FOFEM 6.0

USER GUIDE

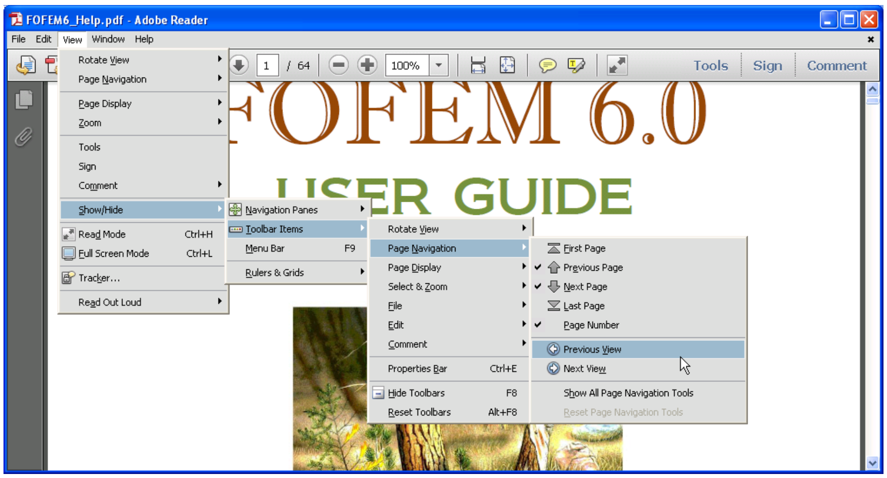
OCTOBER, 2012

Table of Contents

Instructions for Setting up Adobe Reader

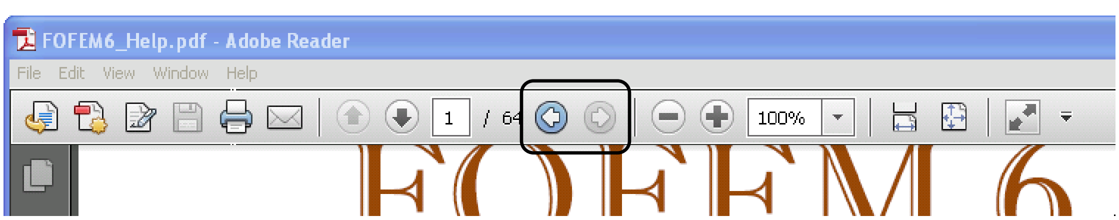
Using the **Previous View** and **Next View** buttons in Adobe Reader (and Adobe Acrobat)will make it easier to navigate the FOFEM Help; however, they are not added to the Reader toolbar by default. Follow these instructions to move them to the Reader toolbar at the top of the screen.

1) Clicking the **Previous View** button will allow you to go back to the last page you were on or to the last hyperlink you selected. To turn on the **Previous View** button select: *View > Show/Hide > Toolbar Items > Page Navigation > Previous View.*



2) The **Next View** button will allow you to go forward to the last place you selected the **Previous View** from. 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, 2000 or 7.

Updates

Version 6.0

1. Complete redesigned 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 stands 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 NOX and SO2.
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.

Installation

The FOFEM installation package can be downloaded from the Science Applications page on the Missoula Fire Sciences Lab website: www.firelab.org.

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 Stand Processing: Multiple stands of data 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.

Frequently Asked Questions

Question: What is different between FOFEM6 and FOFEM5 ?

Answer: The biggest change you will notice is the improved GUI, but there have been some other changes.

Question: Why does it sometimes appear that there are discrepancies between the calculated consumed amounts for the duff fuel load and the duff depth?

> For example: 1 of 1.5 inches of duff depth was consumed for a total of 75 percent as shown in the "FIRE EFFECTS ON FOREST FLOOR COMPONENTS" section of the report, while the duff consumed load shown on the "FUEL CONSUMPTION TABLE" section of the report is 50 percent.

Answer: Equations employed to calculation fuel consumption are different than those used to calculate depth consumption. In most cases these equations will predict similar results, but on occasion the results will be somewhat less than expected.

Question: Why are there no fuel loads for some of the cover types in the drop down list?

Answer: The FOFEM developers could not find existing or useful fuels data for all know cover types. However, the cover types in question were included in FOFEM so that users having fuels data could take advantage of them. There are two ways to do this.

1. The user can simply enter their fuel loads directly into each of the individual fuel loading windows on the user interface and then from the main menu use the Project->Save to save the setting into a project file for future use.
2. The user's fuel loads can be entered directly into one of the fuel loading .dat text files that are in turn are referenced by FOFEM. Fuel load adjustment factors can also be entered into the .dat files. With this method the cover type and its loadings can be selected and used like any other cover type from the dropdown list on the main window. Please contact our office for more details if you want to use this method.

Question: On the soil report, in the Time row, a 999 (minutes) is displayed in the first column and the remaining columns contain the number one. What does this mean?

Answer: No heat from the simulated fire was transferred to the soil based on the specified conditions; possibly due to high duff moisture content which resulted in a minimal amount of duff depth reduction.

Question: How do the screen settings such as region, season, etc., affect output?

Answer: They are used to select herbaceous, shrub and duff consumption equations.

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.

FOFEM 6.0 Authors

Duncan Lutes, Fire Ecologist, Missoula, MT
Robert Keane, Research Ecologist, Missoula, MT
Elizabeth Reinhardt, National Program Leader for Fire Research, Washington, D.C.

FOFEM 6.0 Technical Contact

Duncan Lutes
Fire Modeling Institute
Missoula Fire Sciences Laboratory
5775 US Highway 10 West
Missoula, MT 59808
Email: dlutes@fs.fed.us

Acknowledgements

FOFEM 6.0 was funded by the U.S. Forest Service, National Interagency Fuels Technology Transfer team (NIFTT). Development support was provided by U.S. Forest Service Rocky Mountain Research Station, Missoula Fire Sciences Lab and Fire Modeling Institute; U.S. Forest Service, Fire and Aviation Management; Systems for Environmental Management and NIFTT

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

This section will quickly show you how to run FOFEM to produce a report and a graph.

The very first time you start FOFEM after installation you will want to set your work folder (discussed in the next section) and place a project file in it. Your work folder is where your active project file is stored. It is also your default folder for saving and opening other FOFEM files. Your active project file is always shown in the Project File field.

Once you have created a work folder and stored a project file in it you are ready to run some calculations, create graphs and reports. Notice that as soon as you make any changes to the inputs the values in GUI output text boxes change to reflect the new setting(s).

To create a report or a graph simple click the desired button located on the lower half of GUI. You can print, save and copy reports or graphs by right mouse clicking on them and then selecting the desired action from the small menu that will pop up. You can manipulate the report text in the Report window just like any other word processor document. So you can cut and paste or copy as you like and even move text between other documents such as Microsoft Word documents.

At any time during a FOFEM session you can save all of your setting to a file by going up to the main menu and selecting **File > Save Project**. Any number of project files can be saved. When you exit the current program settings are save to the projects file whose name is shown in the Project File field.

Setting a Work Folder

Your work folder is the folder (directory) that contains your active project file. The work folder path and project file name are always shown in the Project File field located just under the Main menu. The suggested work folder path is: *C:\Documents and Settings\username\My Documents\FOFEM*.

A work folder is also your default folder for dealing with other FOFEM files. When you select a menu item to use some type of FOFEM file a dialog box pops up using your work folder to let you locate the file. You can still move to a different folder if you want to, but the dialog box always starts you off in your work folder.

Also, whenever you start FOFEM it will open your work fold using the last project file you were working with.

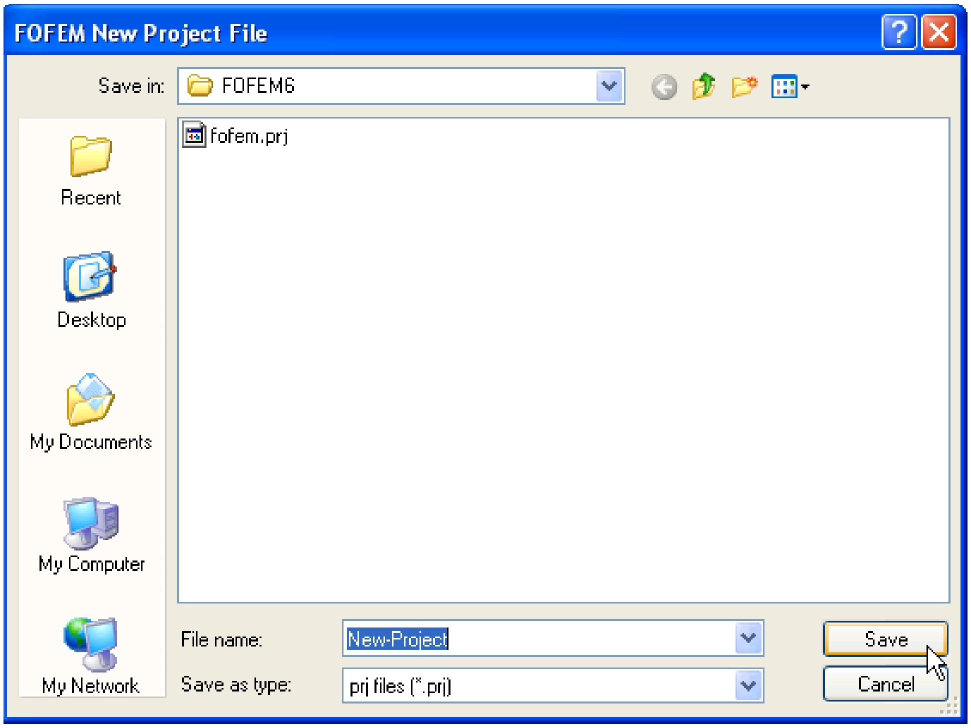
There are two ways to set your work folder, under the main menu option Project:

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.

> *NOTE: The very first time you run FOFEM after installation the work folder will be set to the folder that FOFEM has been installed in, for example C:\ProgramFiles\Fofem6. Because of the security setting set on Government computers you may not have access to the folder unless you have Administrative Privileges or set the folder permissions to allow. To avoid any problems you should change you work folder as soon as you start using FOFEM. Do this by creating a new project file in a different folder. But, before you do that you may want to select the appropriate Region and Cover Type Classification settings so that your new project file will have your region and proper cover types assigned to it.*

Now, go up to the main menu and select Project and then New. The dialog box shown below will pop up, you will use it to create your new Work folder and place a new project file in it.



Once you have selected a folder and file name, hit the **Save** button in the dialog box, the dialog box will then close and you will see that the folder's path and the project file name are now shown in Project File window.

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 Condition effects percent moisture. 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.

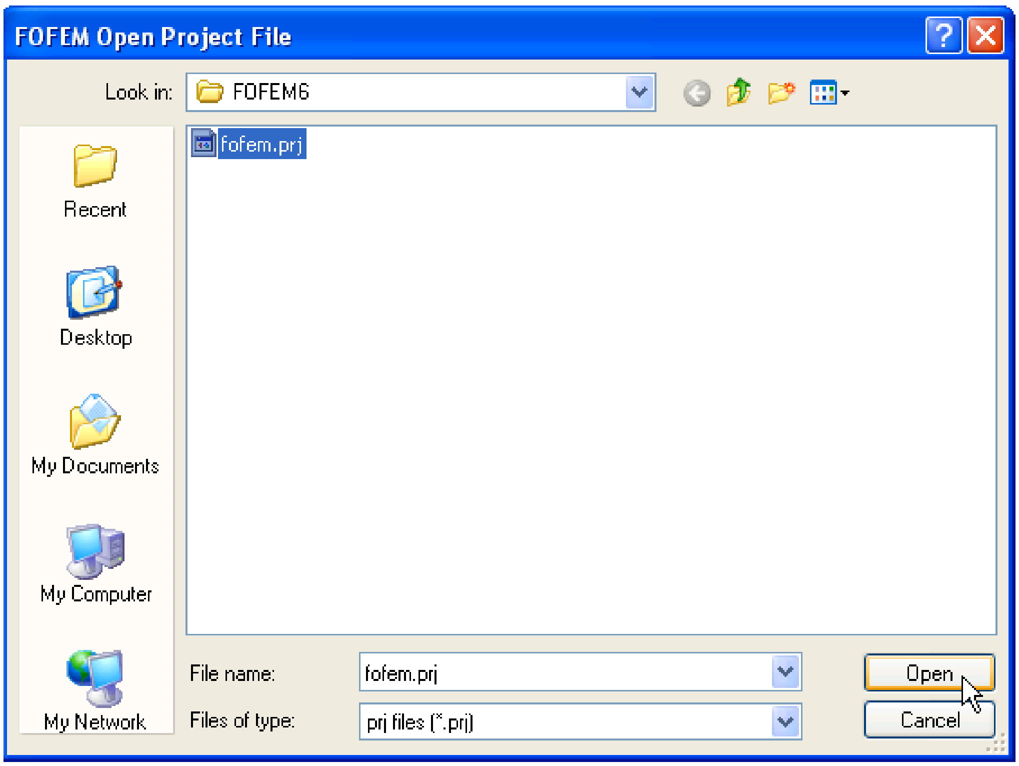
Getting Help

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, a textbox, button, etc.), hit the F1 key and a small dialog box will pop up with the help text in it.

This document is also a 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 extension .prj. This window is similar to other windows used by other programs such as Microsoft Word or Excel. The window allows you to navigate to folders, create folders, etc., it also selectively shows you particular files types.

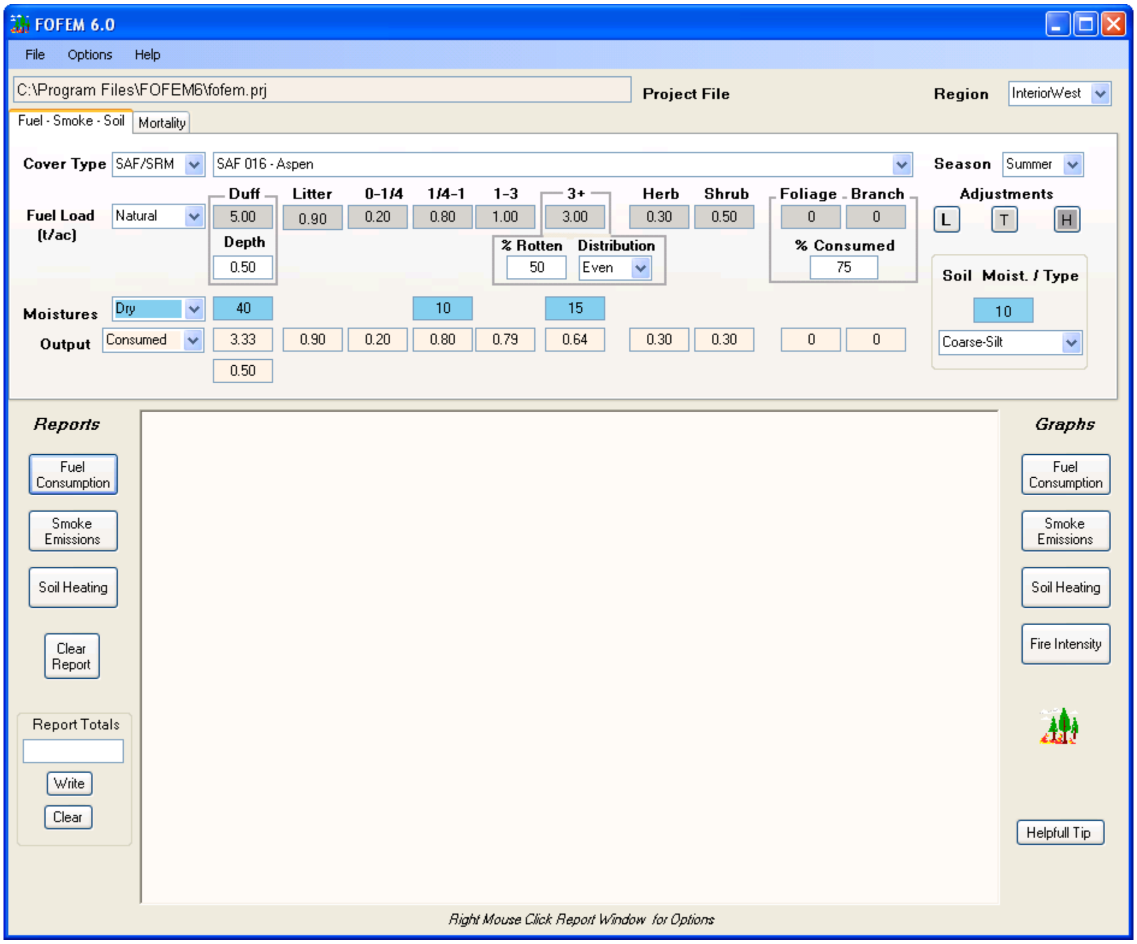


Main FOFEM Window

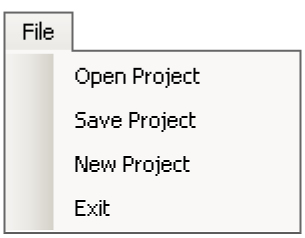
Main Window

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 from multiple stand input files. 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.

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 some sample input files for templates using the Create Sample Soil Input Files menu item below. The samples files contain comments to explain the file. Two sample files are created for modeling both burnable duff and absence of burnable duff. 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

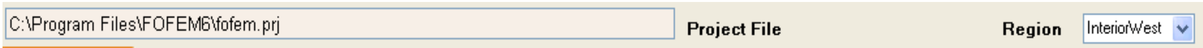
Create Sample Soil Input Files: Create sample files for the Duff model and the Zero Duff model. See Running Soil Heating from Main Menu for more details.

FOFEM Header

Project File

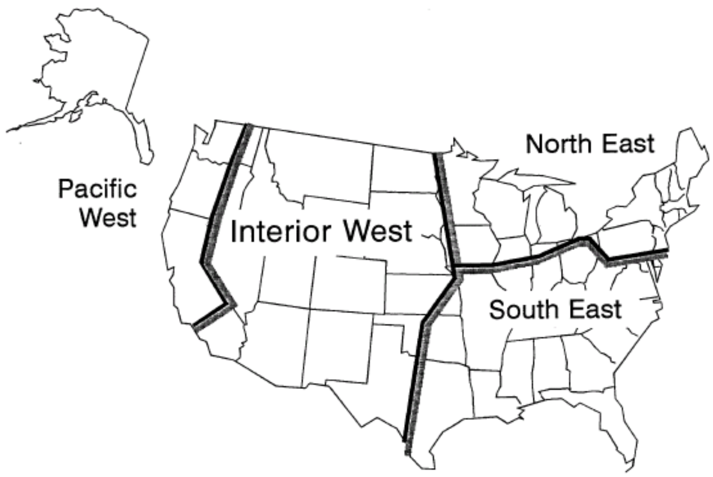
The Project window displays the active (current) project file.

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.



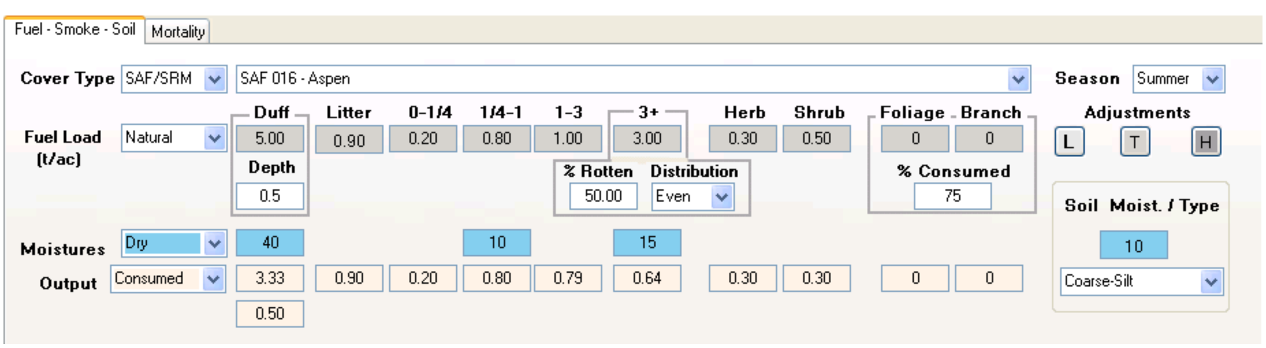
Select a region that is appropriate for you project.

1. Interior West
2. Pacific West
3. South East
4. North 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 the remaining duff will act as an insulator.

NOTE: Litter, 0 -> ¼ and 1->3 inch fuel moistures need 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: 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.dat 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/.

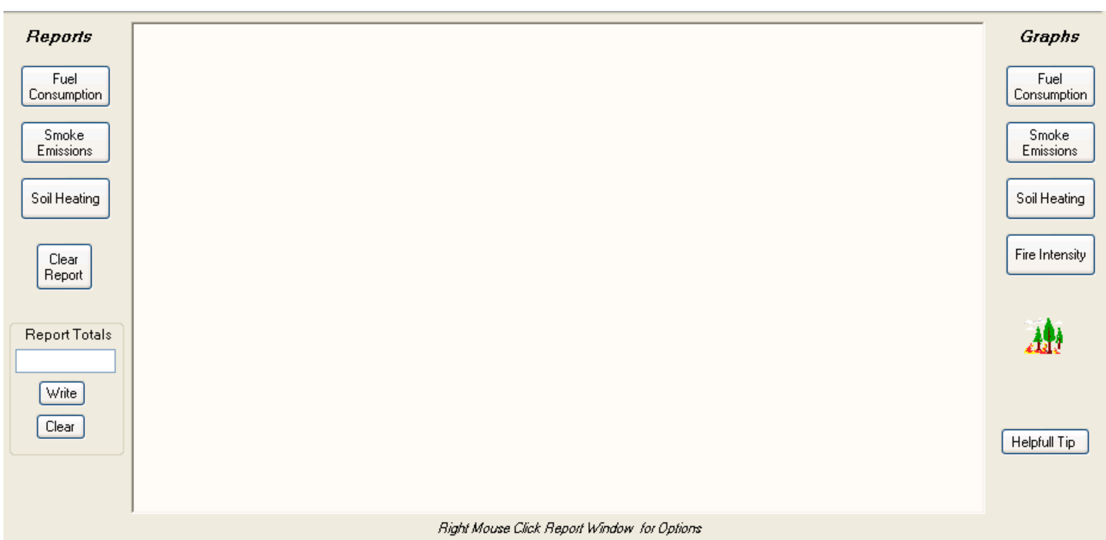
NOTE: For more information about FLMs see:

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.

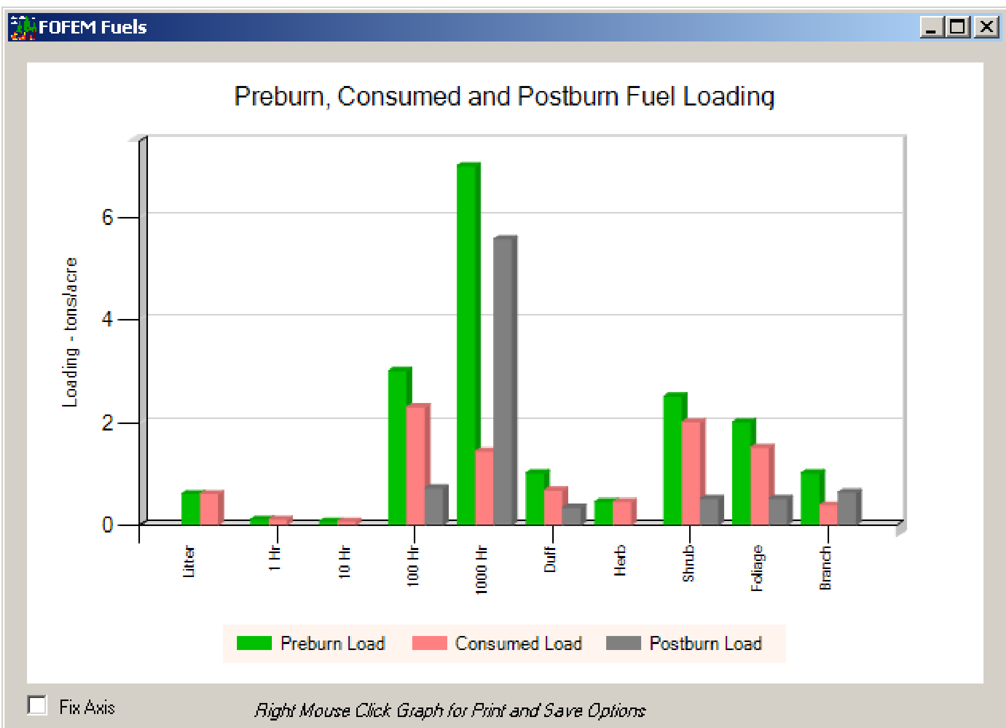


To create a **Report** click any one of the buttons on the left and a report will be placed in the Report window. Each time a button is clicked a new report is added to the end of the report, scroll down in the text window to see it. You can use a right mouse click to Copy, Cut, Paste, Print, Save or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

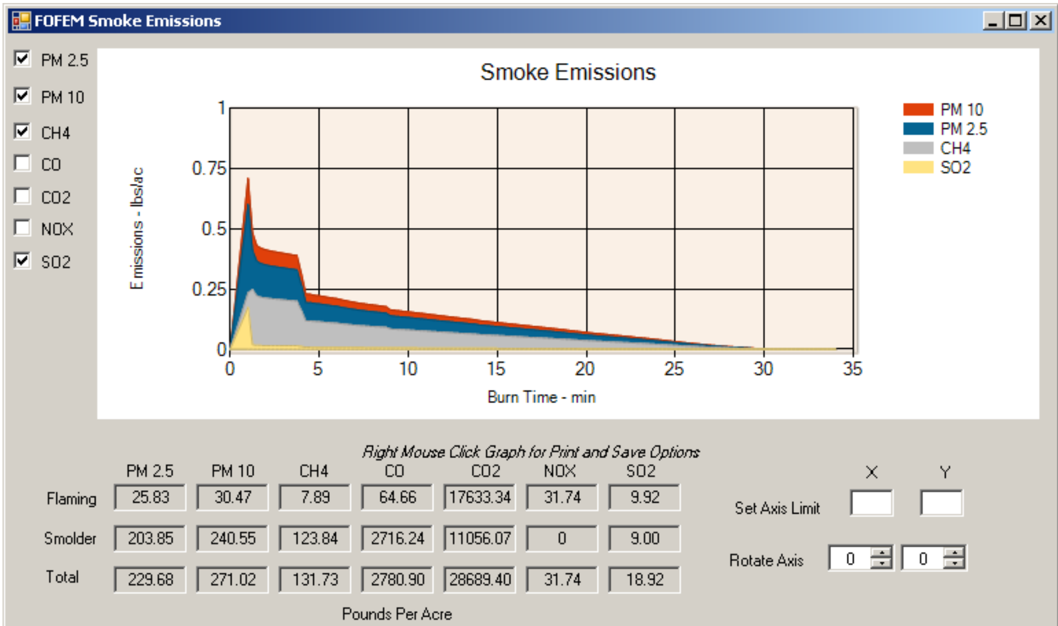
Fuel Consumption Graph



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

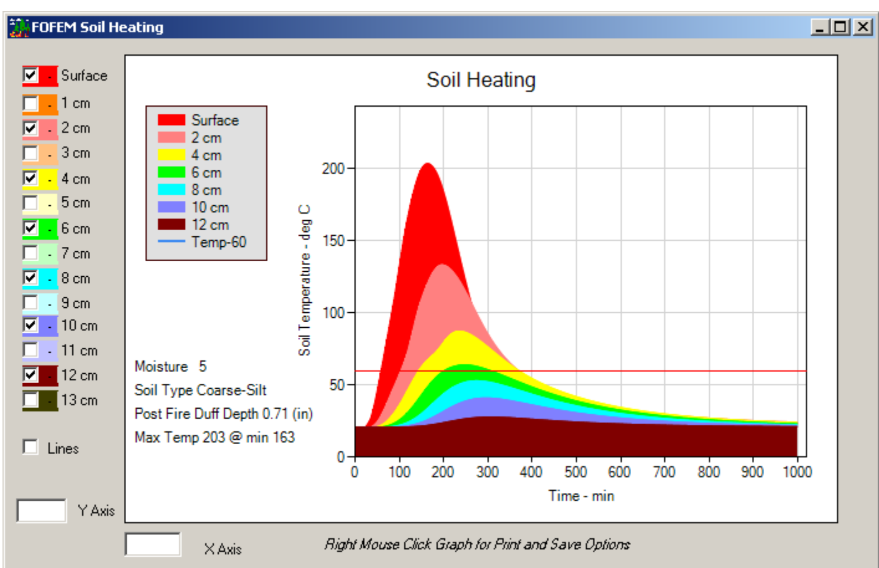


The graph displays the rate which components are being emitted. By selecting the checkboxes on the left you can show one or more of the emission components.

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).

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.

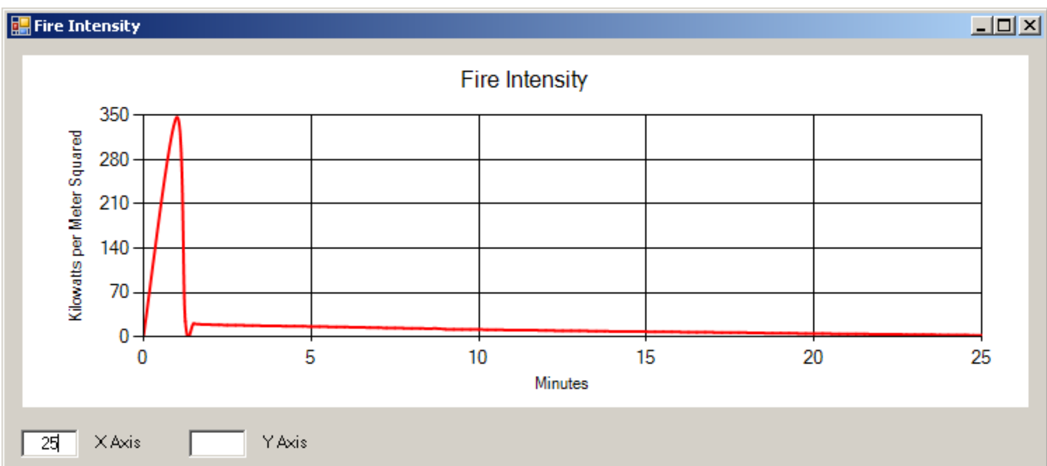
Lines: Selecting this checkbox will show the graph in line form.

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 maybe not completely reduce duff in certain simulation conditions. To correct for this condition 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 COMPONENTS

Duff Depth Consumed (in) 0.9 Equation: 6
Mineral Soil Exposed (%) 50.8 Equation: 10

Ground and Surface Fuel Carbon Loading

Fuel Component Name	Preburn Carbon (t/acre)	Postburn Carbon (t/acre)
Litter	0.22	0.00
Wood	5.11	3.14
Duff	0.37	0.12
Herbaceous	0.22	0.00
Shrub	0.63	0.13
Foliage+Branch	1.50	0.56
Total	8.04	3.95

Smoke Emissions Report

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

> *NOTE: NOX 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.

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 13cm 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 7cm. This example also shows that there were no layers reaching 275 degrees, including the surface, so the word "None" is shown.

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

                          Soil Heat Report

 Region:          PacificWest
 Cover Type:      SRM 210 - Bitterbrush
 Fuel Type:       Natural
 Fuel Reference: PMS-830
 Duff Depth.....: Pre-Fire:   2.54 cm.,  Post-Fire:   0.16 cm.

                       Soil Layer Maximum Temperature
                ( measurements are in centimeters and Celsius )

Depth     0    1    2    3    4    5    6    7    8    9   10   11   12   13
Temp.   270  214  167  124   96   75   70   64   58   51   44   37   29   21
Time    161  182  194  225  241  207  221  240  250  258  265  270  274    1

Max Depth Having 60 degrees: 7
Max Depth Having 275 degrees: - None -
```

Summary Report

Summary reports provide an easy 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 emissions a fuel consumption summary report is included with the emissions summary report).

```
                        Fuel Consumption Summary - (t/acre)

                    ______   Wood    Wood    Wood     Wood    _____    _____   _____   Crown   Crown
        Id          Litter  0->1/4  1/4->1  1->3       3+     Duff     Herb    Shrub   Folge   Brnch
     VeryDry         0.70    0.17    0.93    0.00     1.87    25.56    0.15    0.00    0.00    0.00
         Dry         0.70    0.17    0.93    0.00     1.69    22.66    0.15    0.00    0.00    0.00


                         Smoke Emission Summary (lbs/acre)

        Id           PM10        PM2.5       CH4        CO          CO2        NOX        SO2
     VeryDry        1525.0      1292.0      784.0     17165.0     73253.0      6.0       59.0
         Dry        1361.0      1153.0      699.0     15308.0     65673.0      6.0       53.0
```

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. Likewise a 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.

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 ration as 0 - 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

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 FFI (FEAT/FIREMON/Integrated) tree data from a file. The imported plots will be shown in the **Plot-->** dropdown list and the tree information will be loaded directly into the species tree grid.

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

To delete a row of data click the desired row in the left most gray column, that will highlight the entire row, 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"*

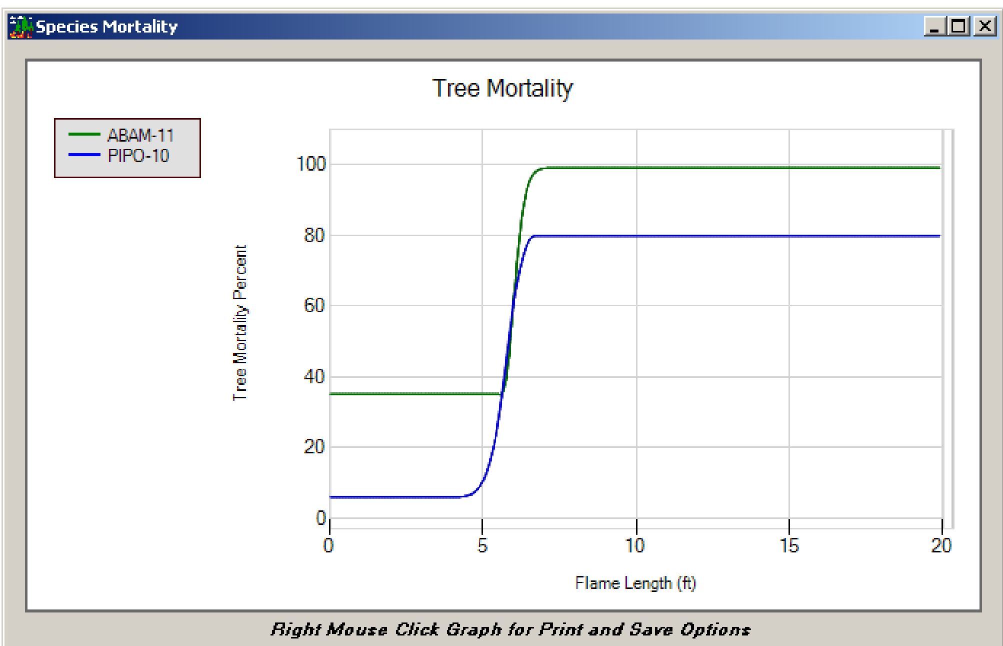
Average Mortality Probability by Species /Diameter: The table shows the probability of mortality at a variety of crown scorch or flame lengths (as set on the **Mortality** tab) for the species/DBH combinations entered in the data grid.

Stand Tree Mortality: Summary information for the simulation.

Mortality Graph - "Pre-fire"

The mortality graph shows below shows all of the species that were selected by the user in the tree grid of the mortality setting tab. The X axis variable graphed as Flame Length or Crown Scorch as set by the user on the **Mortality** tab.

*NOTE: You must check the **Graph** box in the data grid to display the mortality graph for desired record.*



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.

NOTE: Post fire injury simulation is not currently available in the FOFEM batch mode.

NOTE: 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 Scorch: This is a value from 0 to 100 based on either percent crown length scorched (len) or percent crown volume scorched (vol).

NOTE: If the first variable in parenthesis following the species name in the species selection window is "len" then input the percent crown length scorched. If the first variable in parenthesis in "vol" then input the crown volume scorched. For example, in the screen shot above the species ABCO is selected so the crown scorch should be based on scorch length.

DBH: Diameter at breast height in inches.

NOTE: If the second variable in parenthesis following the species name in the species selection window is" dbhR" then DBH is used to predict mortality. If the second variable in parenthesis is "dbh" then DBH is not used to predict mortality but it is still required because it is used in the FOFEM reports

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.

NOTE: 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. Refer to the Estimating Tree Mortality - "Post-fire" section for more information about beetle species used in the models.

NOTE: *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.

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  Crwn   Dia  Camb  Btle  Num  Prob  Mortality Equation
Code     Scrh  (in)  Kill  Atck  Trs  Mort   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 trees 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 trees 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.

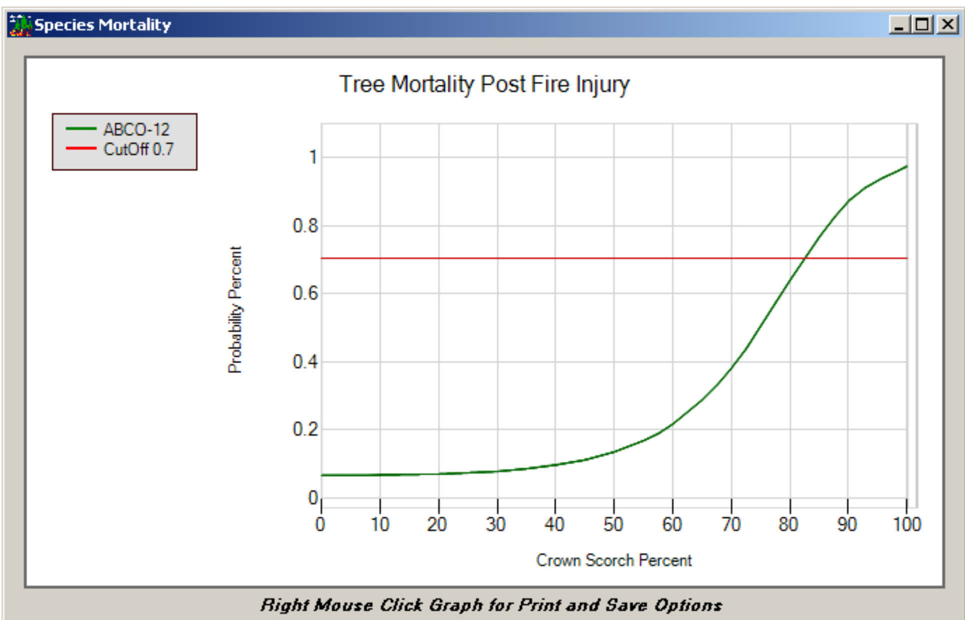
NOTE: Not all tree species have species specific mortality equations so review the equations used for the species in your simulation. See *Estimating Tree Mortality - "Post-fire"*

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.

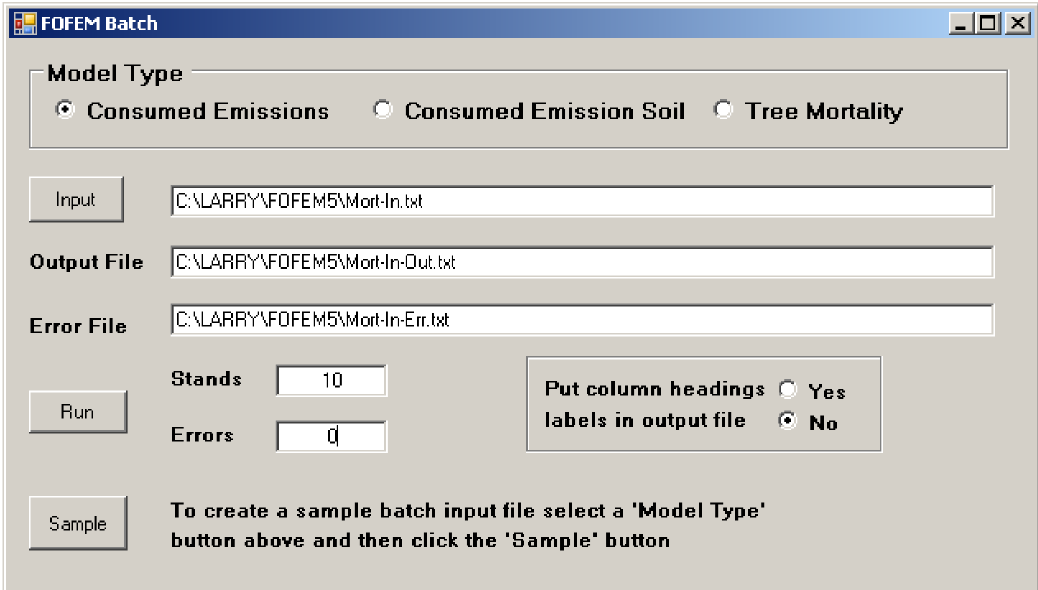
Graph – "Post-fire"

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 stands of data using input and output text 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 Emission, Consumed Emission Soil, 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 stand 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 that you have listed in the batch file itself.*

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. As such all of the program's output, including errors, is written to text files. However, the program will attempt to pop up a Windows dialog box if it detects any command line program arguments.

When running in batch command line mode, depending on the folder you are working in, you may have to set a system *PATH* variable in order for the system to find the FOFEM executable in its install folder.

1. Open a Windows Command Prompt and at the command prompt enter:

   > 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 waning 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 errorfile to see if any errors were encountered, the runfile also contains the number of errors.

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.* #MAX_TIMES *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.

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.

Each line of input data represents one stand and will produce one line of stand output. All columns shown below are numeric unless otherwise specified as text.

Column No.	Column 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	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 0.446 - 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	Soil Type[4]	"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	Soil Moisture[4]	Soil Moisture; range 0 – 25%
26	Moisture Regime[4,5]	Text = "VeryDry", "Dry", "Moderate", "Wet"

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

[2] The following table shows how fuel loads get distributed into each class.

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 24-26.

[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

Entering Individual Size Classes

1000 hour fuel loadings can be entered in total (as described above) or as individual size classes. Output file format will remain the same regardless of input file format.

To enter data in individual size classes insert the *#1k-SizeClass* switch starting in column one at the top of the input file and enter the 1000 hour fuel loads as described below.

To enter 1000 hour fuels in individual size classes replace the columns 7 thru 10 as described above with the following nine columns.

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 (%)

Then enter **Duff** in column 16 and include the remaining columns of data in the same order as described above (i.e., duff, duff moisture, duff depth…).

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]()*

<u>Batch Output File - Consumed Emission Soil</u>

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	Stand Id	Stand Id from input file
2	Litter	Post fire loading (t/ac)
3	Litter	Consumed loading (t/ac)
4	1 Hour	Post fire loading (t/ac)
5	1 Hour	Consumed loading (t/ac)
6	10 Hour	Post fire loading (t/ac)
7	10 Hour	Consumed loading (t/ac)
8	100 Hour	Post fire loading (t/ac)
9	100 Hour	Consumed loading (t/ac)
10	1000 Hour Sound	Post fire loading (t/ac)
11	1000 Hour Sound	Consumed loading (t/ac)
12	1000 Hour Rotten	Post fire loading (t/ac)
13	1000 Hour Rotten	Consumed loading (t/ac)
14	Duff	Post fire loading (t/ac)

15	Duff	Consumed loading (t/ac)
16	Herbaceous	Post fire loading (t/ac)
17	Herbaceous	Consumed loading (t/ac)
18	Shrub	Post fire loading (t/ac)
19	Shrub	Consumed loading (t/ac)
20	Crown Foliage	Post fire loading (t/ac)
21	Crown Foliage	Consumed loading (t/ac)
22	Crown Branch	Post fire loading (t/ac)
23	Crown Branch	Consumed loading (t/ac)
24	Mineral Soil Exposed	%
25	Duff Depth	Pre-fire (in.)
26	Duff Depth	Post-fire (in.)
27	PM_{10}	Flaming (lbs/ac)
28	PM_{10}	Smoldering (lbs/ac)
29	$PM_{2.5}$	Flaming (lbs/ac)
30	$PM_{2.5}$	Smoldering (lbs/ac)
31	CH_4	Flaming (lbs/ac)
32	CH_4	Smoldering (lbs/ac)
33	CO	Flaming (lbs/ac)
34	CO	Smoldering (lbs/ac)
35	CO_2	Flaming (lbs/ac)
36	CO_2	Smoldering (lbs/ac)
37	NO_x	Flaming (lbs/ac)
38	NO_x	Smoldering (lbs/ac)
39	SO_2	Flaming (lbs/ac)
40	SO_2	Smoldering (lbs/ac)
41	Total flame time	Seconds
42	Total smoldering time	Seconds
43	Total flame consumed amount	t/ac
44	Total smoldering consumed amount	t/ac
45[1]	Layer 0	maximum temperature at soil surface (C)
46[1]	Layer 2	maximum temperature at 2 cm. (C)
47[1]	Layer 4	maximum temperature at 4 cm.(C)
48[1]	Layer 6	maximum temperature at 6 cm. (C)
49[1]	Deepest layer reaching 60 degrees C	Depth in cm. “-1” means no layer reached that temperature
50[1]	Deepest layer reaching 275 degrees C	Depth in cm. “-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

Batch Input File – Tree Mortality

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.

Column No.	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
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.	Name	Notes
1	Stand Id	from input file
2	Average morality for the stand	%
3	Total number of trees killed	
4	The average DBH of the killed trees	in.
5	Average mortality for trees having a DBH equal to or greater than 4 inches	%
6	Total number of pre-fire trees	trees/ac
7	Total basal area of pre-fire trees	ft^2
8	Total basal area post fire	ft^2

9	Total basal area of the killed trees	ft^2
10	Total crown cover of pre-fire trees	%
11	Total crown cover of post fire 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. This file is similar but differs from the Example Batch Parameter File in which you also set fuel loads. In this file you just set the Burnup parameters. 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

Introduction

Smoldering duff fires involve the pyrolysis and oxidation of tightly packed fuel materials on the forest floor. Spread rates of these duff fires are slow; three orders of magnitude slower than flaming (Hungerford et al. 1991). Duff fire temperatures are also lower than flaming temperatures, but heating of deep soil layers by duff fires is often greater because of the intimate contact of the fire with the mineral soil surface and the long duration of the fire.

Effects of fire can be both beneficial and detrimental, depending on the duration and intensity of the fire and the initial condition of the soil. The purpose of this model is to quantify the effects of fire intensity, duration and soil conditions on soil heating under both smoldering duff fires and flaming surface fires. The model was 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. The model has been thoroughly tested and refined both in the field and in the laboratory and is able to predict soil temperature reliably, whatever the moisture, density, or mineralogy of the soil might be. Two variation of the model were developed in order to simulate soil heating under conditions when there is a burnable duff material and when there is an absence of any burnable duff. In the latter case, soil heating is attributed to the surface fire rather than the slower moving, lower intensity smoldering duff fire.

Assumptions for the Duff Fire Model

Fire in dry duff spreads horizontally, with a parabolic front, at rates of about 1-3 centimeters per hour (Hungerford et al., 1991). To completely model this phenomenon would require a two or three dimensional soil heat flow model as well as an appropriate model for heat production, spread rate, and heat partitioning. The differential equations governing linked transport of heat and water in soil are highly nonlinear and therefore difficult to solve. One-dimensional simulations are a challenge, and multidimensional simulations are even more challenging. We therefore followed Steward et al. (1990) and Pafford et al. (1991) in assuming that temperature gradients in the horizontal direction are small compared to those in the vertical direction. Therefore, we assumed that we could approximate a downward heat flow into the soil using a one-dimensional model.

By knowing the depth and density of duff, we can compute the total amount of heat that is released when it burns. This heat is released over a period of time, which is determined by the rate of spread of the fire, which in turn is correlated to the moisture of the duff material. The dryer the duff, the faster it will burn. The soil heating model allows the user to input a value for the duff moisture if one is known, otherwise the user may choose one of the default values from the menu bar.

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

Assumptions for the Zero Duff Fire Model

Many of the assumptions that are made in the Duff Fire Model are also applied to the case when there is zero duff. The two models are essentially the same with the major differences being the initial setup of the input file. Unlike the case when there is a burnable duff layer, this version of the model relies strictly on the surface fuels and corresponding fire behavior to generate the soil heating. The necessary fuel and fire behavior data needed to run this model is acquired from the Burn Up model, which is directly linked for convenience. Therefore, in the case when there is zero duff associated with a particular vegetation layer, the model will first run Burn Up, using the appropriate vegetation and environmental parameters, and then the Zero Duff model will be run using the output from Burn Up to generate the corresponding soil heating. Like the Duff fire model, this Zero Duff model uses the heat released during the burn time and applies it to the soil.

It is worth noting that both the Duff and Zero Duff soil heating models in conjunction with FOFEM predict various fire effects on a landscape scale, but the reality is that soiling heating will vary in a mosaic pattern throughout a burn unit. Fires often burn at varying intensities and spread rates depending on a wide range of variables and the corresponding soil heating will vary equally as much. What we are attempting to predict with these models is an average of what the soil heating will be across a user specified unit. We have made FOFEM easy for the user to change various parameters, everything from soil types to fuel loadings of individual size class to duff depth and duff moisture, and we encourage the user to experiment with a variety of pre-burn conditions in order to see several post-burn results.

Results

The results of each soil heating run can be interpreted in either graphical or report form. 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 Celsius (C). This temperature is often referred to as the lethal temperature for living organisms; therefore it is highlighted to allow the user to identify which burning scenarios exceed this temperature at various depths beneath the soil surface. The default lethal temperature for each graphical output is set for 60oC, but the user can change this for each plot setup simply by typing in the desired temperature. The graphical output also includes the maximum temperature reached at the soil surface, amount of duff consumed, soil type, and starting soil moisture.

Users can also view the output of each soil heating simulation in report form. The report form contains everything that the graphical format contains, but also includes a complete summary of the FOFEM pre-burn and post-burn conditions. This option is useful for comparing several scenarios against one another.

Running Soil Heating from Main Menu

FOFEM has a menu item for creating two sample input files one for the Duff model and one for the Zero Duff model (select **Options > Create Sample Soil Input File** from the main FOFEM menu). The Duff model extension is .duf and the Zero Duff file extension is .exp. The sample files contain default information that can be modified as needed.

The soil heating component of FOFEM gives the option to run the Duff model or Zero Duff model from the main soil heating input file if the user so desires (select **Options > Run Soil From Input File** from the main FOFEM menu). Below is an example of the input file for the Duff soil heating model along with a description of each line. The input file has four distinct sections. The first section defines the simulation run time, the second section defines the fuel load and heat content associated with it, the third section defines the soil type and properties, and the fourth section defines the depth increments that the model will predict temperature at.

In the example file below there are 16 lines that are of the form

keyword argument comment

The keyword must start the line and then be followed by its argument. The comment is optional and is used to help describe the line and/or show possible arguments.

This example shows the midburn keyword, its argument, followed by a comment showing some possible arguments.

midburn 360 midburn 720 1680 900 1000 1100

Here is an example for duff density, the comment in this case tells you the unit of measure

duff-density 0.16 duff density - kg/m3

Section 1

Duff-Sim, the identifier must be on the first line. It identifies the file as a Duff model input file. The next 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.

midburn and burn-time are determined by the duff depth and moisture content.

stop-time is the simulation stop time in minutes.

Section 2

duff-depth is the duff depth in inches.

duff-heat is the total amount of heat released and is determine by the depth and bulk density of the duff.

duff-density is the duff bulk density.

Section 3

This section defines the various soil properties and each of the lines is clearly labeled. The soil heating model has a series of five soil types to choose from, each of which has the soil inputs already defined for user convenience.

The five soil types are Loamy-Skeletal, Fine-Silty, Fine, Coarse-Silty, and Coarse-Loamy and are further defined as follows.

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.

The soil heating model is more dependent on the amount of heat released during the burning simulation and the moisture content of the soil and fuels than to the actual soil characteristics, therefore; we limited the user default soil types to the five mentioned above and we encourage the user to experiment with each of the different soil types under varying fuel loadings and moisture contents.

Section 4

This section starts off with the word Layer on a single line starting column 1.

Each of the lines in this section represents a depth in millimeters that the model will predict temperature at. The format (i.e. *10 1*) is interpreted as *10* millimeters and the *1* following it means that the graph will plot that depth. If the *1* were replaced with a *0* then that depth would not be represented on the graphical output. Also note that even though the input file records depth in millimeters, the graphical output shows that same depth as its equivalent in centimeters. An example would be 10 mm in the input file is seen as 1.0 cm on the graphical output. Therefore, the graphical output of the example below will show a temperature profile from 0 being the surface to 13.0 cm below the surface in 1.0 cm increments.

Example Soil Heating Input File

*NOTE: the words **Section** are not to be included in the actual file.*

Section 1
```
Duff-Sim
# Comment
Midburn                 360    midburn        720    1680   900    1000   1100
burn-time               120    burntime       240    180    300    400
stop-time               800    stoptime       1200   2400   1800   1500
```
Section 2
```
duff-depth              1.0    duffdepth      0.08   0.06   0.05   0.04   0.07
duff-heat               17.5e6                duff heat content - J/m3}
duff-density            0.16                  duff density - kg/m3}
```
Section 3
```
soil-bulk-density       1.22e6                soil bulk density - g/m3}
soil-particle-density   2.65e6                soil particle density - g/m3}
extrapolated-water      0.102                 extrapolated water content at -1 J/kg}
thermal-conductivity    2.68                  thermal conductivity of the mineral
fraction}
de-Vries-shape-factor   0.107                 de Vries soil shape factor}
water-content           0.126                 water content for liquid recirculation}
recirculation           2.89                  power for recirculation function}
time-step               60                    time step - s}
start-soil-water        0.10                  starting soil water content - %}
start-soil-temp         21.0                  starting soil temperature - C}
```
Section 4
```
Layers
0 0
0 1
10       1
20       1
30       1
```

```
40        1
50        1
60        1
70        1
80        1
90        1
100       1
110       1
120       1
130       1
```

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 type with the simple click of the mouse. This is the easiest way for the user to compare various burning scenarios to see how soil heating is affected. The option for the user to run the model from the main input files make it possible to manipulate and change more specific inputs to the soil heating model, but the model can be sensitive to such changes and it is recommended that the user become fluent with the soil heating component of FOFEM before attempting such manipulations.

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 FOFEM's graph window. Accordingly you must create a soil graph before you attempt to save the points to a file.

```
Time Lay0  Lay1  Lay2  Lay3  Lay4  Lay5  Lay6  Lay7  Lay8  Lay9  Lay10 Lay11 Lay12 Lay13
min.  cm    cm    cm    cm    cm    cm    cm    cm    cm    cm     cm    cm    cm    cm
1.0  18.4  20.7  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0
2.0  18.3  20.5  20.9  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0
3.0  18.3  20.3  20.9  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0
4.0  18.2  20.1  20.8  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0  21.0
```

Here is how to interpret the file. Starting with the first line in the file; column 1 is the number of minutes since ignition, column 2 is the temperature of layer 0 (surface layer) at the specified time, column 3 is the temperate for next layer, 1 centimeter down, and so on for the rest of the 1 layers. Looking down to the next line you will see the next time interval and its corresponding temperatures for each layer. And so on down for the rest of the lines in the file. The temperature of 21C represents the ambient air temperature.

Conclusions

The soil heating component was a new addition to FOFEM 5.3. It was a product of many years of work from several different researchers and is intended to give the user an overview of soil heating based on surface fuels and soil conditions. As fire users and researchers it is widely understood that fire is non-uniform and often erratic in behavior. Therefore, it is difficult to attempt to predict soil heating on a unit scale when indeed most fire patterns are more mosaic. If for no other reason this is why we strongly encourage the user to experiment with a variety of model input values in order to best predict and understand these varying fire regimes.

Soil Heating Citations

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.

Frandsen, W.H. 1991. Smoldering spread rate: a preliminary estimate. 1991. Proceedings of the 11th Conference on Fire and Forest Meteorology, pp 168-172.

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.

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 $P_m = 1 / \left[1 + \exp(-1.941 + (6.316 * (1.0 - \exp(-BT))) - 0.000535 * (CS^2)) \right]$

If DBH < 1" and Crown Height/Length Scorched < 50% then P_m = 1

If DBH < 1" and Ht < 3' then P_m = 1

Else $P_m = 1 / \left[1 + \exp(-1.941 + (6.316 * (1.0 - \exp(-BT))) - 0.000535 * (CS^2)) \right]$

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

$$P_m = 1 / \left| 1 + \exp((0.251 * (DBH * 2.54) - (0.07 * CH * 2.54 * 12) - 4.407) \right|$$

If Fire Severity <> "Low" then

$$P_m = 1 / \left| 1 + \exp((0.0858 * DBH * 2.54) - (0.118 * CH * 2.54 * 12) - 2.157) \right|$$

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 scorched (0-1).
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; Broackway, 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 (%)

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

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 (%)

$$P_m = 1/\left(1+\exp\left(-\left(-4.2466+(CLS^3*0.000007172)\right)\right)\right)$$

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 (%)

$$P_m = 1/\left(1+\exp\left(-\left(-1.6594+(CVS*0.0327)-(dbh*0.0489)\right)\right)\right)$$

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 (%)

$$P_m = 1/\left(1+\exp\left(-\left(0.0845+(CVS*0.0445)\right)\right)\right)$$

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 (%)

$$P_m = 1/\left(1+\exp\left(-\left(-2.3085+(CLS^3*0.000004059)\right)\right)\right)$$

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 (%)

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

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

Equation 18:
Sugar pine: CLS = crown length scorched (%)

$$P_m = 1/\left(1+\exp\left(-\left(-2.0588+(CLS^2*0.000814)\right)\right)\right)$$

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

Equation 19:

Ponderosa/Jeffrey pine: CVS = crown volume scorched (%)

$$P_m = 1/\left(1+\exp\left(-\left(-2.7103+(CVS^3 * 0.000004093)\right)\right)\right)$$

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

Equation 20:

Douglas-fir: CVS = crown volume scorched (%)

$$P_m = 1/\left(1+\exp\left(-\left(-2.0346+(CVS * 0.0906)-(CVS^2 * 0.0022)+(CVS^3 * 0.000019)\right)\right)\right)$$

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 scorch, cambium kill rating (CKR), and bark beetle attacks.

Crown Scorch: a value from 0 to 100 based on either percent crown length scorched or percent crown volume scorched.

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 Pm 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.

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"

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

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

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

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

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

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

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

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

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

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

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.)

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

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

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

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) 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

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

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.

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.

<u>Litter Consumption</u>

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

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

---

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.

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.

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.

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.

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 biomass).
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.

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 biomass). 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.

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 biomass).
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.

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.

Equation 16:
Used in the Southeast except in pocosin cover groups. %DR=% duff reduction, WPRE=litter load+duffload+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.

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

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

Equation 20:
Pocosin: Calculates duff depth reduction (DR) for deep organic soils in the pocosin cover groups. Preburn duff depth (DPRE) is defined to be the depth of root mat and "muck", and it is assumed that the duff is consumed to within 4" of the water table. If using the FOFEM moisture defaults DPRE is set to be 1" if moisture conditions are wet, 5" if moderate, 14" if dry, and 25" if very dry. These defaults can be modified by changing the preburn duff depth.
If % duff moisture is >= 103% the DR=0
If % duff moisture is < 103% then DR=DPRE - 4
Source: Hungerford 1996, personal communication

Equation 201:
Pocosin: First calculates DR using Equation 20 then assumes the top 8" of the duff is root mat with a bulk density of 11 t ac^{-1} in^{-1}, and the muck below has a bulk density of 22 t ac^{-1} in^{-1}. Percent duff load consumed is calculated by assuming that duff burns from the top down (i.e., consumes the root mat first) to within 4" of the water table.
If DR<=8 then %DR=100*(DR/DPRE)
If DR>8 then %DR=100*(88+22*(DR-8)/Prefire duff load)
Source: Hungerford 1996, personal communication

Mineral Soil Exposure

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

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.

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.

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.

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.

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.

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 221:
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

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

Equation 234:
Used to predict shrub consumption for non-pocosin group in the southeast.
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.

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

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.dat, fof_nvcs.dat, fof_flm.dat or fof_fccs.dat 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 .dat 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**. You may edit this file or create a new file. 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/m2	
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/m2	
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/m2
4	Heat content	J/kg
5	Moisture content	fraction dry load
6	Oven dry mass density	kg/m3
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	

<u>Sample Burnup Output Files</u>

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

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

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.

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.

Frandsen, W.H. 1991. Heat evolved from smoldering peat. International Journal of Wildland Fire 1:197-204.

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.

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.

Hungerford, R.D. 1996. personal communication.

Mincemoyer, S. 2002.

Ottmar, R.D., Sandberg, D.V. 1983. Estimating 1000-hour fuel moistures in the Douglas fir sub region. In: Proceedings of the 7th conference on fire and forest meteorology; Fort Collins, CO: 22-26.

Reinhardt, E.D.; Keane, R.E.; Brown, J.K. First Order Fire Effects Model: FOFEM 4.0, User's Guide. General Technical Report INT-GTR-344. 1997.

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.

Scientific Content - Smoke Emissions

Smoke Production

The Burnup model was modified (Finney 2001) 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/m2. 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 PM2.5, PM10, CH4 CO, CO2, NOX and SO2 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	**Multiplier**	**Formula**	**Multiplier**
PM 2.5	67.4 - (FCE x 66.8)	2.604	67.4 - (SCE x 66.8)	22.644
CH4	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
CO2	FCE x 1833	1778.01	SCE x 1833	1228.11
PM 10[1]	PM2.5 x 1.18	3.07272	PM2.5 x 1.18	26.71992
NOx[2]	3.2	3.2	0	0
SO2[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 PM10 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.