.033 | 32 | 0.057 |
| 13 | 0.034 | 33 | 0.059 |
| 14 | 0.035 | 34 | 0.06 |
| 15 | 0.036 | 35 | 0.062 |
| 16 | 0.037 | 36 | 0.063 |
| 17 | 0.038 | 37 | 0.068 |
| 18 | 0.039 | 38 | 0.072 |
| 19 | 0.04 | 39 | 0.081 |
| 20 | 0.041 | | |

# Scientific Content - Computing Tree Mortality

## Estimating Tree Mortality - "Pre-fire"

Tree mortality in FOFEM is computed using the algorithm developed by Ryan and Reinhardt (1988) for the majority of the species. It uses bark thickness and percent crown volume scorched as predictive variables. This method implicitly assumes that variations in fire caused tree mortality in trees of different species and sizes can be accounted for primarily by differences in bark thickness and proportion of crown killed. This assumption, while undoubtedly extremely simplistic, allows us to predict mortality for any trees as long as we can estimate bark thickness, tree height, crown ratio and scorch height.

New mortality equations for many western conifer species were developed for FOFEM 5.x and offer improvement over the Ryan and Reinhardt algorithm. See Hood et al. (2007) for an evaluation of the Ryan and Reinhardt algorithm. These species and models are listed below. These models all predict tree mortality occurring within 3 years of the fire.

Either scorch height or flame length may be used in FOFEM to predict tree mortality. If flame length is entered, scorch height is computed using Van Wagner's (1973) scorch height model, assuming a temperature of 77 degrees F and a midflame wind speed of 0 mph. These values seem conservative for many situations since computed scorch height varies little with temperature between 40 and 80 degrees F, and wind speeds between 0 and 10 mph. These ranges encompass many prescribed fire situations. At higher wind speeds typical of many wildfires, computed scorch heights actually decrease for a given flame length, so predicted scorch height and consequently, tree mortality will be over predicted. Entering scorch height directly allows the user to bypass these assumptions, if they are of concern. Van Wagner's scorch height model was developed from stands of red pine on flat ground; it can be expected to perform poorly on steep slopes, at ridge tops, and in stands with large openings in the canopy. Again, using scorch height as a predictive variable, instead of flame length, allows the user to avoid errors in predicting scorch height. This may be an especially good option when predicting effects of fire after the fact – in this case scorch height can be observed directly in the field.

In predicting stand mortality, FOFEM assumes a continuous fire. If a burn is very discontinuous or patchy, and the user can estimate the proportion of the area burned, then the per acre estimates of tree mortality computed by FOFEM can be adjusted by multiplying them by the proportion burned.

The data from which the tree mortality algorithm was developed was limited to western conifers greater than 5 inches DBH under burned with prescribed fire. The predictions should apply reasonably well to wildfires. Some post fire insect damage is implicitly included in these predictions, as trees damaged by insects after burning were not excluded from the data. Major post fire insect attacks are not modeled however. Root damage is not explicitly modeled, although it may be correlated with cambial damage in many cases.

The mean, standard error, median, and range of crown scorch and DBH by species of trees used to develop pre-fire mortality models are listed below. Species are listed in order of increasing bark thickness using bark thickness equations in FFE-FVS.

| Species | No. of trees | Type[1] | Crown Scorch % | | | DBH (cm) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean ±SE | Md | Range | Mean ±SE | Md | Range |
| Lodgepole pine | 2196 | V | 19 ± 0.7 | 0 | 0-100 | 20.8 ± 0.1 | 19.6 | 10.2-56.4 |
| Whitebark pine | 148 | V | 24 ± 2.9 | 2 | 0-100 | 22.9 ± 0.6 | 22.5 | 12.4-58.9 |
| Engelmann spruce | 223 | V | 30 ± 2.2 | 20 | 0-100 | 33.2 ± 1.1 | 30.2 | 12.7-85.1 |
| Red fir | 209 | L | 42 ± 1.8 | 46 | 0-89 | 42.1 ± 1.2 | 38.9 | 15.2-104.6 |
| Subalpine fir | 947 | V | 65 ± 1.3 | 85 | 0-100 | 19.4 ± 0.2 | 17.5 | 10.2-75.2 |
| White fir | 2304 | L | 67 ± 0.5 | 74 | 0-100 | 59.2 ± 0.4 | 56.9 | 15.2-152.7 |
| Incense cedar | 783 | L | 40 ± 1.1 | 38 | 0-98 | 51.6 ± 0.9 | 43.7 | 25.4-166.4 |
| Yellow pine[2] | 7309 | V | 58 ± 0.4 | 70 | 0-100 | 41.8 ± 0.3 | 35.1 | 6.3-178.1 |
| Douglas-fir | 1539 | V | 34 ± 0.9 | 20 | 0-100 | 33.7 ± 0.4 | 30.5 | 10.2-105.4 |
| Western larch | 461 | V | 26 ± 1.7 | 5 | 0-100 | 38.1 ± 0.6 | 38.1 | 10.2-98.8 |
| Sugar pine | 719 | L | 40 ± 1.1 | 41 | 0-98 | 73.3 ± 1.0 | 70.4 | 25.6-188.0 |

[1] L = crown length; V = crown volume
[2] Includes ponderosa and Jeffrey pine

## Mortality Equations – "Pre-fire"

---

Equation 1:
Used when other equations are not specified. $P_m$ = probability of mortality, BT=bark thickness (in.), CS= crown volume scorched (%)
If DBH> 1" then $P_m = 1/[1 + \exp(-1.941 + (6.316 * (1.0 - \exp(-BT))) - 0.000535 * (CS^2))]$
If DBH < 1" and Crown Height/Length Scorched > 50% then $P_m$ = 1
If DBH < 1" and Ht < 3' then $P_m$ = 1
Else $P_m = 1/[1 + \exp(-1.941 + (6.316 * (1.0 - \exp(-BT))) - 0.000535 * (CS^2))]$
Source: Ryan, K.C.; Reinhardt, E.D. 1988. Predicting post fire mortality of seven western conifers. Canadian Journal of Forest Research 18:1291-1297.

---

Equation 3:
Spruces other than Engelmann
Same as Equation 1 but constrains mortality to at least 80%
Source: Ryan, K.C.; Reinhardt, E.D. 1988. Predicting post fire mortality of seven western conifers. Canadian Journal of Forest Research 18:1291-1297.

---

Equation 4:
Quaking Aspen.   CH=char height  (CH= Flame height/1.8), DBH (in.)
If Fire Severity = "Low" then
$P_m = 1/[1 + \exp((0.251 * (DBH * 2.54) - (0.07 * CH * 2.54 * 12) - 4.407)]$
If Fire Severity <> "Low" then
$P_m = 1/[1 + \exp((0.0858 * DBH * 2.54) - (0.118 * CH * 2.54 * 12) - 2.157)]$
Source: Brown, J. K.; DeByle, N. V. 1987. Fire damage, mortality, and suckering in aspen. Canadian Journal of Forest Research. 17: 1100-1109.

---

Equation 5:
Longleaf pine: BT=bark thickness (cm);  SCH=proportion of crown volume scorched (0-10).
BT=0.435+(0.031*DBH(cm))
If SCH= 0 then $P_m$=0
If SCH>0 then $P_m$=1/(1+e^0.169+(5.136*BT)+(14.492*BT^2)-(0.348*SCH^2))
Cutoff for mortality is 0.3 rather than 0.5.
Source: Wang, GG; Wangen, S;  Reinhardt, E; Waldrop, TA, Outcalt, KW; Walker, JL; Brockway, DG; Haywood, JD; Hiers, JK. 2007. Modify FOFEM for use in the Coastal Plain Region of the Southeastern US. JFSP Program Report: 05-4-3-06. Available at: http://www.firescience.gov/projects/05-4-3-06/project/05-4-3-06_final_report.pdf

This equation was one of 14 equations developed by Wang and others for predicting probability of longleaf mortality from low severity prescribed fire in the Southeastern Plains, Middle Atlantic Coastal Plains and Southern Coastal Plain in the southeastern U.S. Some of the other longleaf mortality equations included in Wang and others JFSP report have better predictive power but require input of relative humidity, an input not currently available in FOFEM. While not the optimal selection the equation from Wang, et al. that FOFEM uses in this version performs better than the equation used in previous version of FOFEM and was selected because it could be easily included incorporated in

FOFEM. When FOFEM is updated to allow more complex inputs for predicting tree mortality and/or new longleaf pine mortality equations are developed FOFEM will be updated according.

---

Equation 10:
White fir: CLS=Crown length scorched (%)

$$P_m = 1/\left[1+\exp\left(-\left(-3.5083+(\mathrm{CLS}*0.0956)-(\mathrm{CLS}^2*0.00184)+(\mathrm{CLS}^3*0.000017)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

---

Equation 11:
Subalpine fir and grand fir: CVS = crown volume scorched (%)

$$P_m = 1/\left[1+\exp\left(-\left(-1.6950+(\mathrm{CVS}*0.2071)-(\mathrm{CVS}^2*0.0047)+(\mathrm{CVS}^3*0.000035)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

---

Equation 12:
Incense cedar: CLS = crown length scorched (%)

$$P_m = 1/\left[1+\exp\left(-\left(-4.2466+(\mathrm{CLS}^3*0.000007172)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

---

Equation 14:
Western larch: CVS = crown volume scorched (%)

$$P_m = 1/\left[1+\exp\left(-\left(-1.6594+(\mathrm{CVS}*0.0327)-(dbh*0.0489)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

---

Equation 15:
Engelmann spruce: CVS = crown volume scorched (%)

$$P_m = 1/\left[1+\exp\left(-\left(0.0845+(\mathrm{CVS}*0.0445)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

---

Equation #16
Red fir: CLS = crown length scorched (%)

$$P_m = 1/\left[1+\exp\left(-\left(-2.3085+(\mathrm{CLS}^3*0.000004059)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

---

Equation 17:
Whitebark pine and lodgepole pine: CVS = crown volume scorched (%)

$$P_m = 1/\left[1+\exp\left(-\left(-0.3268+(\mathrm{CVS}*0.1387)-(\mathrm{CVS}^2*0.0033)+(\mathrm{CVS}^3*0.000025)-(dbh*0.0266)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation 18:
Sugar pine: CLS = crown length scorched (%)
$$P_m = 1/\left[1+\exp\left(-\left(-2.0588+(\mathrm{CLS}^2 * 0.000814)\right)\right)\right]$$
Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation 19:
Ponderosa/Jeffrey pine: CVS = crown volume scorched (%)
$$P_m = 1/\left[1+\exp\left(-\left(-2.7103+(\mathrm{CVS}^3 * 0.000004093)\right)\right)\right]$$
Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation 20:
Douglas-fir: CVS = crown volume scorched (%)
$$P_m = 1/\left[1+\exp\left(-\left(-2.0346+(\mathrm{CVS} * 0.0906)-(\mathrm{CVS}^2 * 0.0022)+(\mathrm{CVS}^3 * 0.000019)\right)\right)\right]$$
Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

## Estimating Tree Mortality - “Post-fire”

Tree mortality using the post-fire injury option is computed using algorithms developed by Sharon Hood. Each algorithm is species specific and uses additional variables than the main mortality option to more accurately post-fire tree mortality. The mortality models in this option are more accurate than the models in the main mortality window; however, the inputs necessary to run these models may not be known. These models predict tree mortality occurring within 3 years of the fire.

The models were developed using these potential variables: dbh, crown damage percent, cambium kill rating (CKR), and bark beetle attacks.

Crown damage: a value from 0 to 100 based on percent total crown length scorched, percent total crown volume scorched or percent total crown volume killed (bud kill).

DBH: diameter at breast height in inches.

CKR: Cambium Kill Rating. A value from 0 to 4, obtained by sampling a small section of the cambium at ground line at four evenly spaced locations around the tree. CKR is the number of dead cambium samples.

Bark beetles: presence/absence of bark beetle attack signs such as boring dust and pitch tubes. See equations below for species included in model development.

When predicting tree mortality, the post-fire injury option depends on a user entered **Probability Mortality Cutoff** value. The logistic regression models compute a predicted probability of mortality ($P_m$) for each tree entered. This is a value between 0 and 1. Using the cutoff value entered, FOFEM predicts that trees with $P_m$ values above the cutoff are dead and trees with $P_m$ values below the cutoff are alive.

For the vast majority of tree species, the percentage crown needle scorch and crown bud kill are equal. Therefore, the term crown scorch has been used throughout FOFEM to indicate the level of post-fire crown injury. Exceptions to this in the post-fire injury species list include western larch, ponderosa pine, and Jeffrey pine. The western larch algorithm was developed using crown needle scorch data. Actual crown bud kill percentage was likely lower than the needle scorched percentage. For ponderosa and

Jeffrey pine, both crown needle scorch and crown bud kill was assessed. Therefore, both a scorch and a kill mortality model are included. The kill model is more accurate than the scorch model because it reflects the true crown injury level and the ability of the tree to recover its crown over time. However, one cannot assess crown kill until the first bud break after the fire. If post-fire tree mortality must be assessed before bud-break, the scorch model can be used. See the Crown Scorch discussion for more information.

The mean, standard error, median, and range of crown scorch and DBH by species of trees used to develop post-fire mortality models are shown below. Species are listed in order of increasing bark thickness using bark thickness equations in FFE-FVS.

| Species | No. of trees | Type[1] | Crown Scorch % | | | DBH (cm) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean ±SE | Md | Range | Mean ±SE | Md | Range |
| Lodgepole pine | 2038 | V | 19 ± 0.7 | 0 | 0-100 | 20.8 ± 0.1 | 19.6 | 10.2-56.4 |
| Whitebark pine | 148 | V | 24 ± 2.9 | 2 | 0-100 | 22.9 ± 0.6 | 22.5 | 12.4-58.9 |
| Engelmann spruce | 223 | V | 30 ± 2.2 | 20 | 0-100 | 33.2 ± 1.1 | 30.2 | 12.7-85.1 |
| Red fir | 209 | L | 42 ± 1.8 | 46 | 0-89 | 42.1 ± 1.2 | 38.9 | 15.2-104.6 |
| Subalpine fir | 947 | V | 65 ± 1.3 | 85 | 0-100 | 19.4 ± 0.2 | 17.5 | 10.2-75.2 |
| White fir | 2304 | L | 67 ± 0.5 | 74 | 0-100 | 59.2 ± 0.4 | 56.9 | 15.2-152.7 |
| Incense cedar | 783 | L | 40 ± 1.1 | 38 | 0-98 | 51.6 ± 0.9 | 43.7 | 25.4-166.4 |
| Yellow pine[2] | 4115 | V | 62 ± 0.6 | 80 | 0-100 | 47.1 ± 0.4 | 40.1 | 9.7-178.1 |
| Douglas-fir | 1409 | V | 33 ± 0.9 | 20 | 0-100 | 33.2 ± 0.5 | 30.0 | 10.2-105.4 |
| Western larch | 389 | V | 15 ± 1.3 | 0 | 0-100 | 38.8 ± 0.7 | 39.4 | 10.2-98.8 |
| Sugar pine | 719 | L | 40 ± 1.1 | 41 | 0-98 | 73.3 ± 1.0 | 70.4 | 25.6-188.0 |

[1] L = crown length; V = crown volume

[2] Includes ponderosa and Jeffrey pine

### Mortality Equations – "Post-fire"

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Equation WF:

White fir post-fire: CKR = Cambium Kill Rating, CLS = crown length scorched (%), beetles = ambrosia beetle (attacked value = 1; unattacked value = -1), DBH (in.)

$$P_m = 1/\left[1+\exp\left(-\left(-3.5964+(CLS^3 * 0.00000628)+(CKR * 0.3019)+(DBH * 0.019)+(beetles * 0.5209)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation SF:

Subalpine fir and grand fir post-fire: CKR = Cambium Kill Rating, CVS = crown volume scorched (%)

$$P_m = 1/\left[1+\exp\left(-\left(-2.6036+(CVS^3 * 0.000004587)+(CKR * 1.3554)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation IC:
Incense cedar post-fire: CKR = Cambium Kill Rating, CLS = crown length scorched (%)

$$P_m = 1/\left[1 + \exp\left(-\left(-5.6465 + (CLS^3 * 0.000007274) + (CKR * 0.5428)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation WL:
Western larch post-fire: CKR = Cambium Kill Rating, CVS = crown volume scorched (%)

$$P_m = 1/\left[1 + \exp\left(-\left(-3.8458 + (\mathrm{CVS}^2 * 0.0004) + (CKR * 0.6266)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation WP:
Whitebark pine and lodgepole pine post-fire: CKR = Cambium Kill Rating, CVS = crown volume scorched (%), DBH (in.)

$$P_m = 1/\left[1 + \exp\left(-\left(-1.4059 + (\mathrm{CVS}^3 * 0.000004459) + (CKR^2 * 0.2843) - (DBH * 0.0485)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation ES:
Engelmann spruce post-fire: CKR = Cambium Kill Rating, CVS = crown volume scorched (%)

$$P_m = 1/\left[1 + \exp\left(-\left(-2.9791 + (\mathrm{CVS} * 0.0405) + (CKR * 1.1596)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation SP:
Sugar pine post-fire: CKR = Cambium Kill Rating, CLS = crown length scorched (%), beetles = Red turpentine beetle and/or Mountain pine beetle (attacked value = 1; unattacked value = -1)

$$P_m = 1/\left[1 + \exp\left(-\left(-2.7598 + (CLS^2 * 0.000642) + (CKR^3 * 0.0386) + (beetles * 0.8485)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation RF:
Red fir post-fire: CKR = Cambium Kill Rating, CLS = crown length scorched (%)

$$P_m = 1/\left[1 + \exp\left(-\left(-4.7515 + (CLS^3 * 0.000005989) + (CKR * 1.0668)\right)\right)\right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation DF:
Douglas-fir post-fire: CKR = Cambium Kill Rating, CVS = crown volume scorched (%), beetles = Douglas-fir beetle (attacked value = 1; unattacked value =0) , DBH (in.)

$$P_m = 1 / \left[ 1 + \exp\left( - \begin{pmatrix} -1.8912 + (CVS * 0.07) - (CVS^2 * 0.0019) + (CVS^3 * 0.000018) + (CKR * 0.5840) \\ -(DBH * 0.031) - (beetles * 0.7959) + (DBH * beetles * 0.0492) \end{pmatrix} \right) \right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation PP:
Ponderosa pine and Jeffrey pine (scorch) post-fire: CKR = Cambium Kill Rating, CVS = crown volume scorched (%), beetles = mountain pine beetle, red turpentine beetle, or ips beetle (attacked value = 1; unattacked value =0)

$$P_m = 1 / \left[ 1 + \exp\left( - \left( -4.1914 + (CVS^2 * 0.000376) + (CKR * 0.5130) + (beetles * 1.5873) \right) \right) \right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

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Equation PK:
Ponderosa pine and Jeffrey pine (kill) post-fire: CKR = Cambium Kill Rating, CVK = crown volume killed (%)
beetles = mountain pine beetle, red turpentine beetle, or ips beetle (attacked value = 1; unattacked value =0)

$$P_m = 1 / \left[ 1 + \exp\left( - \left( -3.5729 + (CVK^2 * 0.000567) + (CKR * 0.4573) + (beetles * 1.6075) \right) \right) \right]$$

Source: Hood, S. M. (Principal Investigator), 2008, Delayed Tree Mortality following Fire in Western Conifers, JFSP # 05-2-1-105

## Canopy Cover

Canopy Cover is calculated using crown width equations, which are then converted to crown area. The equations use coefficients particular to tree species (see table below). Once crown cover is calculated for individual trees and then accumulated for the tree list, an overlap correction factor is applied.

Equation for trees over 4.5 feet:

CW = A * $D^B$
where;
CW = Crown Width (ft)
A = A Coefficient
D = Diameter (in.)
B = B Coefficient

Equation for trees under 4.5 feet :

CW = R * D
where;
CW = Crown Width (ft)
R = Ratio Coefficient
D = Diameter (in.)

See the FOFEM tree species file (FOF_SPP.dat) in the installation folder for more information.

The overlap calculation is:

CovProp = (Cov / 43560)
PctCov = 100.0 * ( 1.0 - $\exp^{CovProp}$)
where;

CovProp = Proportion of each acre with crown cover
Cov = total accumulated crown cover ($ft^2$)
PctCov = percent crown cover adjusted for overlap ($ac^{-1}$)

Coefficients for tree crown widths are based on data from R6 Permanent Plot Grid Inventory.

| Eq no. | Species Code | A Coeff. | B Coeff. | Ratio Coeff. |
|---|---|---|---|---|
| 1 | "SF" | 3.9723 | 0.5177 | 0.473 |
| 2 | "WF" | 3.8166 | 0.5229 | 0.452 |
| 3 | "GF" | 4.187 | 0.5341 | 0.489 |
| 4 | "AF" | 3.2348 | 0.5179 | 0.385 |
| 5 | "RF" | 3.1146 | 0.578 | 0.345 |
| 7 | "NF" | 3.0614 | 0.6276 | 0.32 |
| 8 | "YC" | 3.5341 | 0.5374 | 0.331 |
| 9 | "C" | 4.092 | 0.4912 | 0.412 |
| 10 | "S" | 3.6802 | 0.494 | 0.412 |
| 11 | "LP" | 2.4132 | 0.6403 | 0.298 |
| 12 | "JP" | 3.2367 | 0.6247 | 0.406 |
| 13 | "SP" | 3.061 | 0.6201 | 0.385 |
| 14 | "WP" | 3.4447 | 0.5185 | 0.476 |
| 15 | "PP" | 2.8541 | 0.64 | 0.407 |
| 16 | "DF" | 4.4215 | 0.5329 | 0.517 |
| 17 | "RW" | 4.4215 | 0.5329 | 0.517 |
| 18 | "RC" | 6.2318 | 0.4259 | 0.698 |
| 19 | "WH" | 5.4864 | 0.5144 | 0.533 |
| 20 | "MH" | 2.9372 | 0.5878 | 0.253 |
| 21 | "BM" | 7.5183 | 0.4461 | 0.815 |
| 22 | "RA" | 7.0806 | 0.4771 | 0.73 |
| 23 | "WA" | 7.0806 | 0.4771 | 0.73 |
| 24 | "PB" | 5.898 | 0.4841 | 0.601 |
| 25 | "GC" | 2.4922 | 0.8544 | 0.14 |
| 26 | "AS" | 4.091 | 0.5907 | 0.351 |
| 27 | "CW" | 7.5183 | 0.4461 | 0.815 |
| 28 | "WO" | 2.4922 | 0.8544 | 0.14 |
| 29 | "J" | 4.5859 | 0.4841 | 0.468 |
| 30 | "LL" | 2.1039 | 0.6758 | 0.207 |
| 31 | "WB" | 2.1606 | 0.6897 | 0.255 |
| 32 | "KP" | 2.1451 | 0.7132 | 0.248 |

| | | | | |
|---|---|---|---|---|
| 33 | "PY" | 4.5859 | 0.4841 | 0.468 |
| 34 | "DG" | 2.4922 | 0.8544 | 0.14 |
| 35 | "HT" | 4.5859 | 0.4841 | 0.468 |
| 36 | "CH" | 4.5859 | 0.4841 | 0.468 |
| 37 | "WI" | 4.5859 | 0.4841 | 0.468 |
| 38 | "" | 4.4215 | 0.5329 | 0.517 |

### Mortality Citations

Hood, S. M.; McHugh, C.; Ryan, K. C.; Reinhardt, E.; Smith, S. L. 2007. Evaluation of a post-fire tree mortality model for western US conifers. International Journal of Wildland Fire. 16: 679-689.

Lutes, D. 2001. Diameter bark thickness relationships. Unpublished report on file at the Missoula Fire Science Lab.

Reinhardt, E.D.; K.C. Ryan. 1988. How to estimate tree mortality resulting from under burning. Fire Management Notes 49(4):30-36.

Ryan, K.C.; Reinhardt, E.D. 1988. Predicting post fire mortality of seven western conifers. Canadian Journal of Forest Research 18:1291-1297.

Van Wagner, C.E. 1973. Height of crown scorch in forest fires. Canadian Journal of Forest Research 3:373-378.

## Scientific Content - Fuel Consumption

### Default Fuelbeds

Default fuelbeds include fuel loading for most, if not all, components. Fuel loads are based on cover type and on fuel type (natural or slash fuels). The default loads can be adjusted (using the Typical, Light, Heavy adjustment buttons) or replaced with a user value. It is always good to enter fuel loadings directly if you have a good estimate, since fuels vary greatly within cover type.

To provide default fuel loads, an exhaustive search of fuels literature was conducted. The resulting database (Mincemoyer 2002) was added in FOFEM 5.3.

### Fuel Consumption

FOFEM predicts the quantity of fuel consumed by prescribed fire or wildfire. Fuel components include duff, litter, 0 - ¼ inch, ¼ - 1 inch, 1 - 3 inch, 3 inch plus dead woody fuels (sound and rotten), herbaceous fuels, shrubs, and canopy fuels affected by crown fire. Mineral soil exposed by fire as a result of duff and litter consumption is also predicted.

One major assumption FOFEM makes in predicting fuel consumption is that the entire area experiences the fire. FOFEM does not predict fire effects for patchy or discontinuous burns. For these situations, results should be weighted by the percent of the area burned.

FOFEM uses the Burnup model to predict consumption of woody fuels. Consumption of other fuels is predicting using a variety of empirical equations and rules of thumb. Previous versions of FOFEM included a number of woody fuel consumption algorithms that were used in different cover types, geographic regions, and fuel types. Although these earlier, empirical algorithms may perform better than Burnup in certain specific circumstances, Burnup is felt to provide a more logically consistent approach to fuel consumption estimation.

Litter Consumption

In most cases litter consumption is simulated in Burnup.

Equations are selection using a decision process that in part based on region. See Decision Dependency

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Equation 999:
The consumption of litter is calculated by Burnup. Generally 100% of the litter is consumed.
Sources: Albini, F.A.; Brown, J.K.; Reinhardt, E.D.; Ottmar, R.D. Calibration of a Large Fuel Burnout Model. International Journal of Wildland Fire 5(3):173-192, 1995. Albini, F.A.; Reinhardt, E.D. Improved Calibration of a Large Fuel Burnout Model. International Journal of Wildland Fire 7(1): 21-28, 1997.

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Equation 223:
In the Southeast region Litter Load Consumed = Prefire Litter Load * 0.8. The consumed litter load is used as an initial input to Burnup, which simulates 100% litter consumption.
Source: Estimate based on personal communication with managers and Reid, A.M.; Robertson, K.M. and Hmielowski, T.L. 2012. Predicting litter and live herb fuel consumption during prescribed fires in native and old-field upland pine communities of southeastern United States. Can. J. For. Res. 42: 1611-1622.
McDaniel, V. L; Perry, R.W.; Guldin, J. M. 2015 (In prep). Evaluation of FOFEM default fuel loading and consumption estimates in forest and woodland communities of Arkansas.
Prichard, S. J.; Karau, E.C.; Ottmar, R.D.; Kennedy, M.C.; Cronan, J.B.; Wright, C.S.; Keane, R.E. 2014. Evaluation of the CONSUME and FOFEM fuel consumption model in pine and mixed hardwood forests of the eastern United States. Can. J. For. Res. 44: 784-795.

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Duff Consumption

A number of different duff consumption algorithms are incorporated into FOFEM6. Separate predictions are made of percent duff consumption and duff depth consumed. These equations, their sources, and the circumstances under which each is used by FOFEM are summarized below.

Equations are selection using a decision process that in part based on region, fuel category, moisture method and Cover Group . See Decision Dependency

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Equation 1:
Used for predicting percent duff consumption (%DR) from lower duff moisture (LDM) content in the Interior West and Pacific West for activity fuels and natural fuels other than ponderosa pine cover groups.
If LDM <=160% then %DR = 97.1 - 0.519 LDM,
If LDM > 160% the %DR = 13.6,
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 2:
Used for predicting percent duff consumption (%DR) from entire or average duff moisture (EDM) 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.
%DR = 83.7 - 0.426 EDM
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 3:
Used for predicting percent duff consumption (%DR) from NFDR 1000 hour moisture (NFDTH) content in the Interior West, Pacific West, and North East.
%DR = 114.7 - 4.20 NFDTH
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 4:
Used for predicting percent duff consumption (%DR) from lower duff moisture (LDM) content in the Interior West and Pacific West for natural fuels in the ponderosa pine groups.
%DR = 89.9 - 0.55 LDM
Source: Harrington, M.G. 1987. Predicting reduction of natural fuels by prescribed burning under ponderosa pine in southeastern Arizona. USDA Forest Service Res. Note RM-472.

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Equation 5:
Used for predicting duff depth consumption (DR) from lower duff moisture (LDM) content in the Interior West and Pacific West (DPRE = pre fire duff depth).
DR = 1.028 - .0089 LDM + 0.417 DPRE
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 6:
Used for predicting duff depth consumption (DR) from entire or average duff moisture (EDM) content in the Interior West and Pacific West (DPRE = pre fire duff depth). This equation is also the default equation that FOFEM uses when it cannot find another duff consumption algorithm.
DR = 0.8811 - 0.0096 EDM + 0.439 DPRE
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 7:
Used for predicting duff depth consumption (DR) from NFDR 1000 hour moisture (NFDTH) content in the Interior West, Pacific West, and North East (DPRE = pre fire duff depth).
DR = 1.773 - 0.1051 NFDTH + 0.399 DPRE
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 15:
Used for predicting residual duff depth (RD) from average duff moisture (EDM) and preburn duff depth (DPRE). (PINE=1 if cover group is jack pine or 0 if other). This equation was based on data assimilated from many studies and is used where a more site specific equation is lacking.
RD = -0.791 + .004 EDM + 0.8 DPRE + 0.56 PINE
Source: Reinhardt, E.D., Keane, R.E., Brown, J.K., Turner, D.L. 1991. Duff consumption from prescribed fire in the U.S. and Canada: a broadly based empirical approach. Proceedings, 11th Conference on Fire and Forest Meteorology.

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Equation 16:
Used in the Southeast except in pocosin cover groups. %DR=% duff reduction, WPRE=litter load+duff load+1-hr load+10-hr load, EDM=entire duff moisture, L=preburn litter load, W=load of litter+duff consumed
W = 3.4958 + (0.3833 WPRE) – (0.0237 EDM) – (5.6075/WPRE)
If W <= L then %DR = 0
If W > L then %DR = ((W - L)/(WPRE - L)) * 100%
Source: Hough, W.A. 1978. Estimating available fuel weight consumed by prescribed fires in the south. USDA Forest Service Res. Pap. SE-187.

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Equation 17:
Piles: FOFEM assumes nominal duff consumption in pile burning (Below the piles). %DR=% duff reduction
%DR = 10%
Source: Anecdotal evidence

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Equation 19:
Chaparral: FOFEM assumes complete duff consumption in chaparral types. %DR=% duff reduction
%DR = 100%
Source: Anecdotal evidence

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Equation 20:
Pocosin: Calculates root mat consumption for deep organic soils in the pocosin cover groups in the southeast US.

*NOTE: This equations does not predict consumption of muck soils underlying the root mat.*

The root mat and is divided into layers of no more than 4” thickness. Consumption of each layer is calculated separately then summed as the total estimated consumption. Moisture content of layer 1 ($MC_{Layer}$) is the duff moisture content set on the UI. Moisture content of layers 2, 3, 4, and 5 are 3%, 9%, 18%, 30%, respectively, greater than the moisture content of layer 1. Moisture content of layers 6 and greater are 12% higher than each previous layer. Percent consumption of each layer is calculated using the following logic:

If $MC_{Layer} < 10$ then 100% consumption

If $MC_{Layer} \geq 10$ and $MC_{Layer} < 30$ then consumption = Load * (0.949932 + ((30- $MC_{Layer}$)*0.00251))

If $MC_{Layer} \geq 30$ and $MC_{Layer} < 140$ then consumption =

Load *(1/(1 + (EXP(-1*(2.033-(0.043* $MC_{Layer}$) + (0.44*Mineral Content*))))))

If $MC_{Layer} \geq 140$ and $MC_{Layer} < 170$ then consumption = Load * (0.143441-(($MC_{Layer}$ -140)*0.0049))

If $MC_{Layer} \geq 170$ then 0% consumption

**Mineral content is set to 5%*

Source: Reardon 2016, per. comm.; Reardon, James; Hungerford, Roger; Ryan, Kevin 2007. Factors affecting sustained smoldering in organic soils from pocosin and pond pine woodland wetlands. International Journal of Wildland Fire. 16: 107-118.

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Mineral Soil Exposure

The amount of mineral soil exposed by a fire is predicted using these equations:

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Equation 9:
Used for predicting % mineral soil exposure (MSE) from lower duff moisture (LDM) content in activity fuels in the west.
If LDM <= 135% then MSE = 80.0 - 0.507 LDM,
If LDM > 135% then MSE =23.5 - 0.0914 LDM,
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 10:
Used for predicting % mineral soil exposure (MSE) from average duff moisture (EDM) content in the west. This is also the default equation FOFEM uses for predicting mineral soil exposure.
MSE = 167.4 - 31.6 log(EDM)
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 11:
Used for predicting % mineral soil exposure (MSE) from NFDR 1000 hour moisture (NFDTH) content in activity fuels in the west.
MSE = 93.3 - 3.55 NFDTH
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 12:
Used for % predicting mineral soil exposure (MSE) from NFDR 1000 hour moisture (NFDTH) content in natural fuels in the west.
MSE = 94.3 - 4.96 NFDTH
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 13:
Used for % predicting mineral soil exposure (MSE) from lower duff moisture (LDM) content in natural fuels in the west.
MSE = 60.4 - 0.440 LDM
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

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Equation 14:
Used for % predicting mineral soil exposure (MSE) from percent duff reduction (%DR) – a robust equation used when other information is lacking.
MSE = -8.98 + 0.899 %DR
Source: Brown, J.K., Marsden, M.M., Ryan, K.C., Reinhardt, E.D. 1985. Predicting duff and woody fuel consumed by prescribed fire in the northern Rocky Mountains. USDA Forest Service Res. Pap. INT-337.

---

Equation 18:
Piles: FOFEM assumes nominal % mineral soil exposure (MSE) in pile burning (beneath the piles).
MSE = 10%
Source: Anecdotal evidence

---

Equation 202:
Pocosin group: For deep organic soils in the pocosin type, no mineral soil is exposed (MSE).
MSE = 0%
Source: Hungerford 1996, personal communication

---

Herbaceous Consumption

Herbaceous fuels generally are a small component of the total fuel load. However, for completeness, especially in modeling emission production, their consumption is computed by FOFEM. Also see Decision Dependency

---

Equation 22:
All the herbaceous fuels are assumed to burn.
Source: Anecdotal evidence

---

Equation 221:
If the cover group is grass, and the season of burn is spring, only 90% of the herbaceous fuels are consumed.
Source: Anecdotal evidence

---

Equation 222:

For the Southeast region Herb Load Consumed = -0.059 + (0.004 * Litter Fuel Load) + (0.917 * Herb Fuel Load)

Source: Reid, A.M.; Robertson, K.M. and Hmielowski, T.L. 2012. Predicting litter and live herb fuel consumption during prescribed fires in native and old-field upland pine communities of southeastern United States. Can. J. For. Res. 42: 1611-1622.

Shrub Consumption

Shrub consumption is modeled using these equations. Also see Decision Dependency

---

Equation 233:
If the cover group is sagebrush and the season is fall, shrub consumption is 90%.
Source: Anecdotal evidence

---

Equation 232:
If the cover group is sagebrush and the season is other than fall, shrub consumption is 50%.
Source: Anecdotal evidence

---

Equation 231:
For cover group not sagebrush but dominated by shrubs, that is shrub group (except in the southeast), shrub consumption is assumed to be 80%.
Source: Anecdotal evidence

---

Equation 23:
For cover groups not dominated by shrubs, shrub consumption is set to 60%.
Source: Anecdotal evidence

---

Equation 233:
For the southeastern region, for the pocosin cover group, in spring or winter shrub consumption is 90%.
Source: Anecdotal evidence

---

Equation 234:
Used to predict percent shrub consumption for non-pocosin group in the southeast region.
Percent consumption = ((( 3.2484 + 0.4322 * preburn litter and duff loading + .6765 * preburn shrub and regeneration loading - .0276* duff moisture – ( 5.0796 / preburn litter and duff loading) – litter and duff consumption ) / preburn shrub and regeneration loading ) * 100%.
Sources: Hough, W.A. 1968. Fuel consumption and fire behavior of hazard reduction burns. USDA Forest Service Res. Pap. SE-36. Hough, W.A. 1978. Estimating available fuel weight consumed by prescribed fires in the south. USDA Forest Service Res. Pap. SE-187.

---

Equation 235:
For the southeastern region, for the pocosin cover group, in summer or fall shrub consumption 80%.
Source: Anecdotal evidence

### Down Woody Fuel Consumption

All down woody fuel consumption is modeled in Burnup

---

Equation 999:
Estimates of woody fuel consumption derived in Burnup.
Sources: Albini, F.A.; Brown, J.K.; Reinhardt, E.D.; Ottmar, R.D. Calibration of a Large Fuel Burnout Model. International Journal of Wildland Fire 5(3):173-192, 1995. Albini, F.A.; Reinhardt, E.D. Improved Calibration of a Large Fuel Burnout Model. International Journal of Wildland Fire 7(1): 21-28, 1997.

---

### Canopy Fuel Consumption

FOFEM does not predict whether a crown fire will occur and canopy fuels will be consumed. It requires the user to estimate the proportion of the stand affected by crown fire. FOFEM simply applies this proportion to the canopy foliage and one-half of the canopy 0-1/4 inch branch wood, so that consumption of these fuels is represented for purposes of estimating smoke production or carbon budget.

---

Equation 37:
Consumed foliage = (Crown Burn %/100)* Foliage
Source: Anecdotal evidence

---

Equation 38:
Consumed branch wood = (Crown Burn %/100) * Branch * 0.5
Source: Anecdotal evidence

---

Carbon

Carbon loading in the carbon report is calculated using two equations:

1) For down woody material, herbaceous, shrub, branch and foliage loading:
   Carbon = loading * 0.50

Source;: Penman, J.; Gytarsky, M.; Hiraishi, T.; Krug, T.; Kruger, D.; Pipatti, L.; Buendia, L.; Miwa, K.; Ngara, T.; Tanabe, K.; Wagner, F., eds. 2003. Good practice guidance for land use, land-use change and forestry. Intergovernmental Panel on Climate Change, Technical Support Unit. Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan. http://www.ipcc-nggip.iges.or.jp

2) For duff and litter:
   Carbon = loading * 0.37

Source; Smith, James E.; Heath, Linda S. 2002. A model of forest floor carbon mass for United States forest types. Res. Pap. NE-722. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 37 p.

## Moisture Regime

Fuel moisture can be entered directly for duff, 10 hour (1/4-1 inch) woody fuel, and 3+ inch woody fuel. Fuel moisture of 1 hour and 100 fuels are set to 2 percent lower and 2 higher, respectively, of the 10 hour moisture.

Users can also select a moisture regime based on western systems– Wet, Moderate, Dry, Very Dry - to have these moisture contents set by default.

| Regime | Duff | 10 Hr | 3+ in. | Soil |
|---|---|---|---|---|
| Wet | 130 | 22 | 40 | 25 |
| Moderate | 75 | 16 | 30 | 15 |
| Dry | 40 | 10 | 15 | 10 |
| Very Dry | 20 | 6 | 10 | 5 |

For duff moisture, users can enter entire duff moisture content, lower duff moisture content, NFDR 1000 hour index values, or adjusted NFDR 1000 hour values (Ottmar and Sandberg 1983). If you want to set fuel moistures for all woody fuel size classes, or separately for sound and rotten fuels, you can run Burnup from an input file, bypassing the FOFEM user interface. See Running Burnup from an input File

## Decision Dependency

This section details the relationship between fuel components and the input variables they depend on to select consumption equations. Not all fuel components base equation selection on input variables (e.g., down woody debris).

Herbaceous Calculations

- Cover Group
- Season

Shrub Calculations

- Cover Group
- Season
- Region

Duff Calculations

- Region
- Cover Group
- Fuel Type
- Moisture Regime

Litter, Crown Branch/Foliage, Down Woody Calculations

This fuel components are always calculated using the same equations regardless of Cover Group, Season, etc.

## Cover Groups

Cover Group is used to determine consumption formulas for herbaceous, shrub and duff fuel loading, in turn fuel consumption is used to compute smoke emission amounts and simulate soil heating.

The codes are assigned to some but not all cover types, for example cover type SAF 001 Jack Pine is assigned a cover group code of RJP

To see the assigned cover group codes for each cover type you can look in FOFEM's fof_saf.csv, fof_nvcs.csv, fof_flm.csv or fof_fccs.csv files for a reference. The files contain cover type codes as well as fuel loads and equation information for SAF/SFM, NVCS, FLM and FCCS cover classifications. The .csv text files can be found in the FOFEM install directory, you can print them out or view them with a text editor; be careful not to alter them in any way. Each row of the file represents a single cover type with its name contained in the same line. If a cover type belongs to a cover group it will have a short character code in the last data column of the row.

| **Type** | **Short code** | **Long code** |
|---|---|---|
| Grass | GG | GrassGroup |
| Shrub | SG | ShrubGroup |
| Sagebrush | SB | Sagebrush |
| Ponderosa pine | PN | Ponderosa |
| Pocosin | PC | Pocosin |
| Balsam, Black, Red, White Spruce | BBS | BalBRWSpr |
| Red, Jack Pine | RJP | RedJacPin |
| White Pine Hemlock | WPH | WhiPinHem |

For more details concerning how cover groups are used to determine consumption see: Cover Groups, Decision Dependency, Duff Consumption, Herbaceous Consumption and Shrub Consumption

### Burnup

Burnup is a physical model of heat transfer and burning rate of woody fuel particles as they interact over the duration of a burn. Duff consumption rate is assumed to be constant (Frandsen 1991). Duff consumption amount is computed as described in the Duff Consumption section, depending on cover type and duff moisture. Duff consumption duration is computed from total consumption and consumption rate. At each iteration of the Burnup model, fuel consumption of each woody fuel size class is determined by modeling the heat transfer at intersections with other fuel particles and with the duff. Fire intensity is derived from the combustion of fuels in each time step. The fire is assumed to go out when the overall fire intensity is too low to sustain further combustion. Burnup thus provides estimates of total fuel consumption by size class, and also of consumption rate and fire intensity over time. Burnup outputs are labeled 999 on the FOFEM reports.

For more information see See: Albini, F.A.; Reinhardt, E.D. (1995) Modeling Ignition and Burning Rate of Large Woody Natural Fuels. International Journal of Wildland Fire 5(2):81-91.

### Running Burnup from an Input File

Burnup can accept as input any number of fuel classes, defined by characteristics including loading, moisture content, surface area to volume ratio, and density. Normally when creating reports and graphs from the FOFEM user interface, Burnup is run using a number of simplified assumptions. For example, only two fuel densities are used, representing sound and rotten wood. However, the full functionality of Burnup is available to users by running Burnup from an input file. If you have a lot of detailed fuel data, you may wish to use this option.

In order to run Burnup from a file, you must first create that file. You can create a sample input file by using the menu item **Options>Create Burnup Sample Input File**. The sample file will include duff, litter, and woody fuel loading, and associated moistures as set on the user interface. Herb, shrub, foliage and branch material are not included in the sample file. They can be added is desired. Select **Options>Run Burnup From Input File** to run the Burnup input file you create. Predicted consumption will be saved by default to a file called BurnCons.txt, and emissions data to a file called BurnEmis.txt. These three files are described in more detail below.

Also remember, that whether you edit the sample file or create your own, it must be a text file, so be sure to save it as such no matter what text editor of word processor you use.

The file has two sections. The first section describes simulation parameters and the second section describes the fuel components being simulated.

Sample Burnup Input File

```
MAX_TIMES              3000
INTENSITY(kW/m2)       50.00
IG_TIME(s)             60.00
WINDSPEED(m/s)         0.00
DEPTH(m)               0.30
AMBIENT_TEMP(C)        27.00
r0                     1.83
dr                     0.40
TIMESTEP(s)            15.00
DUFF_LOAD(kg/m2)       11.459641
DUFF_MOIST             1.000000
dummy_file.nam

1    1   5.76   18600.0  0.230  513.0  8200.00  2750.0  0.133  327.0  377.0   0.05
1    2   6.27   18600.0  0.230  513.0  1480.00  2750.0  0.133  327.0  377.0   0.05
1    3   11.8   18600.0  0.250  513.0   394.00  2750.0  0.133  327.0  377.0   0.05
1    4   20.4   18600.0  0.270  513.0   105.00  2750.0  0.133  327.0  377.0   0.05
1    5   14.73  18600.0  0.200  513.0    39.40  2750.0  0.133  327.0  377.0   0.05
1    6    1.63  18600.0  0.500  224.0    39.40  2750.0  0.133  302.0  377.0   0.05
1    7   14.73  18600.0  0.200  513.0    21.90  2750.0  0.133  327.0  377.0   0.05
1    8    1.63  18600.0  0.500  224.0    21.90  2750.0  0.133  302.0  377.0   0.05
1    9   14.73  18600.0  0.200  513.0    12.70  2750.0  0.133  327.0  377.0   0.05
1   10    1.63  18600.0  0.500  224.0    12.70  2750.0  0.133  302.0  377.0   0.05
1   11   14.73  18600.0  0.200  513.0     5.91  2750.0  0.133  327.0  377.0   0.05
1   12    1.63  18600.0  0.500  224.0     5.91   2750.0 0.133  302.0  377.0   0.05
```

An explanation of simulation parameters in the first section of the input file follows:

| Name | Description | Notes |
|---|---|---|
| MAX_TIMES | The maximum number of iterations Burnup will compute. | |
| INTENSITY | Intensity of the igniting surface fire, kW/m$^2$ | |
| IG_TIME | Residence time of the igniting surface fire, seconds | |
| WINDSPEED | Wind speed at the top of the fueled, meters/second | |
| DEPTH | Fueled depth, meters | |
| AMBIENT_TEMP | Ambient air temperature, degrees C | |
| R0 | Fire environment minimum dimension parameter | |
| DR | Fire environment increment temperature parameter | |
| TIMESTEP | Time step for integration of burning rates | (TIMESTEP * MAX_TIMES gives the maximum simulation period |
| DUFF_LOAD | Duff dry weight loading, kg/m$^2$ | |
| DUFF_MOIST | Duff moisture content, fraction dry weight | |
| dummy_file.nam | This  text must be here[1] | |

[1] The text “dummy_file.nam” must be located exactly as shown above in the sample file. As a file name it is not currently used in the version, but the text is used by FOFEM to separate the upper and lower sections of the file.

Each subsequent line represents one fuel component. The rows of these lines contain, for that fuel component:

| Column No. | Name | Notes |
|---|---|---|
| 1 | Must contain a “1” | |
| 2 | Index label | |
| 3 | Dry loading | $kg/m^2$ |
| 4 | Heat content | kJ/kg |
| 5 | Moisture content | fraction dry load |
| 6 | Oven dry mass density | $kg/m^3$ |
| 7 | Surface area to volume ratio | $m^{-1}$ |
| 8 | Heat capacity | J/kg K |
| 9 | Thermal conductivity | W/m K |
| 10 | Ignition temperature | C |
| 11 | Char temperature | C |
| 12 | Mineral ash fraction | |

## Sample Burnup Output Files

### *Consumption*

```
Column 1: Fuel component
       2: Preburn fuel load, kg/m2.
       3: Moisture content, fraction
       4: Sigma, surface area to volume ratio, m-1.
       5: Time till ignition, seconds.
       6: Time till burnout, seconds.
       7: Post burn fuel load, kg/m2.

   1     0.16   0.23     0.00      0.00000       11.53537     0.00000
   2     0.04   0.23     0.00     13.19217      100.95903     0.00000
   3     0.21   0.25     0.01     34.15087      649.39360     0.00000
   4     0.15   0.20     0.10    149.06430      100.00000     0.04342
   5     0.02   0.50     0.10     33.87733     6592.50000     0.00030
   6     0.15   0.20     0.18    145.23737     1000.00000     0.08723
   7     0.02   0.50     0.18     39.29486     6832.50000     0.00505
   8     0.15   0.20     0.31    159.10688       10.00000     0.11398
   9     0.02   0.50     0.31     43.91532     8790.54796     0.00945
  10     0.15   0.20     0.68    167.31803      100.00000     0.13441
  11     0.02   0.50     0.68     49.58486    20156.23184     0.01330
```

*Emissions*

```
Column 1:  Time since ignition, seconds
       2:  Intensity,  kw/m2.
       3:  PM 2.5 production,   g/m2.
       4:  PM 10 production,   g/m2.
       5:  CH4 production,   g/m2.
       6:  CO2 production,   g/m2.
       7:  CO production,   g/m2.
       8.  NOX production,   g/m2.
       9.  SO2 production,   g/m2.
       10: Fuel consumed in flaming combustion, kg/m2.
       11: Fuel consumed in smoldering consumption, kg/m2.
```

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 56.2436 | 1.3818 | 1.6305 | 0.7051 | 354.721 | 13.5953 | 1.5430 | 0.1801 | 0.1709 | 0.0414 |
| 75 | 25.5548 | 0.6543 | 0.7720 | 0.3975 | 35.4842 | 8.7177 | 0.0000 | 0.0030 | 0.0000 | 0.0289 |
| 90 | 20.4480 | 0.5555 | 0.6555 | 0.3375 | 30.1271 | 7.4016 | 0.0000 | 0.0020 | 0.0000 | 0.0245 |
| 105 | 16.1658 | 0.4670 | 0.5511 | 0.2837 | 25.3291 | 6.2228 | 0.0000 | 0.0020 | 0.0000 | 0.0206 |
| 120 | 13.7649 | 0.4276 | 0.5046 | 0.2598 | 23.1928 | 5.6980 | 0.0000 | 0.0020 | 0.0000 | 0.0189 |
| 135 | 12.5357 | 0.4040 | 0.4767 | 0.2454 | 21.9113 | 5.3831 | 0.0000 | 0.0019 | 0.0000 | 0.0178 |
| 150 | 11.6437 | 0.3869 | 0.4565 | 0.2350 | 20.9814 | 5.1547 | 0.0000 | 0.0019 | 0.0000 | 0.0171 |
| 165 | 10.9653 | 0.3738 | 0.4411 | 0.2271 | 20.2741 | 4.9809 | 0.0000 | 0.0018 | 0.0000 | 0.0165 |
| 180 | 10.4309 | 0.3635 | 0.4290 | 0.2208 | 19.7170 | 4.8441 | 0.0000 | 0.0018 | 0.0000 | 0.0161 |
| 195 | 9.9534 | 0.3544 | 0.4182 | 0.2153 | 19.2192 | 4.7218 | 0.0000 | 0.0018 | 0.0000 | 0.0156 |
| 210 | 9.5085 | 0.3458 | 0.4081 | 0.2101 | 18.7554 | 4.6078 | 0.0000 | 0.0018 | 0.0000 | 0.0153 |
| 225 | 9.0807 | 0.3376 | 0.3984 | 0.2051 | 18.3094 | 4.4982 | 0.0000 | 0.0017 | 0.0000 | 0.0149 |
| 240 | 8.6590 | 0.3295 | 0.3888 | 0.2002 | 17.8697 | 4.3902 | 0.0000 | 0.0017 | 0.0000 | 0.0146 |
| 255 | 8.2383 | 0.3214 | 0.3792 | 0.1952 | 17.4312 | 4.2825 | 0.0000 | 0.0017 | 0.0000 | 0.0142 |
| 270 | 7.8179 | 0.3133 | 0.3697 | 0.1903 | 16.9928 | 4.1748 | 0.0000 | 0.0016 | 0.0000 | 0.0138 |
| 285 | 7.3926 | 0.3051 | 0.3601 | 0.1854 | 16.5494 | 4.0658 | 0.0000 | 0.0016 | 0.0000 | 0.0135 |
| 300 | 6.9561 | 0.2967 | 0.3502 | 0.1803 | 16.0944 | 3.9540 | 0.0000 | 0.0016 | 0.0000 | 0.0131 |
| 315 | 6.6379 | 0.2906 | 0.3429 | 0.1766 | 15.7626 | 3.8725 | 0.0000 | 0.0016 | 0.0000 | 0.0128 |
| 330 | 6.6222 | 0.2902 | 0.3424 | 0.1763 | 15.7381 | 3.8665 | 0.0000 | 0.0015 | 0.0000 | 0.0128 |
| 345 | 6.3491 | 0.2851 | 0.3364 | 0.1732 | 15.4616 | 3.7986 | 0.0000 | 0.0014 | 0.0000 | 0.0126 |
| 360 | 6.0465 | 0.2793 | 0.3295 | 0.1697 | 15.1461 | 3.7211 | 0.0000 | 0.0013 | 0.0000 | 0.0123 |
| 375 | 5.8318 | 0.2751 | 0.3246 | 0.1671 | 14.9203 | 3.6656 | 0.0000 | 0.0012 | 0.0000 | 0.0121 |
| 390 | 5.6619 | 0.2719 | 0.3208 | 0.1652 | 14.7452 | 3.6226 | 0.0000 | 0.0010 | 0.0000 | 0.0120 |
| 405 | 5.3910 | 0.2666 | 0.3146 | 0.1620 | 14.4599 | 3.5525 | 0.0000 | 0.0009 | 0.0000 | 0.0118 |
| 420 | 5.1458 | 0.2620 | 0.3091 | 0.1591 | 14.2071 | 3.4904 | 0.0000 | 0.0009 | 0.0000 | 0.0116 |
| 435 | 4.9960 | 0.2591 | 0.3057 | 0.1574 | 14.0509 | 3.4520 | 0.0000 | 0.0008 | 0.0000 | 0.0114 |

## Fuel Consumption Citations

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# Scientific Content - Smoke Emissions

## Smoke Production

The Burnup model was modified to provide separate estimates of flaming and smoldering consumption in each time step for each fuel component by assuming that flaming combustion cannot be sustained below an intensity of about 15 kW/$m^2$ (Finney 2001). Since Burnup computes a local intensity at the point of intersection of fuels, flaming and smoldering combustion can be simulated simultaneously – i.e. at fuel concentrations flaming combustion may occur in the same time step that smoldering combustion is occurring in the duff or in isolated woody fuels.

By distinguishing fuel weight consumed in flaming and smoldering phases of combustion, the Burnup model allows emission factors to be applied separately to the fuel consumed in each phase. Emission factors for particulate and chemical emission species (Ward et al. 1993) were applied to the fuel consumed in flaming and smoldering combustion assuming the values of combustion efficiencies of 0.97 for flaming and 0.67 for smoldering. Thus, the total is combined from the emissions calculated separately from fuel weight consumed in flaming and smoldering.

In the emissions report, total emissions of $PM_{2.5}$, $PM_{10}$, $CH_4$, CO, $CO_2$, $NO_X$ and $SO_2$ are listed, as well as burn duration. If desired, however, burn intensity and emissions over time can be simulated using the FOFEM menu item **Options>Save Burnup Emission File** . This information is suitable for use in predicting smoke dispersion.

## FOFEM Emission Factors

FOFEM assumes Flaming combustion efficiency (FCE) = 0.97 and
Smoldering combustion efficiency (SCE) = 0.67

In g/kg of fuel consumed:

| Pollutant | Flaming Phase | | Smoldering Phase | |
|---|---|---|---|---|
| | **Formula** | **EF** | **Formula** | **EF** |
| $PM_{2.5}$ | 67.4 - (FCE x 66.8)= | 2.604 | 67.4 - (SCE x 66.8)= | 22.644 |
| $CH_4$ | 42.7 - (FCE x 43.2)= | 0.796 | 42.7 - (SCE x 43.2)= | 13.756 |
| CO | 961 - (FCE x 984)= | 6.520 | 961 - (SCE x 984)= | 301.720 |
| $CO_2$ | FCE x 1833= | 1778.01 | SCE x 1833= | 1228.11 |
| $PM_{10}$[1] | $PM_{2.5}$ x 1.18= | 3.07272 | $PM_{2.5}$ x 1.18= | 26.71992 |
| $NO^{x}$[2] | 3.2= | 3.2 | 0= | 0 |
| $SO^{2}$[2] | 1.0= | 1.0 | 1.0= | 1.0 |

[1] Emission factor for PM 10 is computed as 1.18 times emission factor for PM 2.5
[2] Updated September 3, 2003

## Citations

Finney, M.A. 2001. FARSITE help documentation.

Hardy, C.C., Burgan, R.E., Ottmar, R.D., Deeming, J.C. 1996. A database for spatial assessments of fire characteristics, fuel profiles, and $PM_{10}$ emissions. Unpublished paper on file at USDA Forest Service, Missoula Fire Sciences Laboratory, Missoula, MT.

Ward, D.E., Peterson, J., Hao, W.M. 1993. An inventory of particulate matter and air toxic emissions from prescribed fires in the USA for 1989. In: Proceedings of the Air and Waste Management Association 1993 annual meeting, Denver, CO. 19 p.

# Appendix A: Field Name and Description for .FFI and .TRE Files Produced by FFI

Files exported from FFI can be imported into FOFEM. There will be two files (required), one with the fuels information (with a FFI extension) and one with the tree information (with a TRE extension). These files may also be manually created. Example files are included with the FOFEM installer.

**Table A-1**: FFI file field names and descriptions.

| .FFI | |
|---|---|
| **Field name** | **Description** |
| **PlotId** | FFI Macro plot identifier |
| **Monitoring Status** | FFI Monitoring status |
| **Monitoring Status Order** | FFI Monitoring status order |
| **TotalDuffLoad**[1] | Duff load (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **DuffDepth** | Duff Depth (in.). From Surface Fuels protocol |
| **LitterLoad**[1] | Litter load (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **LichenLoad**[1] | Lichen load (t $ac^{-1}$). From Surface Fuels – Alaska protocol and/or the Biomass – Fuels protocol |
| **LiveMossLoad**[1] | Live moss load (t $ac^{-1}$). From Surface Fuels – Alaska protocol and/or the Biomass – Fuels protocol |
| **DeadMossLoad**[1] | Dead moss (t $ac^{-1}$). From Surface Fuels – Alaska protocol and/or the Biomass – Fuels protocol |
| **OneHour**[1] | 1-hr (0 - <0.25 in) woody load (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **TenHour**[1] | 10-hr (0.25 - <1.0 in) woody load (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **HundredHour**[1] | 100-hr (1.0 - <3.0 in) woody load (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc1Sz1**[1] | Load of 3 - < 6 in. decay class 1 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc1Sz2**[1] | Load of 6 - < 9 in. decay class 1 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc1Sz3**[1] | Load of 9 - < 12 in. decay class 1 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc1Sz4**[1] | Load of 12 - < 20 in. decay class 1 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc1Sz5**[1] | Load of >= 20 in. decay class 1 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc2Sz1**[1] | Load of 3 - < 6 in. decay class 2 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc2Sz2**[1] | Load of 6 - < 9 in. decay class 2 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc2Sz3**[1] | Load of 9 - < 12 in. decay class 2 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc2Sz4**[1] | Load of 12 - < 20 in. decay class 2 fuels (t $ac^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |

| | |
|---|---|
| **ThousandHourDc2Sz5**[1] | Load of >= 20 in. decay class 2 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc3Sz1**[1] | Load of 3 - < 6 in. decay class 3 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc3Sz2**[1] | Load of 6 - < 9 in. decay class 3 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc3Sz3**[v] | Load of 9 - < 12 in. decay class 3 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc3Sz4**[1] | Load of 12 - < 20 in. decay class 3 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc3Sz5**[1] | Load of >= 20 in. decay class 3 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc4Sz1**[1] | Load of 3 - < 6 in. decay class 4 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc4Sz2**[1] | Load of 6 - < 9 in. decay class 4 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc4Sz3**[1] | Load of 9 - < 12 in. decay class 4 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc4Sz4**[1] | Load of 12 - < 20 in. decay class 4 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc4Sz5**[1] | Load of >= 20 in. decay class 4 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc5Sz1**[1] | Load of 3 - < 6 in. decay class 5 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc5Sz2**[1] | Load of 6 - < 9 in. decay class 5 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc5Sz3**[1] | Load of 9 - < 12 in. decay class 5 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc5Sz4**[1] | Load of 12 - < 20 in. decay class 5 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **ThousandHourDc5Sz5**[1] | Load of >= 20 in. decay class 5 fuels (t ac$^{-1}$). From Surface Fuels protocol and/or the Biomass – Fuels protocol |
| **HerbLoadDead** | Dead herb load (t ac$^{-1}$). From Surface Fuels – Vegetation protocol |
| **HerbLoadLive**[1] | Live herb load (t ac$^{-1}$). From Surface Fuels – Vegetation protocol and/or the Biomass – Fuels protocol |
| **ShrubLoadDead** | Dead shrub load (t ac$^{-1}$). From Surface Fuels – Vegetation protocol |
| **ShrubLoadLive**[1] | Live shrub load (t ac$^{-1}$). From Surface Fuels – Vegetation protocol and/or the Biomass – Fuels protocol |
| **ShrubLiveSAV**[2] | Not exported from FFI |
| **HerbSAV**[2] | Not exported from FFI |
| **WoodySAVOneHour**[2] | Not exported from FFI |
| **FractionGroundAreaPile Covered**[2] | Not exported from FFI |
| **PileLoadWholePlot**[1] | Load of piled fuels (t ac$^{-1}$) From Biomass Fuels |
| | |

[1] If loading data for the same component exists in both protocols, the average of the two values will be exported out of FFI.

[2] If you enter data in these fields in the .FFI file, FOFEM will use the data.

**Table A-2**: TRE file field names and descriptions. Files exported from FFI will include tree data from the Trees-Individuals, Saplings and Seedlings methods but only the Individuals and Sapling data are imported into FOFEM.

| .TRE | |
|---|---|
| **Field name** | **Description** |
| **PlotId** | FFI Macro plot identifier |
| **Monitoring Status** | FFI Monitoring status |
| **Monitoring Status Order** | FFI Monitoring status order |
| **TreeSpecies** | Tree species code (NRCS Codes only |
| **TreeExpansionFactor** | Representative tree density (trees $ac^{-1}$) |
| **Diameter**[1] | Tree DBH or DRC (in.) |
| **TreeHeight** | Tree height (ft) |
| **CrownBaseHeight**[2] | Live crown base height (ft) |
| **TreeStatus**[3] | Tree status (L, H, U, S, D) |
| **CrownClass**[4] | Crown class (D, C, I, S) |
| **CrownRatio**[5] | Crown ratio (0 - 100) |

[1] If values for both DBH and DRC are entered in FFI, this file will use DBH. For trees <4.5' tall, DBH=0.1" but the seedlings are not imported into FOFEM.

[2] This field is populated with values in the Live Crown Base Height field in the FFI Trees-Individual protocol.

[3] Trees coded D (Dead) are valid but will not be displayed in the tree list in FOFEM.

[4] This field is ignored in FOFEM.

[5] If Crown Ratio is null then FOFEM will calculate Crown Ratio = (1 – (Crown Base Height / Tree Height)) * 100. If Crown Base Height and Crown Ratio fields are null the tree record will not be imported into FOFEM.

NOTE: To convert older version TRE files so they work in FOFEM, change the extension of the tree file from TRE to CSV, open the file in Excel, add a column header named *CrownRatio* and Save the file. Close Excel, change the tree file extension from CSV to TRE.

# Updates

Version 6.3.1

1. Updated soil heating logic for duff and non-duff models
2. Updated litter and herb consumption equations, and updated some default fuel loadings for the southeast
3. New pocosin duff consumption equation added
4. FLM fuelbeds updated to match LANDFIRE attribute table
5. Accepts new FFI file imports files that include monitoring status

Version 6.2 Not released

Version 6.1

1. Updated NVCS and SAF default fuel loads for some shortleaf pine – oak and oak types in the southeast.
2. Modified user folder location for better performance on Window 7 and 8 machines.
3. Added ability to input fuels from FFI export files.

Version 6.0

1. Complete redesign of the user interface
2. Improved graphics
3. Mortality tree species codes changed to NVCS codes (FOFEM5 used six character codes)
4. FCCS cover types have been updated and now include foliage and branch fuels.
5. FFI (FEAT/FIREMON/Integrated) tree data can now be imported directly into the Mortality model.
6. The soil simulation model has been refined.
7. Added new tree mortality model for longleaf pine

Version 5.9.1

1. A new batch feature has been added that allows for creating individual emission files, see Batch Processing
2. A second new batch feature is the ability to more precisely set the input parameters of the Burnup consume model. See Batch Burnup Parameter File

Version 5.9

1. Updated the FLM fuel models.
2. Added a Burnup command line option. See Running Burnup from an input File

Version 5.8

1. Program updated to use new revised FCCS fuel loading classes.
2. FLM fuel classes added to program.

Version 5.7

1. Added post-fire injury option to tree mortality window. Updated mortality models for several species.

Version 5.6

1. Feature added to allow batch input files to be run from command line, see

Version 5.5

1. Miscellaneous changes: updates to help text, minor program bug fixes

Version 5.3

1. Batch processing feature added. Multiple plots of input data can be processed to model fuel consumption, smoke emissions, soil heating and tree mortality.
2. Unit Average Combustion Efficiency added to Smoke Emission Report.

Version 5.2

1. Canopy Cover estimates added to the tree mortality report.

Version 5.1

1. Includes additional emissions for $NO_X$ and $SO_2$.
2. Default moisture settings for moisture regime were changed.
3. Problems with the Mortality Species window for the Windows 2000/XP version were been corrected

Version 5.0

1. Original Release, Windows graphic user interface version enhanced and upgraded from original FOFEM DOS version.