FuelCalc 1.8

USER GUIDE

August 2026

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Aug. 16, 2026

Preface

Ground, surface, and canopy fuel characteristics serve as essential inputs to computer models of fire behavior and fire effects. FuelCalc is a fuel characteristics simulation software program that calculates initial canopy fuel characteristics and quickly simulates the effects of thinning, pruning, piling and broadcast burning on ground, surface and canopy fuel characteristics. Consequently, FuelCalc is useful for planning fuel treatments, as well as for estimating the effects of wildfire on surface and canopy fuel characteristics. FuelCalc works by simulating changes in ground, surface, piled, and canopy fuel loads by size class as fuel treatments add to, or subtract from, the load in each class. Input files can be either created in the monitoring software tool FFI (FEAT/FIREMON Integrated; https://www.frames.gov/partner-sites/ffi/ffi-home) or by manually creating an input file in FuelCalc's standard format.

FuelCalc was developed for fire planners to:

- Calculate canopy fuel characteristics from an existing treelist; and
- Simulate the effects of fuel treatments and fire on ground (duff and other below surface fuel), surface, and canopy fuels.

Prerequisites

Before using FuelCalc, you should have a working knowledge of fuel characteristics, fuel treatments, and fire behavior. Because FuelCalc uses input files from FFI, some knowledge of how FFI generates output files will be useful. Many FuelCalc processes are based on the First Order Fire Effects Model (FOFEM) consequently, familiarity with FOFEM will increase the understanding of FuelCalc outputs. Likewise, familiarity with the BehavePlus fire behavior prediction system may increase an understanding of the algorithms used for calculating FuelCalc outputs.

Obtaining copies

Copies of FuelCalc and its associated user documents can be obtained on the FuelCalc homepage: https://research.fs.usda.gov/firelab/products/dataandtools/fuelcalc-canopy-fuel-calculator-and-model.

Credits

FuelCalc was conceived by Elizabeth Reinhardt and Joe Scott and initially funded through a grant from the Joint Fire Sciences Program. Additional financial support is provided by the U.S. Forest Service Fire and Aviation Management; U.S. Forest Service Research and Development, Rocky Mountain Research Station, Science Integration and Applications Program; the Fire, Fuel and Smoke Science Program; and the Fire Modeling Institute.

Stu Brittain is the primary software contractor. The FuelCalc User's Guide was originally written by Heather Heward, Duncan Lutes, Robert Keane, Joe Scott, and Larry Gangi, and was edited by Christine Frame. User Guide updates provided by Duncan Lutes.

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Citing FuelCalc and the FuelCalc User's Guide

Duncan Lutes. 2026. FuelCalc User's Guide (version 1.8). Available:
https://research.fs.usda.gov/firelab/products/dataandtools/fuelcalc-canopy-fuel-calculator-and-model

About the FuelCalc User's Guide

Before you begin

This user's guide describes the basic operation of FuelCalc and does not repeat instructions specific to other software related to FuelCalc: FOFEM, FFI, and BehavePlus (as well as Microsoft Windows in general). Instead, you are encouraged to refer to the help functions available with these programs should more detailed questions arise.

How to use this guide

By reading the entire user's guide, you will have complete knowledge of FuelCalc's function and operation. Additionally, this user's guide is organized so that you can either 1) learn to use FuelCalc by reviewing the guide and learning about each feature and tip, or 2) you can use the guide as a "quick reference" by simply navigating to the specific information in which you are interested (note that some information is repeated between sections so that sections are relatively self-contained). Wherever appropriate, screen captures are used to illustrate the steps required to complete a task.

Introduction to FuelCalc

FuelCalc is a software system for assisting local and regional fuel management planners and related resource specialists (silviculturists, for example) in designing and implementing fuel treatments in forest stands. The inherent spatial scale of FuelCalc is the plot or sample point (small group of integrated plots). As you will see later in this guide, FuelCalc inputs are provided to FuelCalc for each plot in a FuelCalc project. A FuelCalc project is simply a collection of data for one or more plots, plus information regarding associated fuel treatment scenarios and other FuelCalc settings. A project is commonly represented by all of the plots within a stand that is proposed for treatment. However, a project can also represent a collection of unrelated plots to be analyzed individually. Using meaningful codes to identify each plot in FuelCalc will allow the FuelCalc results to be analyzed in a number of ways. The number of plots allowed within a FuelCalc project is limited by computer resources; multiple projects may be necessary when dealing with more than 100 plots.

FuelCalc has two primary applications. First, FuelCalc is a tool to calculate current, or initial, canopy fuel characteristics at an inventory plot. The only input required for this application is a treelist—a listing of the characteristics of trees measured on a forest inventory plot. The required tree characteristics for use in FuelCalc include: tree species, diameter at breast height, tree height, crown base height, crown class (crown position), tree status, and the number of trees per acre represented by each tree in the treelist. These tree characteristics will be described in later sections.

Second, FuelCalc is a tool for simulating the effects of a fuel treatment—thinning, pruning, pile burning, and broadcast burning—on ground, surface and canopy fuel characteristics. In addition to the treelist inputs mentioned above, simulating the effects of a fuel treatment on canopy fuel characteristics requires a quantitative description of the treatment, including the type and intensity of thinning, the height of pruning, how much existing or activity fuel is to be piled, and the nature of a broadcast burn. Any combination of these four fuel management activities can be specified. In order to also simulate the effects of a fuel treatment on ground and surface fuel characteristics, FuelCalc requires a description of initial ground and surface fuel load, by size class. These initial ground and surface fuel inputs are described in later sections of this guide.

In addition to the primary functions mentioned above, FuelCalc also has ancillary functions that may be useful to fuel management planners and silviculturists. From the initial surface fuel loads and from the loads after simulation of a fuel treatment, FuelCalc suggests a surface fire behavior fuel model (FBFM) that may be appropriate for the situation. If the fuel treatment simulation includes a broadcast burn, FuelCalc estimates fuel consumption and smoke production. FuelCalc also calculates several summary characteristics based on the initial or simulated treelist that may be useful to the fuel treatment planner, silviculturist, or even wildlife biologist, including stand height, stem density, Stand Density Index (SDI), canopy cover, basal area, quadratic mean diameter, and quadratic mean diameter 75th percentile. Each of these stand measurements is described in later sections of this guide.

FuelCalc is not a temporal simulation system; it does not simulate the effects of forest growth, litterfall (deposition), and decomposition on surface or canopy fuel characteristics. The Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS; https://www.fs.usda.gov/managing-land/forest-management/fvs) is the best tool to use for that application. Although FuelCalc simulates tree mortality, fuel consumption, and emission production, it is not the best available tool for those tasks unless the simulation of thinning, pruning, or pile burning is also required. In cases where the simulation of thinning, pruning, and pile burning is not required , FOFEM is a better software system for simulating tree mortality and fuel consumption because it allows for more details and guidance for both inputs and outputs.

Installing FuelCalc

- Go to https://research.fs.usda.gov/firelab/products/dataandtools/fuelcalc-canopy-fuel-calculator-and-model and download the FuelCalc installation file.
- Double–click *Setup.exe* to initiate the installation.
- On the "Welcome to the FuelCalc Setup Wizard," click **Next.**
- Select a location for the installation of FuelCalc and click **Next.**
- Confirm the installation and click **Next.**
- When the installation is complete, click **Close.**

When upgrading to new FuelCalc versions

Save custom files before removing the previous version of FuelCalc:

- If you have created a custom *species.csv* file, copy it to the new FuelCalc folder. If you have installed FuelCalc in the default folder the file will have been saved here: C:\Users*username*\AppData\Local\FuelCalcx.x
- Copy any saved projects (FCD file extension), plot files (FFI extension) and tree files (TRE extension) that you want to keep in the new FuelCalc folder: C:\Users*username*\AppData\Local\FuelCalcx.x

The FuelCalc Interface

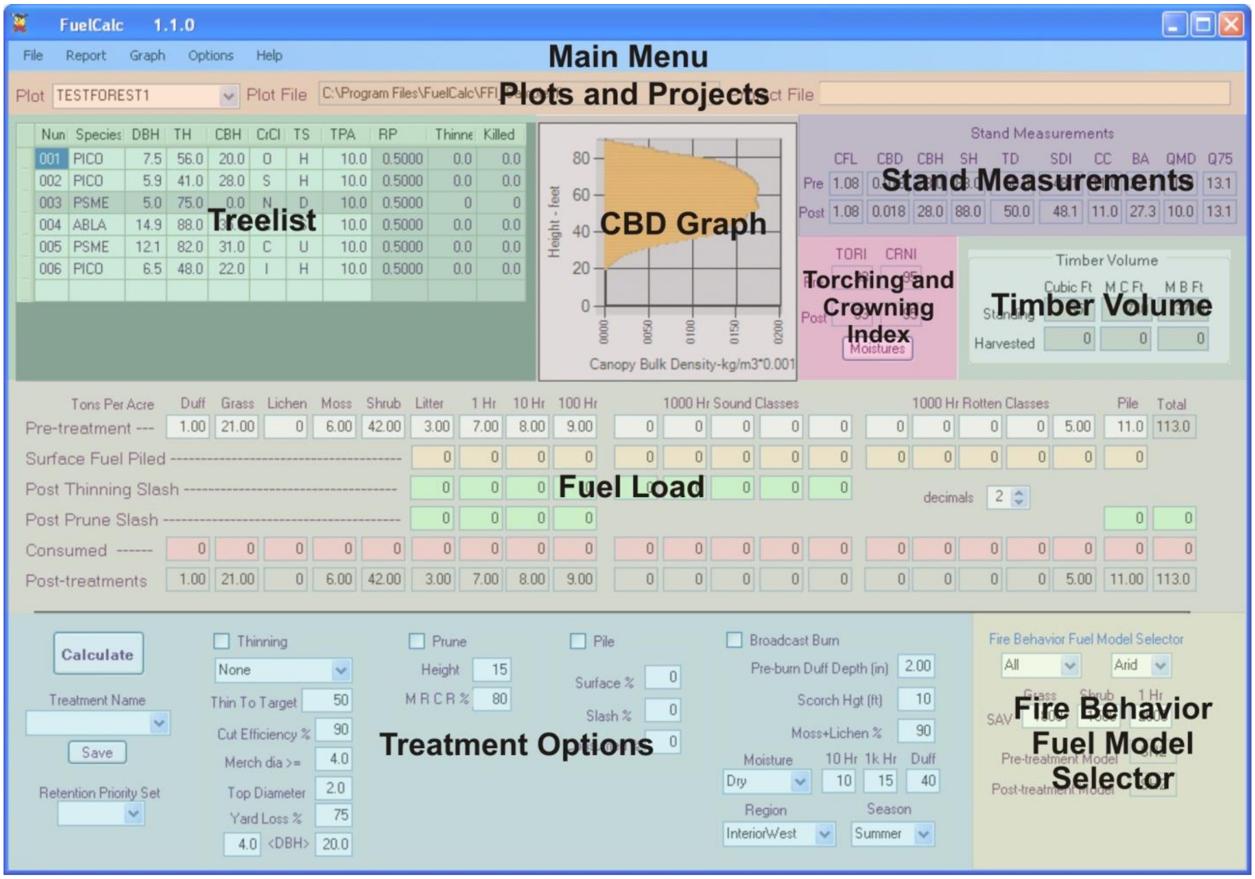


Figure 3-1: FuelCalc interface with labels to identify the sections of this guide where they are discussed.

> ***Note**: By hovering your mouse over many of the terms on the FuelCalc interface, a "tool-tip" will appear with a short description of the term including the units, if applicable. White colored fields can be edited. Other fields represent model outputs and cannot be changed.*

The main FuelCalc window is somewhat different than many other software applications in that all of the main input and output fields are contained within a single screen. This design allows you to quickly simulate fuel treatment effects over many alternative fuel treatments and among many sample plots.

The *Main Menu* allows you to open and save projects, input data, view reports, view and edit graphs, change FuelCalc options, and access the FuelCalc Help Utility.

The *Plots and Projects* section of the user interface allows you to select the plot you wish to view and shows you the folder location of the plot and project file.

The *Treelist* table displays the tree records for a plot in your input file and contains columns for *Thinned* and *Killed*, which become populated after treatment has been applied.

The *Canopy Bulk Density Graph* shows the CBD (kg m^{-3}) on the site pre-treatment (blue) and post-treatment (orange).

The *Stand Measurements* characterize pre- and post-treatment stand conditions for a plot. Pre-treatment measurements are calculated from the treelist by FuelCalc when a plot is initially selected; post-treatment measurements are calculated after treatment has been applied. The pre- and post-treatment measurements will be identical if a treatment is not applied.

Torching and crowning indices are displayed for assessing crown fire potential. Crown index is the 20-foot windspeed at which active crown fire is possible for the specified fire environment. Torching index is the 20-foot windspeed at which crown fire activity can initiate for the specified fire environment.

Timber Volume is expressed in 3 different units (that is, cubic feet, merchantable cubic feet, and merchantable board feet) and is displayed for both standing and harvested timber.

Fuel Loads are expressed as t ac^{-1}. Pre-treatment fuel loads are derived directly from the input file. Five post-treatment fuel load outputs are available, depending upon the treatment scenario selected (piled, thinning, pruning, post-burn, and post-treatment).

Treatment scenarios are developed by selecting *Treatment Options*. To activate the Thinning, Prune, Pile, and Broadcast burn treatments, simply check the box next to the title. If the box is unchecked, the treatment will not be applied to the stand when you click **Calculate.**

The *Fire Behavior Fuel Model Selector* identifies the pre- and post-treatment fire behavior fuel models (FBFM). You have the option to select either the Anderson (1982) or Scott & Burgan (2005) models, as well as filter the output by arid or humid models.

Main Menu

The FuelCalc Main Menu (Fig. 4-1) is where many features of the program are controlled, including opening and saving projects, importing input files, generating reports and graphs, setting FuelCalc options, and accessing help.

File menu

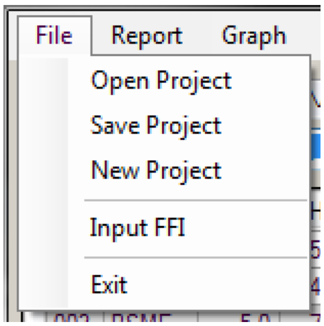


Figure 4-1: File drop-down menu

Open Project / Save Project

A FuelCalc project is simply a collection of data for one or more plots, plus information regarding associated fuel treatment scenarios and other FuelCalc settings. A project is commonly represented by all of the plots within a stand that is proposed for treatment. However, a project can also represent a collection of unrelated plots to be analyzed individually. Selecting **Save Project** will save the input data file assignment, the current state of any FuelCalc settings, including Treatments, Retention Priorities, Species Priorities (on the Settings page) and selections in the Treatment Options section of the user interface. The information is saved as an .fcp file. This file contains information on treatment and other settings, but not the input data itself. Instead, the .fcp file contains a link to any input files used for the project. By saving your project, you can return to your work by clicking on **Open Project**.

FFI (FEAT/FIREMON Integrated) Input

The ecological monitoring program FFI allows export of tree and fuels data that can be imported into FuelCalc. In FFI, the FuelCalc input files can be created by on the **Reports and Analysis** navigation bar. On the **Settings** tab users determine which macro plots and monitoring statuses to include in the file and then export the data on the **FuelCalc/FOFEM Export** tab (Figure 4-2).

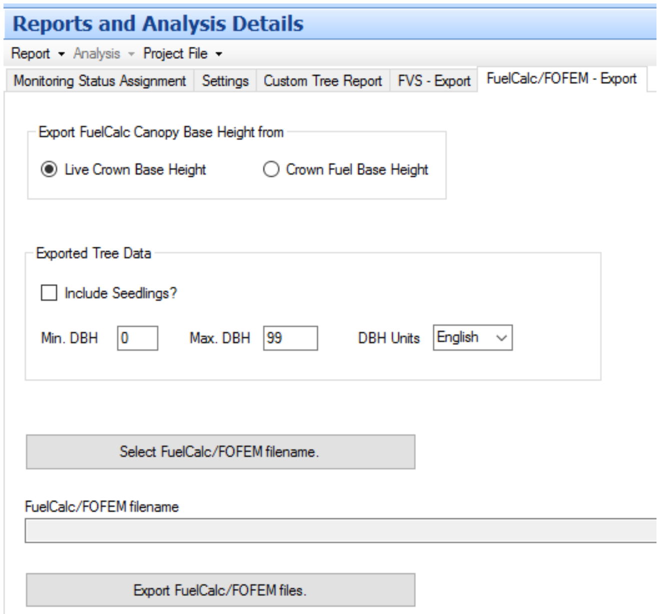


Figure 4-2: The FuelCalc/FOFEM export option in FFI.

The FFI export utility creates two file types: .ffi and .tre. The .ffi file includes summarized ground and surface fuel data. The .tre file includes tree records for the selected plots. The same prefix is used for both files (for example, Plot 1.ffi and Plot 1.tre). Files can be saved in any folder. Initially, FuelCalc will look for files in the ***C:\Users*\username*AppData\Local\FuelCalc folder***.

Field names, descriptions, and data sources for information in the .ffi file can be found in *Appendix A.* Data are exported from both the English and metric data collection protocols in FFI. Data from metric protocols are converted to English units for import to FuelCalc.

The FFI .tre file includes data from the FFI Trees data collection protocol or the Trees – Individual, Trees – Saplings, and/or Trees – Seedlings protocols. The field names and descriptions for a .tre file are listed in *Appendix A*.

FuelCalc contains a sample .ffi file with installation so that you can explore the FuelCalc interface and functions before creating an input file of your own. By selecting **File > Input FFI**, the *Select FFI Plot Input* dialog box will automatically open to the location of the .ffi file.

Exit

Select **File > Exit** from the main menu to exit the FuelCalc program. FuelCalc will prompt you to confirm that you want to exit the program and will also prompt you to save your settings as a project before exiting, even if you have just done so. Clicking on the "close" button in the upper right had corner of the FuelCalc window will close FuelCalc without properly exiting; you will not be offered the opportunity to save your work.

Report menu

FuelCalc reports display the information presented on the main FuelCalc window in a format that is easy to print or save. The reports do not contain information on the treatments used to create the potential site conditions. You can view the Plot and/or Tree Report. The Tree Report includes only trees from the active plot displayed on the main FuelCalc window. To see tree reports from other plots, use the plot drop-down menu to select a new plot and then run the Tree Report again. Plot and tree data can also be exported in CSV format.

Graph menu

FuelCalc generates several graphs for the fuel stand and a graph for the emissions if broadcast burning is selected as a treatment. The fuel stand graphs clearly display the pre-treatment, post thinning/pruning, post piling, and post burn for litter and down woody material. The percent removed is displayed in pie charts for the stand measurements and the timber volume; a stand watch is also available, which allows for the comparison of the pre-treatment conditions of a selected stand measurement to several post-treatment scenarios. The emissions graph displays the predicted amount of emissions during the flaming and smoldering phase of a broadcast burn. These graphs can be used in reports and for comparisons between treatments and plots. See the *Graph* section for more detailed information on the FuelCalc graphs.

Options menu

The *Options* menu is where the FuelCalc settings can be adjusted, the plot summaries can be created and displayed, the equations table can be displayed, and the display of the FuelCalc can be adjusted. The *Settings* option allows the user to create and save different treatments and to specify the desired retention priority for the plot. Plot summaries can then be created as a way to store, transfer, and display the results of the FuelCalc calculations. The *Equations Table* displays the fuel component biomass scientific reference for the tree species that are recognized by FuelCalc. The *Color Setting* and *Show Fuel Model* checkboxes are used to adjust the display of the main FuelCalc window. For more detailed information on the options menu, go to *Options*.

Help menu

This *Help* utility contains the information presented in this User's Guide but is embedded within the tool and includes an associated search function.

Plots and Project Files

The plots and project files section of the main FuelCalc window consists of three items: a *Plot* drop-down list, a text box indicating the name and location of the plot file and a text box indicating the name and location of the project file (Fig. 5-1).

Figure 5-1: *Plot, Plot File,* and *Project File* menus located at the top of the main FuelCalc window.

Plot

In the *Plot* drop-down menu, you can select the plot to display and treat according to the selected treatment scenario. These plots were specified in the project or from the FFI inputs. After you have finished with one plot, another plot can be selected and the treatment specifications will stay the same so that you can see how that same treatment affects other plots. In other words, treatments will be applied to all of the plots in the input file.

Plot file

The *Plot File* field of the user interface identifies the pathway to the input data. The *Plot File* field on the main window is present so that you can quickly determine the name of the input file to which the data on the main window correspond.

Project file

The *Project File* field of the user interface displays the path to and name of the project file. This field remains blank until a project is saved.

Treelist

The Treelist (Fig. 6-1) identifies all of the trees on a plot by each individual tree, or groups of similar trees. Each tree or group of trees is attributed by species, height, diameter at breast height (DBH), crown base height, canopy class, tree status, and tree density (Table 6-1). For example, in the main FuelCalc window, one record (which is a row) in the treelist can be one tree with a unique set of characteristics (DBH, HT, CBD), or it can be multiple trees all of which have those characteristics. Multiple trees within a group are specified using the tree density field (see TPA on the main window). The retention priority column is used to display the current retention priority for the individual trees and the columns for Thinned and Killed are outputs that are populated after a treatment has been performed. All outputs from FuelCalc are reported at the plot level, but are summarized on a per area (acre-1) basis.

A Treelist is created using the .tre file format (and associated .ffi file) as shown in *Appendix A* or can be exported out of the FFI application. It is possible to manually edit records in the Treelist; however, you cannot add new records. Modifications made in the tree grid will not be saved in the .tre file. For permanent changes modify the .tre file, instead.

Tree records can be temporality removed from calculations by clicking the small rectangular area to the left of the row, to highlight the row, and clicking the Calculate button. Use Control-Click to select multiple rows. To restore calculation to the entire treelist, click anywhere in the tree grid to un-highlight rows and click the Calculate button.

> ***Tip:*** *Treelist records can be sorted in ascending or descending order by clicking on the following field headings: Tree Number (Num), Species, Crown Class (CrCl), and Tree Status (TS).*

Nun	Species	DBH	TH	CBH	CrCl	TS	TPA	RP	Thinne	Killed
001	PICO	7.5	56.0	20.0	O	H	10.0	0.5000	9.0	0.0
002	PICO	5.9	41.0	28.0	S	H	10.0	0.5000	9.0	0.0
003	PSME	5.0	75.0	0.0	N	D	10.0	0.5000	0	0
004	ABLA	14.9	88.0	35.0	C	S	10.0	0.5000	6.1	1.0
005	PSME	12.1	82.0	31.0	C	U	10.0	0.5000	0.0	1.0
006	PICO	6.5	48.0	22.0	I	H	10.0	0.5000	0.0	3.0

Figure 6-1: Treelist variables and units. Rows that are grayed out, such as dead trees, will not be included in any calculations.

Table 6-1: *Treelist* table on the main FuelCalc window.

Treelist input	Description	Native units
Number	Row number	number
Species	Species code	NRCS code
DBH	Diameter breast height	inches
TH	Tree height	feet
CBH	Canopy base height	feet
CrCl	Crown class	category
TS	Tree status	category
TPA	Tree density	stems per acre
RP	Retention priority	number
Thinned	Trees removed by thinning	stems per acre
Killed	Trees removed by fire	stems per acre

Num

This is an integer value row identifier.

Species (Tree Species)

FuelCalc species codes are 4- to 6-character alphanumeric codes developed by the Natural Resource Conservation Service (NRCS; http://plants.usda.gov/java/). FuelCalc uses a subset of the NRCS codes to assign crown and bole biomass for each tree record in the Treelist. If a project includes a tree species code that has not been assigned crown and bole biomass equations, FuelCalc will display an error when the Calculate button is clicked. Species codes available in FuelCalc are shown in the file named *sample-species.csv* in the in the application installation folder (default is here: *C:\Users*\username*\AppData\Local\FuelCalc)*. To create a sample species select **Options>Equation Table** and click the button to create a Sample Species File. See *Appendix C* for more information about editing sample-species.csv.

DBH (Diameter at Breast Height)

Diameter at Breast Height (DBH) refers to the outside-bark diameter, in inches, of the tree measured 4.5 feet above the forest floor on the uphill side of the tree. Tree DBH is used to estimate a tree's crown biomass, which is subsequently used to estimate canopy fuel characteristics. For trees less than 4.5 feet tall set DBH=0.1 inches.

TH (Tree Height)

Tree Height (TH) refers to the vertical distance, in feet, from the ground to the top of the tree stem. Tree height is used to distribute biomass vertically along each tree's crown length, and, in conjunction with the height of other trees on the plot, to determine a plot's overall stand height.

CBH (Crown Base Height)

Crown Base Height (CBH) refers to the vertical distance, in feet, from the ground to the lowest height above the ground where an individual tree contains enough available fuel to propagate fire vertically through its crown. This definition includes any ladder fuel, such as needle drape or moss, associated with the tree. As with tree height, Crown Base Height is used to distribute biomass along a tree's crown length.

CrCl (Crown Class)

Crown Class (CrCl) refers to the crown position of each tree. Crown Class is used to adjust the estimated biomass for each tree and to prioritize trees for removal. The available crown classes are:

> <u>D – Dominant</u> - A tree whose crown extends above the general level of the main canopy of even-aged stands or, in uneven-aged stands, above the crowns of the tree's immediate neighbors and receiving full light from above and partial light from the sides (SAF 2008).
> <u>C – Co-dominant</u> - A tree whose crown helps to form the general level of the main canopy in even-aged stands or, in uneven-aged stands, the main canopy of the tree's immediate neighbors, receiving full light from above and comparatively little from the sides (SAF 2008).
> <u>I – Intermediate</u> - A tree whose crown extends into the lower portion of the main canopy of even-aged stands or, in uneven-aged stands, into the lower portion of the canopy formed by the tree's immediate neighbors, but shorter in height than the co-dominants and receiving little direct light from above and none from the sides (SAF 2008).
> <u>E – Emergent *</u> - A tree whose crown is completely above the general level of the main canopy, receiving full light from above and from all sides (SAF 2008).
> <u>S – Suppressed</u> - A tree whose crown is completely overtopped by the crowns of one or more neighboring trees; note that the vigor of overtopped (suppressed) trees varies from high to low depending on individual circumstances (SAF 2008).
> <u>O – Open Grown *</u> - Tree crown receives full sunlight from above and all sides (ECODATA 1987).
> <u>N – None/Unknown</u>

*These classes are not included in .ffi input files (See *Appendix A* for more information). See *Appendix D* for more information on the canopy reduction factors used in FuelCalc.

TS (Tree Status)

Tree Status (TS) refers to the health of the tree stem in the Treelist. This variable is used to prioritize trees for removal during a thinning. The four possible tree health status categories are:

> <u>H – Healthy</u> - Tree with very little biotic or abiotic damage (Lutes and others 2006).
> <u>U – Unhealthy</u> - Tree with some biotic or abiotic damage, and this damage will reduce growth. However, it appears the tree will fully recover from this damage (Lutes and others 2006).
> <u>S – Sick</u> - Tree with extensive biotic or abiotic damage, and this damage will ultimately cause death within the next 5-10 years (Lutes and others 2006).
> <u>D – Dead</u> - Tree with no observable living tissue (Lutes and others 2006). Dead tree records appear as gray rows in the Treelist and are not included in any calculations.

TPA (Trees per Acre)

Trees per Acre (TPA) refers to tree density of the Treelist record or the number of trees per acre represented by the tree record. FuelCalc uses this input to weight the contribution of each tree record in summarizing plot-level characteristics. For example, if two healthy whitebark pine trees of 10 inches DBH, 50 feet tall, and having codominant crowns 10 feet high were sampled on a 0.1-acre plot, then the number 20 would be entered for TPA.

RP (Retention Priority)

The *Retention Priority* (RP) column displays the retention priority value calculated from the *Options > Settings* window. Retention priority can be set between 0.1 and 1.0. Trees with low retention priority are removed first. There are also two special codes. Trees with retention priority of 0.0 will always be removed and trees with retention priority of 99 will always be retained. A complete description of retention priority with examples can be found in *Retention Priority Factors* in the *<u>Options</u>* section.

Thinned

The *Thinned* column displays the number of trees per acre that were removed from the plot during the thinning treatment; this is not affected by the broadcast burn treatment (that is, trees not selected for thinning can be killed by prescribed burning). More information on how thinning treatments work in FuelCalc can be found in the *<u>Thinning</u>* section.

Killed

The *Killed* column displays the number of trees per acre that were simulated to die during the broadcast burn treatment as specified in the Treatment Inputs; this number does not include any thinned trees. Fire-caused tree mortality simulated in FuelCalc is a function of species, crown scorch, and tree diameter. Mortality equations and other tree mortality algorithms and parameters were taken from the FOFEM computer model, thus their details are provided in the FOFEM User's Guide (Reinhardt and others 1997).

Canopy Bulk Density Graph

The Canopy Bulk Density (CBD) graph (Fig. 7-1) is a vertical profile of canopy bulk density (see *Canopy Bulk Density*) in kilograms per cubic meter (kg m^{-3}). Pre-treatment stand conditions are shown in blue and post-treatment stand conditions are shown in orange.

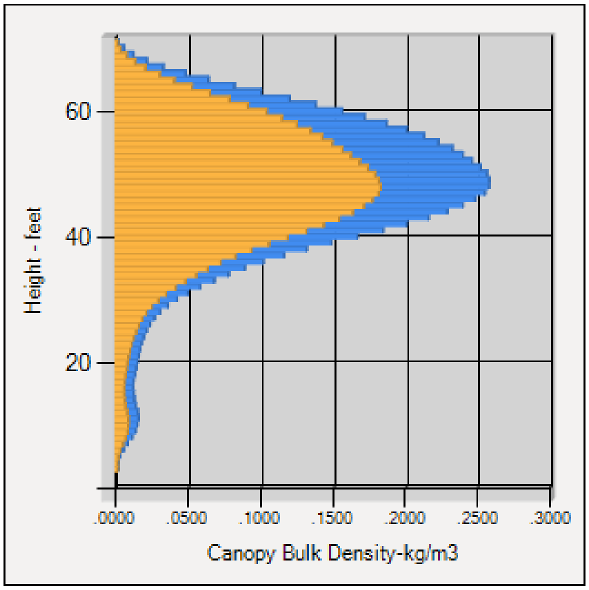


Figure 7-1: *Canopy Bulk Density* graph.

> ***Note:*** *CBD is the only value in FuelCalc displayed in metric units; this is done to follow standard practice in fire behavior modeling systems. All other values in FuelCalc are displayed in English units.*

Stand Measurements

Pre-treatment stand measurements (Fig. 8-1) are calculated from the information entered in the initial Treelist and will remain constant throughout the treatment process. Post-treatment stand measurements are re-calculated after each treatment application and are based on the initial Treelist and the treatment options selected (Table 8-1).

Stand Measurements

	CFL	CBD	CBH	SH	TD	SDI	CC	BA	QMD	Q75
Pre	1.08	0.018	28.0	88.0	50.0	48.1	11.0	27.3	10.0	13.1
Post	0.46	0.008	29.0	84.0	16.6	16.9	5.37	9.53	10.2	12.4

Figure 8-1: *Stand Measurements* table.

Table 8-1: Table of stand characteristics and native units in the stand measurements table.

Characteristic	Description	Units
CFL	Canopy Fuel	t ac^{-1}
CBD	Canopy Bulk Density	Kg m^{-3}
CBH	Canopy Base Height	feet
CSH	Canopy Stand Height	feet
TD	Tree Density	trees/acre
SDI	Stand Density Index	number
CC	Canopy Cover	percent
BA	Basal Area	ft^2 ac^{-1}
QMD	Quadratic Mean Diameter	inches
Q75	Quadratic Mean Diameter (75th Percentile)	inches

***Note:** By default, hardwood trees input to FuelCalc are not considered in canopy fuel calculations (CFL, CBD, CBH, and SH) since in most cases they do not contribute significantly to crown fire activity. For the instances where this is not the case, the species file can be changed to include hardwood trees in the calculation of canopy fuels by following the directions in Appendix C.*

CFL - Canopy Fuel Load

The plot-level available Canopy Fuel Load (CFL) is the sum-product of available adjusted crown fuel mass and trees per acre for every tree in the Treelist. Available adjusted crown fuel mass includes the load of all of the tree foliage and 50 percent of the tree's twig (0- ¼ inch) branch material adjusted for crown class (Scott and Reinhardt 2001).

CBD - Canopy Bulk Density

Canopy Bulk Density (CBD) refers to the mass of CFL per unit canopy volume (Scott and Reinhardt 2001) in kilograms per cubic meter.

FuelCalc estimates an effective plot-level CBD as the maximum 5-meter running average CBD that occurs in the profile.

CBH - Canopy Base Height

FuelCalc calculates Canopy Base Height (CBH) as the lowest height above the ground at which CBD is greater than or equal to a calculated Threshold CBD. The maximum Threshold CBD used is 0.012 kg m^{-3}, which works well in most situations. However, this threshold value is not ideal in stands with low CBD (for example, in stands that have been extensively thinned or in a naturally open stands). We addressed this issue in FuelCalc by calculating Threshold CBD as the maximum stand-level CBD * 0.1 for CBD values up to 0.12 kg m^{-3}. Using this approach, the Threshold CBD for determining CBH is equal to 1/10th the CBD up 0.12 kg m^{-3}, after which the Threshold CBD is held at the maximum: 0.012 kg m^{-3} (Fig. 8-2).

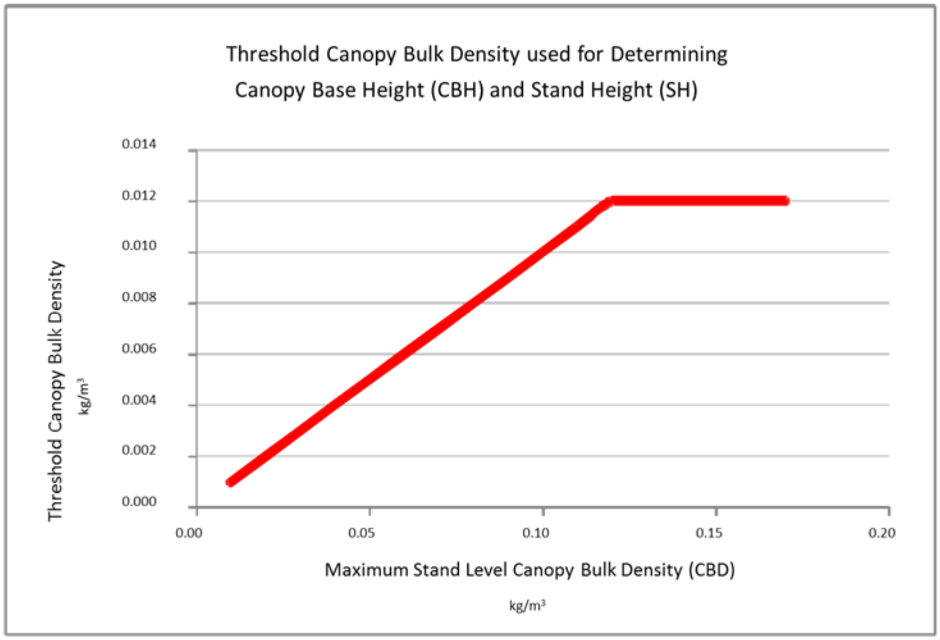


Figure 8-2: Threshold Canopy Bulk Density used for determining canopy base height and stand height.

SH - Stand Height

FuelCalc calculates plot-level stand height as the maximum height where calculated CBD exceeds the same Threshold CBD value used for determining CBH. Double-clicking the CBH or SH value in the *Stand Measurements* table will display the CBD Threshold value (Fig. 8-3).

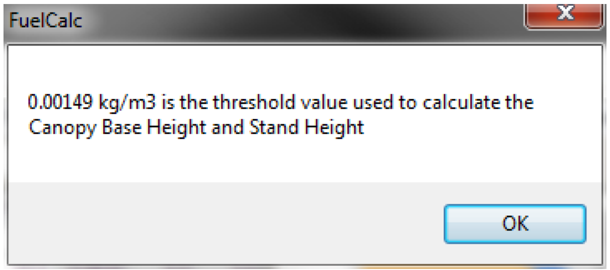


Figure 8-3: This box will appear when the CBH or SH fields are double-clicked. It displays the threshold value used to calculate CBH and SH**.**

TD - Tree Density

Tree Density (TD) refers to the number of trees per acre on the plot. It is calculated as the sum of the TPA values for each tree record in the *Treelist*. All live trees, regardless of diameter, are included in this measure.

***Tip:** If there is a tree record that you wish to exclude from the calculations, highlight the row(s) in the treelist of the record you wish to exclude and click **Calculate**. The selected tree records will be excluded in any stand measurement and timber volume calculations, nor will they be included in or affected by treatments (Fig. 8-4).*

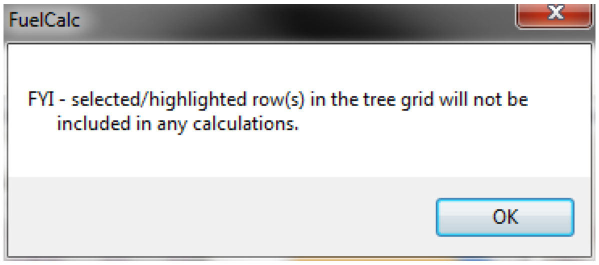


Figure 8-4: This dialog box will appear when a tree record is excluded from the calculations.

SDI - Stand Density Index

Stand Density Index (SDI; Reineke 1933) is a measure of stand density that combines stem density and Quadratic Mean Diameter (QMD). SDI represents the density of trees per unit area that an even-aged stand would have at a standard average DBH (25 cm).

CC - Canopy Cover

Canopy Cover (CC) refers to the non-overlapping fraction of the vertical projection of tree crowns that cover the plot.

BA - Basal Area

Basal Area (BA) represents the outside-bark cross-sectional area per acre of live tree stems, measured 4.5 feet above the ground.

QMD - Quadratic Mean Diameter

Quadratic Mean Diameter (QMD) is the square root of the arithmetic mean of the squares of the tree diameters on a plot (the root-mean-square diameter).

Q75 - Quadratic Mean Diameter 75th Percentile

Quadratic Mean Diameter 75th Percentile (Q75) refers to the QMD of trees in the largest 75th percentile by basal area.

Torching and Crowning Indices

Torching index is the 20-foot windspeed at which crown fire activity can initiate for the specified fire environment. It is a function of surface fuel loading and composition, surface fuel moisture, canopy base height, slope and wind reduction due to canopy. Crowning index is the 20-foot windspeed at which active crown fire is possible for the specified fire environment. It is a function of canopy bulk density, surface fuel moisture and slope. The indices can be used as a measure of potential fire behavior where fuel treatments that increase torching index and crowning index indicate reduced probability of crown fire activity. Maximum wind speed displayed for either index is 100 MPH. The torching and crowning index section of the user interface is shown in Figure 8.5.

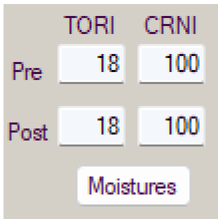


Figure 8.5: Pre-treatment and post-treatment torching and crowning index are displayed on the user interface. Clicking the *Moistures* button will display the moisture values used in Nexus for the calculation of the values.

FuelCalc links directly to an embedded copy of Nexus (Scott 1999) to calculate crowning and torching index. FuelCalc produces a custom fire behavior fuel model that includes fuel loading of 1-hr, 10-hr, 100-hr litter, shrub and herbaceous biomass; surface area to volume ratios for 1-hr, herb and shrub; fuelbed depth; dead fuel moisture and heat content. Fuel load and surface area to volume ratios come directly from the FuelCalc user interface. Dead fuel moisture of extinction and heat content are set to 25% and 8000 BTU lb^{-1}, respectively. Fuelbed depth is calculated using the equations presented in *Appendix **B***.

Nexus requires percent moisture inputs (gravimetric) for 1-hr, 10-hr, 100-hr, live herb, live shrub and foliage. In FuelCalc these moisture settings are linked to the moisture regime set on the user interface (Figure 8.6). Table 8.5 displays the relationship of FuelCalc moisture regime and the fuel moisture used in Nexus.

Figure 8.6: The FuelCalc moisture regime field.

Table 8.5. Relationship of moisture regime set on the FuelCalc interface and the percent moisture values used to calculate torching and crowning index in Nexus.

	Percent Moisture used in Nexus					
Moisture Regime	**1-hr**	**10-hr**	**100-hr**	**Live Herb**	**Live Shrub**	**Foliar[5]**
Very Dry[1]	3	4	5	30	60	100
Dry[2]	6	7	8	60	90	100
Moderate[3]	9	10	11	90	120	100
Wet[4]	12	13	14	120	120	100

[1] Dead fuel moisture = D1 and live fuel moisture = L1; in Scott and Burgan 2005
[2] Dead fuel moisture = D2 and live fuel moisture = L2; in Scott and Burgan 2005
[3] Dead fuel moisture = D3 and live fuel moisture = L3; in Scott and Burgan 2005
[4] Dead fuel moisture = D4 and live fuel moisture = L4; in Scott and Burgan 2005
[5] Nexus suggested default

The user may modify the moisture settings for 10-hr, 1000-hr and duff on the user interface to any percent moisture desired and these changes will modify the fire effects simulated in FuelCalc; however, the percent moisture for components used simulate fire behavior in Nexus and shown in table 5.8 are always linked to the moisture regime setting (Very Dry, Dry, Moderate, Wet). To see the moisture values used to calculate torching and crowning index click the *Moistures* button (Figure 8.5).

Timber Volume

In FuelCalc, all of the timber volumes (Fig. 9-1) are calculated using the National Volume Estimator Library (NVEL; https://www.fs.usda.gov/managing-land/forest-management/products/measurement/volume-estimation). FuelCalc uses general species-specific equations so consider the volume estimates approximate values. Volume of only live trees is included in the Timber Volume table.

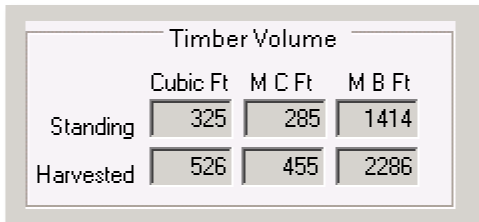


Figure 9-1: *Timber Volume* table.

Cubic Ft

Cubic Feet (Standing and Harvested) refers to the total woody bole volume of all live trees on the plot and is measured in cubic feet per acre. Harvested values are calculated after a thinning treatment has been applied.

M C Ft

Merchantable Cubic Feet (M C Ft) refers to the merchantable volume of standing or harvested timber on the plot measured in cubic feet per acre. Merchantable volume is less than total volume because small trees and tree tops are not merchantable. The FuelCalc estimate of merchantable volume does not include trees less than the critical tree height used in the volume library (typically 5 feet) or any reduction for stem defects.

M B Ft

Merchantable Board Feet (M B Ft) represents the merchantable board-foot volume of standing or harvested timber on the plot measured in board feet per acre. The FuelCalc estimate of merchantable volume does not include trees less than critical tree height used in the volume library (typically 5 feet) or any reduction for stem defects.

Fuel Loads

Pre-treatment Fuel Load

Pre-treatment fuel loadings are derived directly from the plot input file (Fig. 10-1). These amounts can also be edited by typing directly into the text box, which is useful for seeing how pre-treatment values can influence post-treatment conditions. Edited values, however, will not be saved in the project file or stored back to the input file.

Tons Per Acre	Duff	Grass	Lichen	Moss	Shrub	Litter	1 Hr	10 Hr	100 Hr	1000 Hr Sound Classes					1000 Hr Rotten Classes					Pile	Total
Pre-treatment ---	1.00	21.00	0	6.00	42.00	3.00	7.00	8.00	9.00	0	0	0	0	0	0	0	0	0	5.00	11	113.0

Figure 10-1: *Fuel Load* table, *Pre-treatment* row. All loadings are in tons per acre.

<u>Duff</u> –The layer of decomposing organic materials lying below the litter layer of freshly fallen twigs, needles, and leaves and immediately above the mineral soil (NWCG Online Glossary).

<u>Herb</u> – Any of a large family of monocotyledonous; mostly herbaceous plants with jointed stems, slender sheathing leaves, and flowers borne in spikelets of bracts (Merriam Webster).

<u>Lichen</u> – Any of numerous complex plantlike organisms made up of an alga and a fungus growing in symbiotic association on a solid surface (such as a rock) (Merriam Webster).

<u>Moss</u> – Any of a class (Musci) of bryophytic plants characterized by a gametophyte having a small leafy often tufted stem bearing sex organs at its tip; also: a clump or sward of these plants (Merriam Webster).

<u>Shrub</u> – A woody perennial plant differing from a perennial herb by its persistent and woody stem and differing from a tree by its low stature and habit of branching from the base (NWCG Online Glossary).

<u>Litter</u> – The top layer of forest floor, composed of loose debris of dead sticks, branches, twigs, and recently fallen leaves or needles; little altered in structure by decomposition (NWCG Online Glossary).

<u>1-hr</u> – Dead fuels consisting of dead herbaceous plant material and roundwood less than 0.25 inches in diameter estimated to reach 63 percent of equilibrium moisture content in 1 hour or less (NWCG 1994).

<u>10-hr</u> – Dead fuels consisting of roundwood 0.25 to 1.0 inches in diameter estimated to reach 63 percent of equilibrium moisture in 10 hours (NWCG 1994).

<u>100-hr</u> – Dead fuels consisting of roundwood in the size range from 1.0 to 3.0 inches in diameter estimated to reach 63 percent of equilibrium in 100 hours (NWCG 1994).

<u>1000-hr</u> – Dead fuels consisting of roundwood 3.0 to 8.0 inches in diameter estimated to reach 63 percent equilibrium moisture content in 1000 hours (NWCG 1994).

<u>Sound down woody fuel</u> – Woody material that is still mostly intact and relatively difficult to break apart. Sound woody material has higher wood density than rotten woody material of the same species (Brown 1974).

<u>Rotten down woody fuel</u> – Woody material that is not intact or is easily broken apart. Rotten woody material has lower wood density than rotten woody material of the same species (Brown 1974).

Pile

Pile represents the load of any piled fuels that may exist on the plot before treatment. If you have created your own input file and have not included information on pile loading, there will be no value here. You can manually enter and change this value, but your change will not be saved to your input file.

Total

Total refers to the total of all fuel loading, including the piled amount.

Surface Fuel Piled

Fuel loading of the individual components is calculated based on percentages entered in the *Pile* treatment area (Fig. 10-2) and include fuels from: 1) the *Pre-treatment* row (piled using *Surface %*) and 2) *Post Thinning Slash* row and *Post Prune Slash* row (piled using *Slash %*).

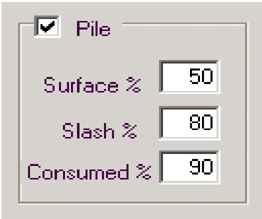
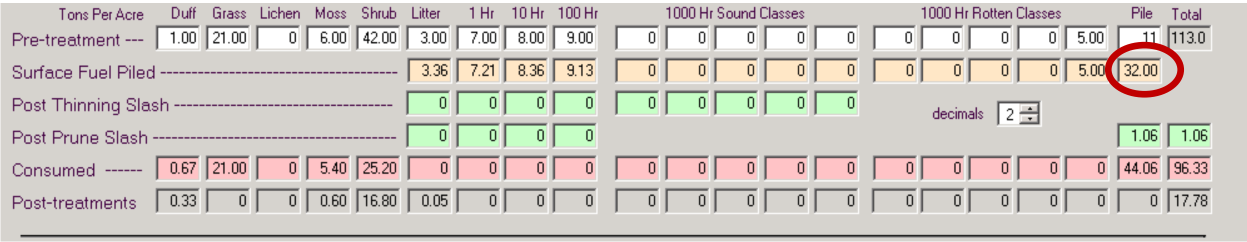


Figure 10-2: Pile treatment options. In this example, 50% of the pre-treatment surface fuel and 80% of the activity or slash fuel is piled, and 90% of the pile is consumed.

The litter, 1-hr, 10-hr, 100-hr, and 1000-hr fields of the *Surface Fuel Piled* row (Fig. 10-3) show the load of the individual piled fuel components. The last field in the row displays ONLY the total load of piled surface fuels and does not include post thinning and post pruning slash.

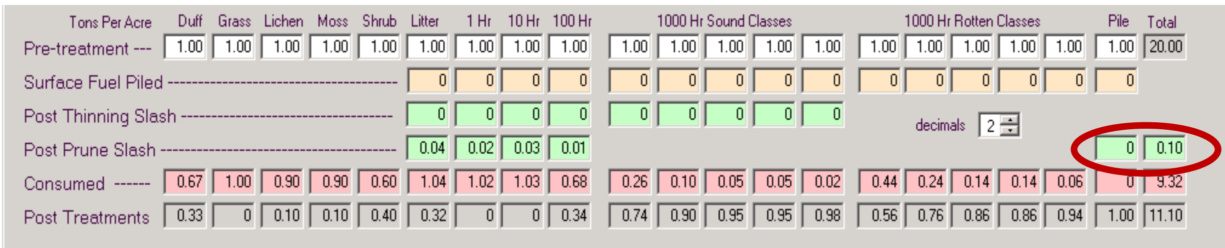


Tons Per Acre	Duff	Grass	Lichen	Moss	Shrub	Litter	1 Hr	10 Hr	100 Hr	1000 Hr Sound Classes					1000 Hr Rotten Classes					Pile	Total
Pre-treatment ---	1.00	21.00	0	6.00	42.00	3.00	7.00	8.00	9.00	0	0	0	0	0	0	0	0	0	5.00	11	113.0
Surface Fuel Piled ----------						3.36	7.21	8.36	9.13	0	0	0	0	0	0	0	0	0	5.00	32.00	
Post Thinning Slash ----------						0	0	0	0	0	0	0	0	0							
Post Prune Slash ----------						0	0	0	0											1.06	1.06
Consumed ------	0.67	21.00	0	5.40	25.20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44.06	96.33
Post-treatments	0.33	0	0	0.60	16.80	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17.78

decimals 2

Figure 10-3: *Fuel Load* table; circled are the sum of all existing ground fuels that are piled.

The total load of piled thinning and pruning slash is included in the *Pile* column of the *Post Prune Slash* row (Fig. 10-4). The field in the *Total* column displays the total thinning and pruning slash and includes piled and un-piled slash.



Tons Per Acre	Duff	Grass	Lichen	Moss	Shrub	Litter	1 Hr	10 Hr	100 Hr	1000 Hr Sound Classes					1000 Hr Rotten Classes					Pile	Total
Pre-treatment ---	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	20.00
Surface Fuel Piled ------------------------------------						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Post Thinning Slash ----------------------------------						0	0	0	0	0	0	0	0	0							
Post Prune Slash -------------------------------------						0.04	0.02	0.03	0.01											0	0.10
Consumed ------	0.67	1.00	0.90	0.90	0.60	1.04	1.02	1.03	0.68	0.26	0.10	0.05	0.05	0.02	0.44	0.24	0.14	0.14	0.06	0	9.32
Post Treatments	0.33	0	0.10	0.10	0.40	0.32	0	0	0.34	0.74	0.90	0.95	0.95	0.98	0.56	0.76	0.86	0.86	0.94	1.00	11.10

Figure 10-4: *Fuel Load* table; circled are the total slash piled and the total slash created for both thinning and pruning.

Post Thinning Slash

The amounts in the *Post Thinning Slash* row represent any slash that is created from a thinning simulation in tons per acre, not including the material removed and put in piles. Any piled amounts are added to the above corresponding fields in *Surface Fuel Piled* row.

Post Prune Slash

The amounts in the *Post Prune Slash* row represent any slash that is created from a pruning operation in tons per acre not including any piled amounts, which are added to the above corresponding fields in the *Surface Fuel Piled* row.

Consumed

The amounts in the *Consumed* row of the Fuel Loads section are the individual and total fuel loads in tons per acre that are consumed during a broadcast burn treatment. Calculations are based on algorithms in FOFEM (Reinhardt and others, 1997). Percent piled fuel loading consumed is set in the *Pile* treatment area as described in the Pile section.

Post Treatment

The *Post Treatment* row contains the remaining fuel loads after all treatments have been applied. See Table 11-1 for specific effects of each of the treatments on the different fuel loading inputs

> ***Note:*** *The Litter amount includes scorched foliage that is expected to fall within 1-year post-fire from any trees damaged in a broadcast burn.*

Treatment Options

The effects of fuel treatments on surface and canopy fuels are calculated using the surface fuel load information you entered, and the canopy fuel characteristics calculated by FuelCalc using the Treelist. This section describes the process used to define and simulate fuel treatments in FuelCalc.

In FuelCalc, a fuel treatment is an ordered, sequential regime of fuel management actions. The actions that FuelCalc simulates are in order:

Thinning – Cutting or harvesting procedure that reduces stand density (Smith 1986).

Pruning – Procedure that remove only tree branches (Smith 1986).

Piling and burning – Manual or mechanical piling of slash resulting from logging or fuel management activities and subsequent burning the individual piles (NWCG Glossary).

Broadcast burning – Prescribed burning activity where fire is applied generally to most or all of an area within well-defined boundaries for reduction of fuel hazard, as a resource management treatment, or both (NWCG Glossary).

To activate the Thinning, Prune, Pile, and Broadcast burn treatments, simply check the box next to the title. If the box is unchecked, the treatment will not be applied to the stand when you click **Calculate.** The rare cases in which a different order would produce a different result cannot be simulated. The following sections describe how the characteristics of each treatment action are applied. The initial plot condition (also called pre-treatment or untreated) is simulated by unchecking the box next to each of the treatment options. The potential effects that the four different treatments could have on fuel or biomass components are shown in Table 11-1 and summarized in the bulleted list that follows.

Table 11-1: The potential effects of thinning, pruning, piling, pile burning, and broadcast burning on fuel loadings. The "+" sign means that the fuel/biomass component will be positively affected or increase after a treatment. The "-" symbol means that the fuel/biomass component will be negatively affected or decrease after a treatment.

Fuel / biomass component	Thinning	Pruning	Piling	Pile burning	Broadcast burning
Duff					-
Herb					-
Lichen					-
Moss					-
Shrub					-
Litter	+	+	-		+ / -
1-hr	+	+	-		-
10-hr	+	+	-		-
100-hr	+	+	-		-
1000-hr (sound)	+		-		-
1000-hr (rotten)			-		-
Piled fuel			+	-	

- *Duff* consumption is affected only by the moisture scenario, region, and season of broadcast burn, which reduces duff load by burning across the plot.
- *Herb* will be consumed in any burning conditions specified in FuelCalc.
- Thinning and pruning both add to the *Litter* fuel component, even though the needles are initially still attached to the branches and not necessarily on the ground; piling reduces *Litter* by adding to piles the needles that are still attached to branches; broadcast burning reduces the *Litter* load (representing an initial drop as it is consumed from the ground), but may also increase *Litter* load (representing the scorched foliage that falls to the ground after the burn).
- The *Lichen*, *Moss*, *Herbaceous*, and *Live Woody* fuel components are not affected by any treatment except burning, which reduces their loads.
- The *1-hr*, *10-hr*, and *100-hr* timelag size class dead and down fuel components are increased by thinning and pruning but decreased by piling and broadcast burning.
- Thinning adds to the *1000-hr* timelag class fuel load (all of it sound) but piling and broadcast burning can then reduce this load; piling and broadcast burning reduces the load of both sound and rotten *1000-hr* timelag class logs.
- Nothing adds to the load of rotten *1000-hr* timelag class fuel because all activity fuel is presumed to be in the sound class, and FuelCalc does not simulate decay of fuel from sound to rotten over time.
- Piling adds to any existing *Piled* fuel load and burning the piles subsequently reduces the *Piled* fuel load.

The potential effects that the four different treatments could have on stand measures are shown in Table 11-2 and summarized in the bulleted list that follows.

Table 11-2: The potential effects of thinning, piling, pile burning, and broadcast burning on stand measurements. The "+" sign means that the fuel/biomass component will be positively affected or increase after a treatment. The "-" symbol means that the fuel/biomass component will be negatively affected or decrease after a treatment. The "0" symbol indicates that the treatment could have no effect on fuel/biomass.

Stand Measurement	Thinning	Pruning	Piling	Pile burning	Broadcast burning
Canopy Fuel Load	-	-			0 / -
Canopy Bulk Density	0 / -	0 / -			0 / -
Canopy Base Height	0 / +	0 / +			0 / +
Stand Height	0 / +				0 / +
Tree Density	-				0 / -
Stand Density Index	-				0 / -
Canopy Cover	-				0 / -
Basal Area	-				0 / -
Quadratic Mean Diameter	-				0 / -
Q75	0 / -				0 / -

- Thinning and pruning will always reduce *Canopy Fuel Load (CFL)*; broadcast burning will reduce *CFL* if the fire causes tree mortality or scorch height exceeds crown base height.
- Thinning either decreases *Canopy Bulk Density (CBD)* or leaves it unchanged, depending on the nature of the stand and the intensity of the thinning. For thinning to decrease *CBD*, it must remove fuel in the most densely packed layers of the canopy. Understory removal may not reduce *CBD* if the highest *CBD* is found in the overstory; overstory thinning may not reduce *CBD* if the highest *CBD* is found in the understory.
- Thinning either increases *Canopy Base Height (CBH)* or leaves it unchanged, depending on the nature of the stand and the intensity of the thinning. For thinning to increase *CBH*, it must remove enough trees that the height to the Threshold CBD is higher in the canopy. High thinning or commercial thinning that leaves small non-commercial trees standing may not change *CBH*.
- As with *CBH*, thinning and burning either decreases *Stand Height* or leaves it unchanged, depending on whether trees with taller than the pre-treatment stand height are thinned or killed.
- *Tree Density* will be affected if trees are thinned or killed.
- *Stand Density Index* will be affected if trees are thinned or killed.
- *Canopy Cover* will be affected if trees are thinned or killed.
- *Basal Area* will be affected if trees are thinned or killed.
- *Quadratic Mean Diameter (QMD)* will be affected if trees are thinned or killed. Removal of small trees may not change QMD noticeably.
- *Quadratic Mean Diameter 75th Percentile (Q75)* will be affected if the large diameter trees are thinned or killed. Removal of small diameter trees may not change Q75.

Treatment Name

FuelCalc allows you to descriptively name and save your treatment parameters for use in future calculations. Saving treatments allows for quick replication of treatments for different projects (Fig. 11-1). Type the name into the box and click save or click the drop-down arrow and select a previously created treatment.

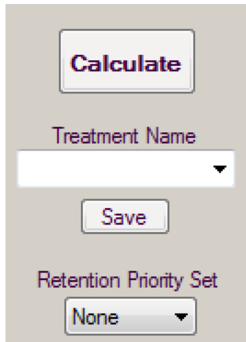


Figure 11-1: The *Calculate* button, *Treatment Name* creator and selector drop-down menu, and the *Retention Priority Set* drop-down menu.

Retention Priority Set

This control allows you to select any retention priorities you have previously created. Information on creating retention priorities can be found in *Retention Priority Factors* in the *Settings* section.

Thinning

Thinning is the commercial or non-commercial cutting of trees (that is, reduction of tree density in a forest stand) to meet a forest stand management objective (Fig.11-2). Canopy fuel load reductions from thinning are usually offset by surface fuel load increases in *Litter*, *1-hr*, *10-hr*, *100-hr*, and *1000-hr* timelag dead fuel classes (Table 11-1).

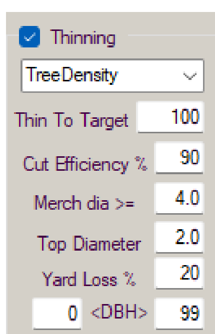


Figure 11-2: *Thinning* treatment box.

Thinning drop-down menu

This group of controls allows you to select the attribute by which you wish to thin. Figure 11-3 shows the available stand measurements you can choose from when creating a thinning treatment. Note that this list of options corresponds to the list of stand measurements in the upper-right area of the user interface. See the section on *Stand Measurements* for detailed definitions of the terms in this menu.

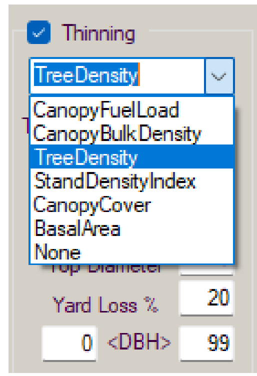


Figure 11-3: *Thinning* drop-down menu.

The selection you make here will determine where the following parameters for the treatment will be applied.

Thin To Target

This is the target value that FuelCalc will try to achieve while simulating a thinning treatment. For example, if you are thinning by tree density and set this value to 100, FuelCalc will remove trees until there are 100 trees left on the plot or it has removed every tree it is allowed to remove while operating within your specified cutting efficiency and diameter limits.

> ***Note:*** *This target value must be in the proper measurement units applicable to the thinning attribute you have selected (See Table 8-1 for units). In other words, if, for example, you select basal area, the target unit will be in square feet per acre; for canopy bulk density, the target unit will be in kg m^{-3}, and so on.*

Cutting Efficiency %

Once the retention priority has been calculated for each tree (see *Retention Priority Factors* in the *Settings* section for information), the order of removal is from lowest priority to highest. Cutting efficiency represents the percentage of trees that can be removed for each tree record (a single line in the treelist). For example, if you have a tree record (for example, PSME) in the treelist with 10 trees per acre (TPA), and the cutting efficiency is set to 80%, then FuelCalc is allowed to remove up to 8 trees; it may remove less, but no more. The *default* cutting efficiency is 90, meaning that 90% of all trees represented by a particular record are removed.

Merch dia ≥ (Merchantable Diameter ≥ [inches])

Merchantable diameter specifies the smallest DBH of thinned trees that are to be included as merchantable timber in the *Merchantable Cubic Feet* and *Merchantable Board Feet* fields (see the *Timber Volume* section, instead of just *Cubic Feet* in the *Timber Volume* Field. Thinned tree bole material less than the merchantable diameter is left in the stand (shown in the *Post Thinning Slash* row).

Top Diameter

The merchantable top diameter parameter specifies the diameter at which the tree is topped or cut off and left in the plot; the remainder of the tree bole is assumed to be brought to the landing and therefore counted as *Timber Volume*. Set Top Diameter to 0 to simulate whole tree removal from the stand. Biomass in the tree top is activity fuel that affects the *Post Thinning Slash* and can be specified for piling and burning.

Yard Loss %

Yard loss % is the portion of cut trees - including branches, limbs and foliage - lost as trees are yarded (moved) from where the tree was felled to the landing. Factors affecting yard loss include the logging method and whether landing slash is backhauled to the stand. For example, a value of 0 percent would mean that no amount of slash from the merchantable tree(s) is left on the plot, and the tree in its entirety was removed from the plot. Alternately, a value of 100 percent would mean that all of the slash from a merchantable tree is left on the plot. The biomass is counted as activity fuel, it affects the loading of the *Post Thinning Slash* (that is, slash not moved to the landing), and it can be specified for piling and burning.

<DBH>

These two diameters globally specify the range of trees that can be thinned. For example, a setting of 4 and 12 inches would result in all trees less than 4 and greater than 12 inches being retained from being cut, regardless of retention priority and other factors, whereas trees between 4 and 12 inches would be harvested.

The setting is this field overrides DBH settings in the Species Groups. If the Species Groups include records with DBH set outside range entered in the <DBH> fields those records will be removed from consideration for the thinning simulation.

Prune

Pruning is the mechanical removal of the lower branches of trees (Fig. 11-4).

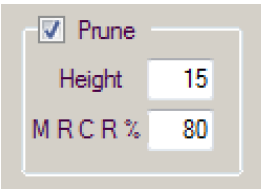


Figure 11-4: *Prune* treatment box.

FuelCalc uses a very simple approach to simulating pruning. If pruning is included, the only characteristics to specify are the pruning height and the minimum residual crown ratio. All trees are pruned to the specified pruning height or the height that maintains the residual crown ratio after pruning, whichever is less. (This prevents pruning a tree to death.) Reductions from pruning are exactly offset by increases in *Litter* and the *1-hr*, *10-hr,* and *100-hr* timelag classes (Table 11-1).

Pruning does not change *Canopy Cover* in FuelCalc, but it does change *CBH* and *CBD*. Pruning raises *CBH* as long as the pruning height is greater than the pre-pruning *CBH*. Pruning can reduce *CBD* if the pruning height approaches the height of maximum bulk density. Pruning heights are usually limited to relatively low values (for example, < 10-ft). Consequently, pruning generally reduces *CBD* only if the highest *CBD* is very low to the ground (in the understory layer, for example). (See Table 11-2.)

Height

If pruning is included as part of the treatment, the maximum height (in feet) of the pruning is specified. However, the maximum thinning height may be adjusted by the minimum residual crown ratio percent (see below).

M R C R % (Minimum Residual Crown Ratio Percent)

The Minimum Residual Crown Ratio Percent (M R C R %) specifies the minimum crown ratio of a tree to be maintained after pruning. For example, if you specify a prune height of 10 feet and an M R C R of 40 percent, then the pruning height on a 10-foot tree would be only 6 feet, leaving the minimum 40 percent crown ratio. In this case, the M R C R prevents FuelCalc from pruning the entire tree crown. A tree would need to be at least 25 feet tall to be pruned up to 10 feet and still have an M R C R of 40%

Pile

Pile simulates the piling (for example, hand-piling and machine piling) of fuel in the plot and subsequent burning of the piles (Fig. 11-5).

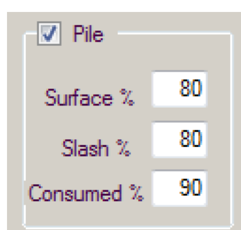


Figure 11-5: *Pile* treatment box.

Piling and burning is simulated by specifying the percent of surface fuel piled, the percent of the slash fuel piled, and the percent of the piled material that is consumed. Piling reduces the *Litter,* and all dead and down size classes; the decreases are exactly offset by an increase in the load of *Piled* fuel. Pile burning reduces the piled fuel load.

FuelCalc assumes that no trees are scorched or killed when making or burning piles. Consequently, piling and pile burning are assumed to have no effect on canopy characteristics. Emissions for pile burns are included in the total emission production estimate (25% short-term flaming and smoldering and flaming and 75% residual smoldering) but are not in the emission graph.

Surface %

Surface % refers to the percentage of the pre-treatment woody fuel load that is piled. The remainder stays as part of the surface fuel complex. The Surface % is applied to all size classes of pre-treatment fuel.

Slash %

Slash % refers to the percentage of thinning and pruning slash that is to be placed on the pile. This includes the topped portions of merchantable trees. The Slash % is applied to all size classes of slash fuel.

Consumed %

Consumed % refers to the percentage of piled fuels that will be consumed in a pile burn. For the fuel loading shown in the *Pile* cell of the Pre-Treatment row, FuelCalc consumes the percentage as set in the Consumed % field. For piled slash fuels (shown in the *Pile* cell of the Post Prune Slash row and the *Pile* cell of the Surface Fuel Piled row), total consumed equals 100% of the litter, 1-hr, 10-hr and 100-hr piled slash loading plus the Consumed % of the 1000-hr (>3 inch) piled slash fuel loading. By setting *Consumed %* to 0, pile burning will not occur (emissions for pile burning are not included in the emissions calculations). The reason the Consumed % is applied differently to Pre-Treatment and Slash fuels is because the fuel size distribution of the fuels in the Pre-Treatment *Pile* cell is unknown.

Broadcast Burn

Broadcast burning is the application of prescribed fire to a whole unit, not just to piles or jackpots in a unit (Fig. 11-6).

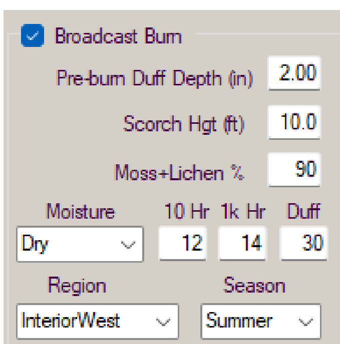


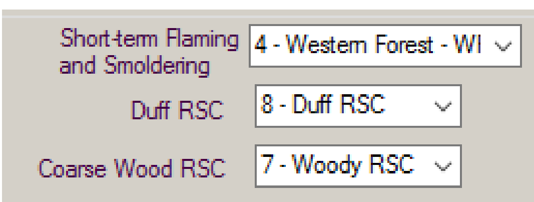
Figure 11-6: *Broadcast Burn* treatment box.

Due to the effects of ignition pattern on fire behavior, FuelCalc does not attempt to simulate the behavior of a prescribed fire. Instead, the user must set *Scorch Height*, along with the fuel moisture content, region, and season of the broadcast burn. The consumption routine from the First Order Fire Effects Model (FOFEM; Reinhardt and others 1997; Reinhardt 2003) is used in FuelCalc to calculate the consumption of the different fuel components. See the FOFEM Users Guide for details on the algorithm decision key used by FOFEM (Reinhardt and others 1997). Within FOFEM, woody fuel consumption is calculated using the Burnup model (Albini and Reinhardt 1995; Albini and others 1995; Albini and Reinhardt 1997), and duff, litter, shrub, and herbaceous fuel consumption are calculated from empirical equations or through general assumptions. Broadcast burning reduces all ground and surface fuel components and potentially reduces *CFL* if crown scorch occurs. Broadcast burning may also increase *Litter* and the *1-hr* timelag class if crown scorch occurs. The net sum of those reductions and increases (Table 11-1) is the *Fuel Load Consumed.*

Broadcast burning has two direct effects on the canopy: it scorches trees (thereby having a similar effect to pruning) and may kill trees (similar to thinning). Indirectly, these effects can increase *CBH*, reduce *CBD*, and reduce *Canopy Cover* just as thinning and pruning do. Whether these effects take place depends on the nature of the broadcast burn (Table 11-2).

Emissions are the product of consumed fuels and emission factors. FuelCalc uses the FOFEM emissions routine, which includes emission factors from Urbanski 2014. The FOFEM User Guide includes a complete discussion of the emission factors and the logic used to calculate emissions.

The group box has options for selecting the emission factors to be used for *Short Term Flaming and Smoldering*, *Duff Residual Smoldering Component* and *Coarse Wood Residual Component*. Currently, only the *Short Term Flaming and Smoldering* have optional emission factors. The selection will be used for all plots if a batch simulation is run. If plot specific selections are desired when simulating multiple plots, then the FuelCalc command line batch must be used.



Pre-burn Duff Depth (inches)

If duff depth is included as part of your input file, the value will be added here, but the value can be edited. Duff depth is included in FuelCalc files exported from FFI; but if you manually create FuelCalc files in the FFI format and do not include duff depth, then the field will have a beige background and duff depth will be calculated from the duff load (tons per acre) using a ratio of 1 ton of duff load to 0.1 inches of duff.

Scorch Hgt (feet)

Specify the expected or prescribed scorch height. This value is used to determine tree mortality and may therefore affect *CBD* and *CBH*. FuelCalc does not calculate emissions from scorched crowns.

Moss+Lichen %

This field defines the percentage of lichen and moss biomass consumed in the broadcast burn. Moss and lichen biomass are used in the *Fire Behavior Fuel Model* selector, and the consumed amounts are included in the total emissions. Consumption of these fuels in FuelCalc is calculated by multiplying the value in this field times the pre-treatment lichen and moss biomass.

Moisture

FuelCalc allows you to specify a fuel moisture scenario (Table 11-3), which sets fuel moisture for the different fuel components. Selecting a fuel moisture regime from the drop-down menu will offer some default moisture settings, but the values can be edited. Changing the fuel moisture value will modify fuel consumption and emission outputs. Moisture regime is used to set fuel moistures for calculating Torching Index and Crowning Index even when Broadcast Burn treatments are not simulated. See the Torching and Crowning Indices section for more information.

Table 11-3: Fuel Moisture regimes and percent moisture for down woody material and duff.

Regime	10-hr	1000-hr	Duff
Very dry	6	10	20
Dry	10	15	40
Moderate	16	30	75
Wet	22	40	130

Region

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

Season

FuelCalc uses the variable "Season" in the FOFEM algorithm decision key to select herbaceous and shrub consumption algorithms. The available seasons in FuelCalc are Spring, Summer, Fall, and Winter.

Calculate button

Clicking this button causes a treatment simulation to occur (Fig.11-7). In some cases, a treatment simulation is run automatically (for example, using the *Retention Priority Set* selector) when you select or change certain inputs, but it is always best to click this button to ensure that the simulation actually takes place. To reset the plot to pre-treatment conditions, uncheck the boxes next to each treatment and click **Calculate**.

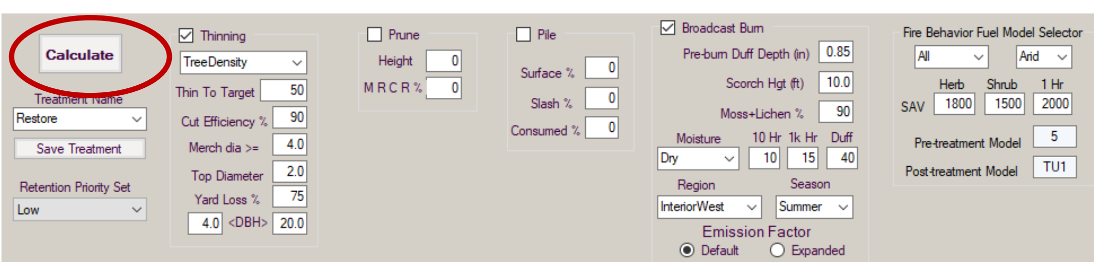


Figure 11-7: *Treatment* area of FuelCalc with the *Calculate* button circled.

Note: *Below the 1000-Hr Rotten Classes, there is a place to adjust the number of decimal places that are shown in various output text boxes. Setting this value to 3 may show trace amounts that otherwise would be shown as zeros due to rounding (Fig. 11-8).*

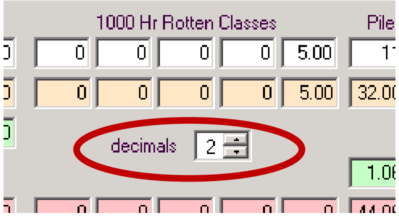


Figure 11-8: Decimal place selector.

Fire Behavior Fuel Model Selector

Surface fuel characteristics are fundamental inputs to the Rothermel (1972) surface fire spread model used in fire behavior modeling systems (Fig. 12-1). FuelCalc contains an algorithm for selecting a standard fire behavior fuel model based on the modeled surface fuel characteristics present before and after treatment. The Fire Behavior Fuel Model Selector may be used for making fire behavior calculations in future versions of FuelCalc. In this version, it will simply let you see how the treatment (s) you've applied change the predicted fire behavior fuel model.

> ***Note:*** *the results provided by this version of the Fire Behavior Fuel Model Selector have not been verified.*

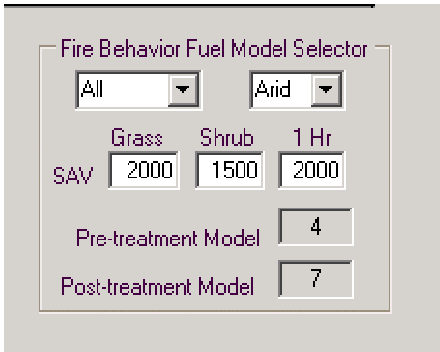


Figure 12-1: *Fire Behavior Fuel Model Selector*.

[Appendix B](#) contains details on the process used in FuelCalc to select a standard fire behavior fuel model from measured or calculated fuel characteristics.

> ***Note:*** *The Fire Behavior Fuel Model Selector box can be hidden using* ***Main Menu > Options > Show Fuel Model*** *(Fig. 12-2)****.***

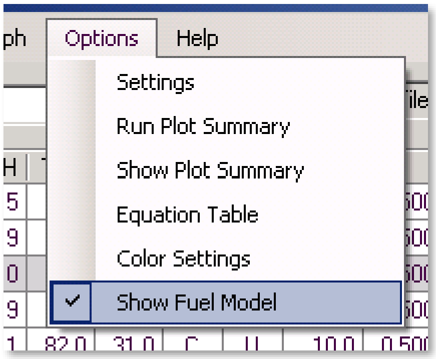


Figure 12-2: From the *Options* menu you can de-select the *Show Fuel Model* feature.

Fire Behavior Fuel Model

Using the plot fuel inputs, FuelCalc keys the input surface fuel load characteristics on your plot into a fire behavior fuel model (FBFM; Appendix B). You can set FuelCalc to use the original 13 fuel models (Albini 1976; Anderson 1982), the 40 fuel models (Scott and Burgan 2005), or all of the fuel models, in which case the most appropriate fuel model will be selected from the Albini and Scott and Burgan models combined. Clicking **Calculate** will then activate the change, which will appear in the *Pre-treatment* and *Post-treatment* model boxes.

Climate Type

Select whether your plot is in an arid or humid climate. This is required for determining the most appropriate FBFM.

SAV - Surface Area to Volume Ratio

Surface area to volume ratio (SAV) is a function of piece diameter and is an important variable in fire behavior calculations. Surface area to volume ratio is the surface area of fuel particles per unit volume (Scott and Reinhardt 2007) and, for fuels that are long in relation to their thickness, is calculated with the formula:

SAV = $\frac{4}{d}$ where,

SAV is the surface area to volume ratio on a per meter basis and *d* is the diameter, in meters

A characteristic of SAV ratio is that it decreases as particle volume increases. For more information on SAV ratio and its effect on fire behavior modeling, refer to Rothermel (1972) and Burgan and Rothermel (1984).

There are three fields for entering the surface area to volume ratios: Herb, Shrub, and 1-Hour fuels. FuelCalc provides default SAV ratio values of 8200, 1480, and 1480 for herb, shrub, and 1-hr fuels, respectively. Unfortunately, SAV values are rarely calculated in the field and difficult to find in the literature, so some suggested values are listed in Table 12-1.

Table 12-1: Suggested SAV values for use in the *Fire Behavior Fuel Model Selector*.

	Herb	Shrub	1-Hr	Source
FuelCalc default	8200	1480	1480	Burnup calibration files
Grass and grass-dominated	1500		3500	Albini 1976
Chapparral and shrubfields	1500		1750-2000	Albini 1976
Timber litter	1500		2000-2500	Albini 1976
Logging slash	1500		1500	Albini 1976

Graph

Two graphing options are available that can be used to visualize the effects of treatments on the plot. Three graphs are generated to represent the fuel stand: they include fine and course fuel graphs, pie charts of the percent removed, and stand watch for stand measurements. A separate emissions graph can also be created if broadcast burn is selected as a treatment option. The *Graph*s window can be left open while adjustment to the treatments are made and calculated. This allows you to see the influence of the changes that you are making to the plot.

Fuel Stand

Fine and Coarse Fuel graphs

These graphs show the amount of fine and coarse fuels on the plot in tons per acre (Fig. 13-1). For each fuel class, there are four bars displaying the loading of pre-treatment, post-thinning and pruning, post-piling and post-burn fuels. Pre-treatment is the loading before any treatment (including piling), post-thinning and pruning is the loading after those activities but before piling, post-piling is the loading of un-piled fuels spread across the site and post-burn is the what is left after all the treatments have been completed.

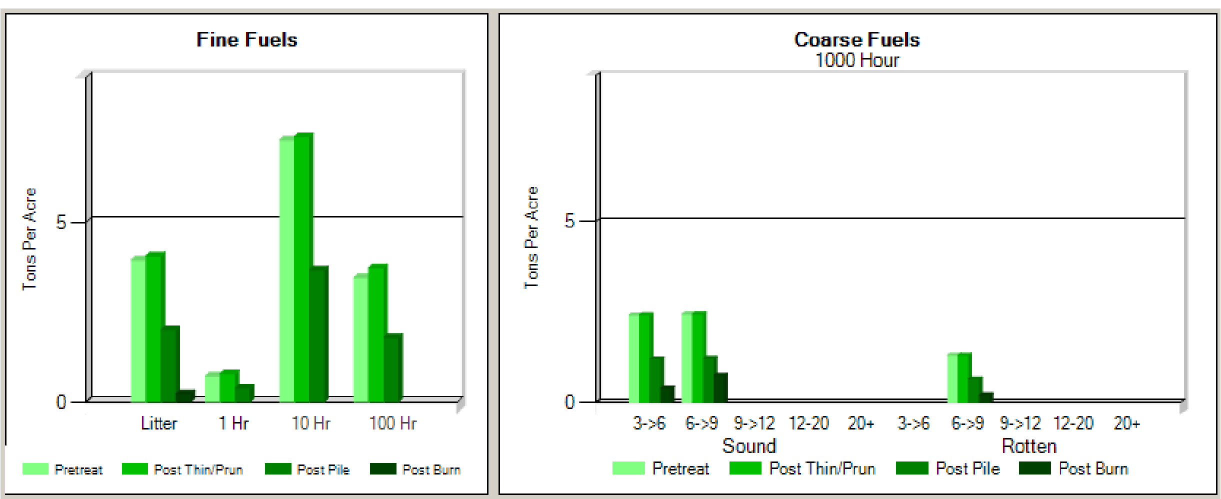


Figure 13-1: *Fine Fuels* and *Coarse Fuels* graphs.

Note: *You can save and/or print these two tables by right-clicking on them. Other tables and charts that you are interested in saving and printing will have to be saved as screen captures.*

Pie charts

The pie charts graphically show the percentage of each category that has been removed or harvested (Fig. 13-2). The value next to each pie chart indicates the actual percent change. Looking at the example below, we see that, for most of the categories, approximately 80% was removed, which leaves about 20% remaining. The change shown for canopy cover is relative to the initial amount. A value of 80% shown next to the canopy cover pie chart indicates there was an 80% reduction. Thus, if there were 30% canopy cover pre-treatment, there would be approximately 6% canopy cover when reduced by 80%.

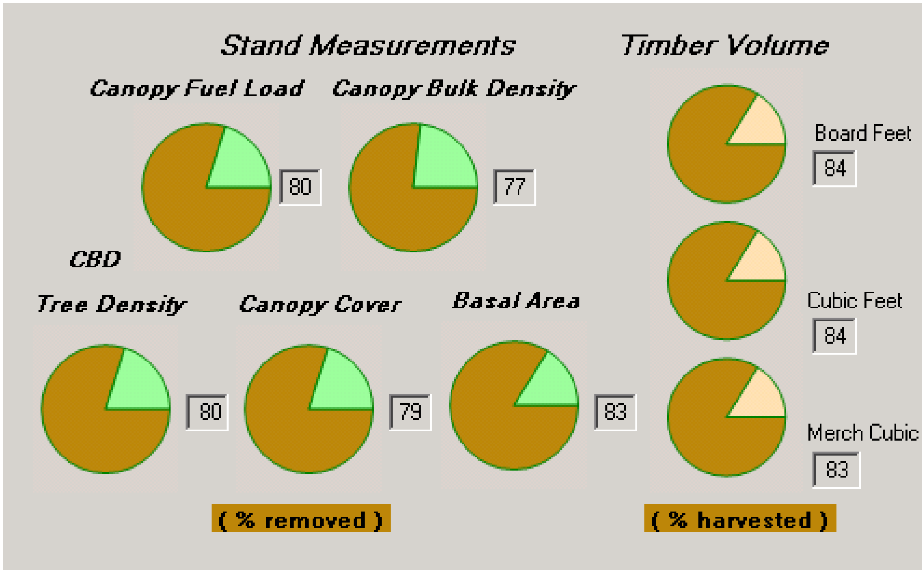


Figure 13-2: *Stand Measurements* and *Timber Volume* pie charts.

Stand Watch

This chart displays pre- and post-treatment values for the selected stand attribute (Fig. 13-3); the available stand attributes are canopy fuel load, canopy bulk density, tree density, and basal area. The blue column represents pre-treatment conditions, and the orange column represents post-treatment conditions. An additional feature of this graph is that it will display the post-treatment values for up to 50 treatment scenarios (after which it will reset), allowing for the comparison of stand attributes between treatments. To clear the graph back to a single comparison, click the **Reset** button.

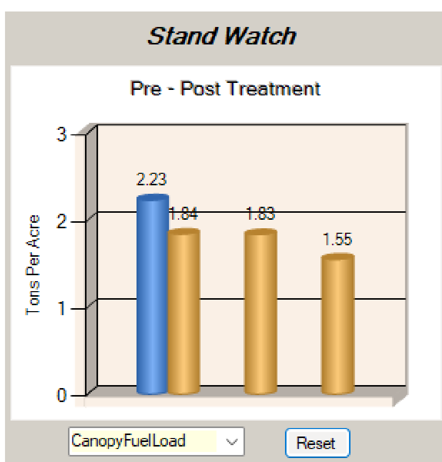


Figure 13-3: *Stand Watch* graph on FuelCalc *Graphs* window.

Emissions

Although predicting emissions is not the main focus of FuelCalc, this graph is included to give an idea of the amount of emissions released from a broadcast burn treatment (it does not include estimates for crown consumption or pile burning) (Fig. 13-4). The table area below the graph displays emissions for both the flaming and smoldering phases of combustion, in pounds emitted per acre, for the following pollutants: PM 2.5, PM 10, CH 4, CO2, CO, NOX, and SO2. FuelCalc uses the same logic used in FOFEM 6.9.4 to calculate emissions by simulating the proportion of flaming and smoldering combustion. Emissions production estimates combustion efficiency and emission factors, which vary with fuels and moisture. Combustion efficiency is the proportion of carbon that is released as CO2 during burning (Reinhardt and others 1997); Emission factors are calculated from combustion efficiency (Ward and others 1993).

To display an emissions graph of a specific combustion component, click the box next to the component. Using the graph properties shown in Figure 13-4, you can adjust the way that the emissions data are displayed. You can adjust the extent of the graph by adding smaller or larger values to the X and Y axis. For example, if the graph originally has 10 as the highest value on the Y axis, you can zoom into the graph by checking the *Fixed Axis* box and entering a lower value for the X and/or Y coordinate(s). You can also rotate the graph to see different values from a different angle. Right-click the graph to see options for printing and saving the graph.

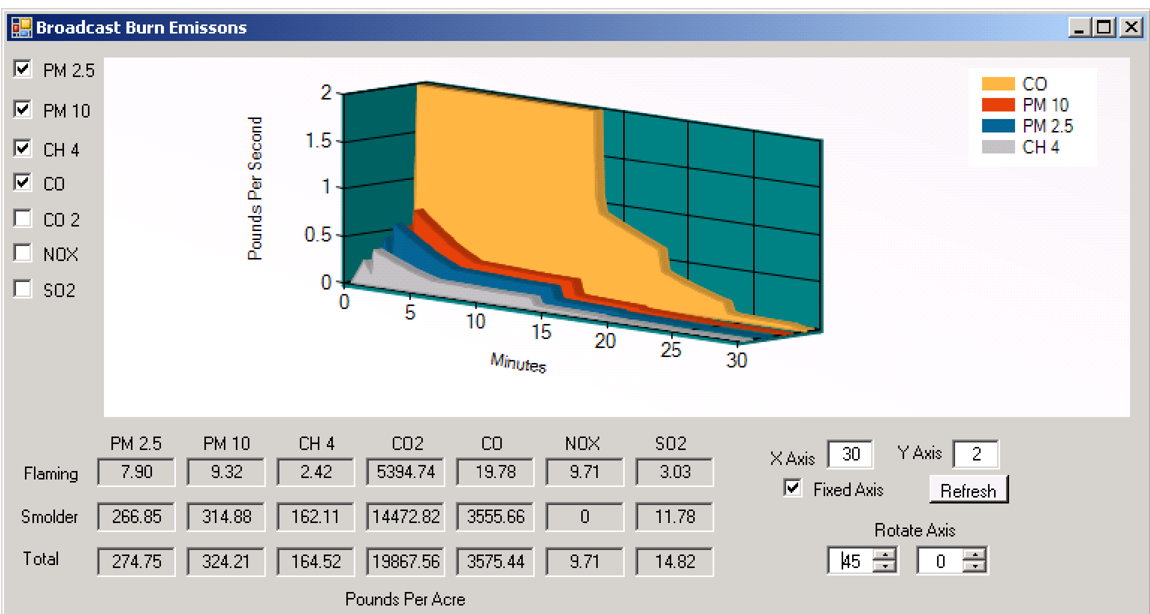


Figure 13-4: *Emissions* graph.

Options

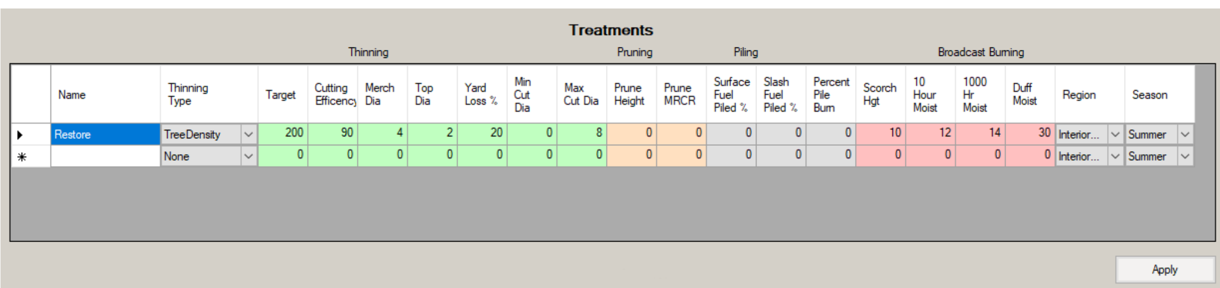
The options menu is where the FuelCalc settings can be adjusted, the plot summaries can be created and displayed, the equations table can be displayed, and the display of the FuelCalc can be adjusted. The *Settings* option allows the user to create and save different treatments and to specify the desired retention priority (RP) for the plot. Plot summaries can then be created as a way to store, transfer, and display the results of the FuelCalc calculations. The equations table displays the fuel component biomass scientific reference for the tree species that are recognized by FuelCalc. The *Color Setting* and *Show Fuel Model* checkboxes are used to adjust the display of the main FuelCalc window.

Settings

Treatments

The treatments table (Fig. 14-1) displays all treatment scenarios that you have named and saved in the main FuelCalc window or entered in this window. By saving the treatment that you applied, you can then go back and make adjustments until you have reached your desired plot conditions. You can also track the different treatments that you have performed. The treatments table allows you to edit previously saved treatments as well as create new treatments. By naming any new treatment created and clicking **Apply**, the new treatment names will be made available in the *Treatment Name* drop-down menu in the main FuelCalc window

> ***Note:*** *The data grid row with the asterisk at the left (Fig. 14-1) indicates the empty row that will always be present. If the empty row is edited, a new row will be added. A pencil will appear on the row that is being edited. To delete a data grid row, select the row by clicking the gray area to the left of the row and hitting the* ***Delete*** *key.*



Treatments

	Thinning									Pruning		Piling			Broadcast Burning					
	Name	Thinning Type	Target	Cutting Efficency	Merch Dia	Top Dia	Yard Loss %	Min Cut Dia	Max Cut Dia	Prune Height	Prune MRCR	Surface Fuel Piled %	Slash Fuel Piled %	Percent Pile Burn	Scorch Hgt	10 Hour Moist	1000 Hr Moist	Duff Moist	Region	Season
▸	Restore	TreeDensity	200	90	4	2	20	0	8	0	0	0	0	0	10	12	14	30	Interior...	Summer
*		None	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Interior...	Summer

Apply

Figure 14-1: *Treatments* table on the *Settings* window.

Retention Priorities

When choosing which trees to select for retention or removal before a thinning operation, a forester considers a variety of factors, including tree species, size, health, and vigor. We have attempted in FuelCalc to simulate that same approach to choosing which trees are retained and which are removed during a simulated thinning. FuelCalc does this by calculating a Retention Priority for each tree listed in the Treelist. Retention priority is calculated by multiplying together five individual retention priority factors for each tree record: tree status, crown class, crown ratio, diameter, species/diameter . Each of these factors varies from 0 to 1, so the product of the five factors also varies from 0 to 1. Trees with the lowest retention priorities are removed first, followed by trees with increasing retention priority. Trees are removed in this order until the thinning target is met.

Each retention priority factor has one or more user-definable settings, which allow the simulation of different types of thinning, such as low thinning or high (crown) thinning. Default retention priority factor settings for three thinning types are included within FuelCalc; however, you can create and save custom settings.

Values must be selected in the *Retention Priorities* table in order for the *Species Priorities* to take effect.

The trees-per-acre value for a removed tree will be reduced by the specified *Cutting Efficiency* (see *Cutting Efficiency %* in the *Thinning* section) until the target thinning criteria value has been reached, subject to constraints on the minimum and maximum size of trees that may be removed.

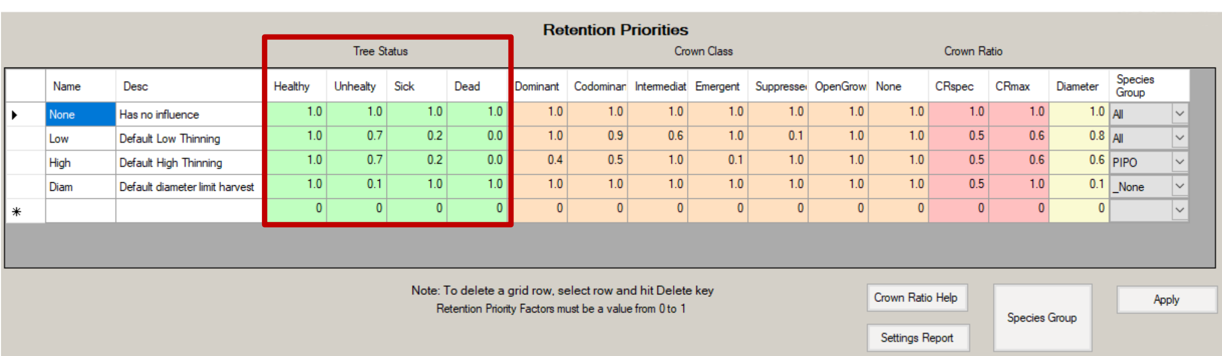
The following sections describe the different priority factors and how they are combined to an overall retention priority.

Tree status retention priority factor

The tree status factor is a scaling value that indicates the relative priority for retaining each of the four different tree status categories recognized in FuelCalc (See the *Tree Status* section for definitions of tree status):

- Healthy (H)
- Unhealthy (U)
- Sick (S)
- Dead (D)

Tree status priority factors range from 0 to 1. A value of 1 means that a tree is highly desired for retention; whereas a value near 0 means the tree is highly desired for removal. A tree record without a tree status value defaults to a retention priority factor value of 1. Tree status retention priority factors for FuelCalc's default thinning types are shown below (Fig. 14-2).



Retention Priorities

			Tree Status				Crown Class							Crown Ratio			
	Name	Desc	Healthy	Unhealty	Sick	Dead	Dominant	Codominar	Intermediat	Emergent	Suppresse	OpenGrow	None	CRspec	CRmax	Diameter	Species Group
▸	None	Has no influence	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	All
	Low	Default Low Thinning	1.0	0.7	0.2	0.0	1.0	0.9	0.6	1.0	0.1	1.0	1.0	0.5	0.6	0.8	All
	High	Default High Thinning	1.0	0.7	0.2	0.0	0.4	0.5	1.0	0.1	1.0	1.0	1.0	0.5	0.6	0.6	PIPO
	Diam	Default diameter limit harvest	1.0	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	0.1	_None
*			0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 14-2: *Retention Priorities* table with Tree Status highlighted.

Crown class retention priority factor

The crown class factor indicates the relative priority to retain trees of different crown classes. Crown class is a categorical variable specified for each tree record as part of the *Treelist*. A thinning type may emphasize retention of certain crown classes over others. These priority factors are used to specify which classes are emphasized for retention versus removal. Crown class priority factors can range from 0 to 1. A value of 1 indicates a tree that is highly desired for retention; a value near 0 indicates that a tree is highly desired for removal. Crown class retention priority factors for FuelCalc's default thinning types are shown below (Fig. 14-3).

Retention Priorities

		Tree Status				Crown Class							Crown Ratio			
Name	Desc	Healthy	Unhealty	Sick	Dead	Dominant	Codominar	Intermediat	Emergent	Suppresse	OpenGrow	None	CRspec	CRmax	Diameter	Species Group
None	Has no influence	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	All
Low	Default Low Thinning	1.0	0.7	0.2	0.0	1.0	0.9	0.6	1.0	0.1	1.0	1.0	0.5	0.6	0.8	All
High	Default High Thinning	1.0	0.7	0.2	0.0	0.4	0.5	1.0	0.1	1.0	1.0	1.0	0.5	0.6	0.6	PIPO
Diam	Default diameter limit harvest	1.0	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	0.1	_None
*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Note: To delete a grid row, select row and hit Delete key
Retention Priority Factors must be a value from 0 to 1

Crown Ratio Help | Species Group | Apply | Settings Report

Figure 14-3: *Retention Priorities* table with *Crown Class* in the red box.

Crown ratio retention priority factor

Each tree record in the *Treelist* has an implied crown ratio (CR), which is the ratio of the live crown length to total tree height (Fig. 14-4). Crown length is the height of the tree (TH) minus the height to the base of the crown (CBH), so CR is calculated from the Treelist variables as follows:

$$CR = \frac{TH - CBH}{TH}$$

Retention Priorities

		Tree Status				Crown Class							Crown Ratio			
Name	Desc	Healthy	Unhealty	Sick	Dead	Dominant	Codominar	Intermediat	Emergent	Suppresse	OpenGrow	None	CRspec	CRmax	Diameter	Species Group
None	Has no influence	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	All
Low	Default Low Thinning	1.0	0.7	0.2	0.0	1.0	0.9	0.6	1.0	0.1	1.0	1.0	0.5	0.6	0.8	All
High	Default High Thinning	1.0	0.7	0.2	0.0	0.4	0.5	1.0	0.1	1.0	1.0	1.0	0.5	0.6	0.6	PIPO
Diam	Default diameter limit harvest	1.0	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	0.1	_None
*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Note: To delete a grid row, select row and hit Delete key
Retention Priority Factors must be a value from 0 to 1

Crown Ratio Help | Species Group | Apply | Settings Report

Figure 14-4: *Retention Priorities* table with Crown Ratio highlighted.

Trees with higher crown ratios are generally more vigorous and therefore are usually a higher priority for retention during a thinning. However, beyond a certain CR value, increases in crown ratio do not necessarily indicate increased vigor, and therefore do not increase retention priority. Two settings are therefore used to specify the calculation of crown ratio retention priority factor: CRmax and CRspec. CRmax is the CR above which the crown ratio factor is 1. All trees with CR greater than CRmax are assigned a crown ratio factor of 1 and are thus equally desired for retention. CRspec is the user-defined crown ratio retention factor for a tree with CR = 0.1 (corresponding, roughly, to the lowest CR possible for a living tree). The two settings are used to define a straight line (see Fig. 14-5 below). Trees with CR between 0.1 and CR of maximum priority are assigned a crown ratio priority that is proportionally scaled between this user-controlled value and 1 (Fig. 14-5). The result of the default values of CRmax and CRspec for both low and high thinning is shown in the figure below.

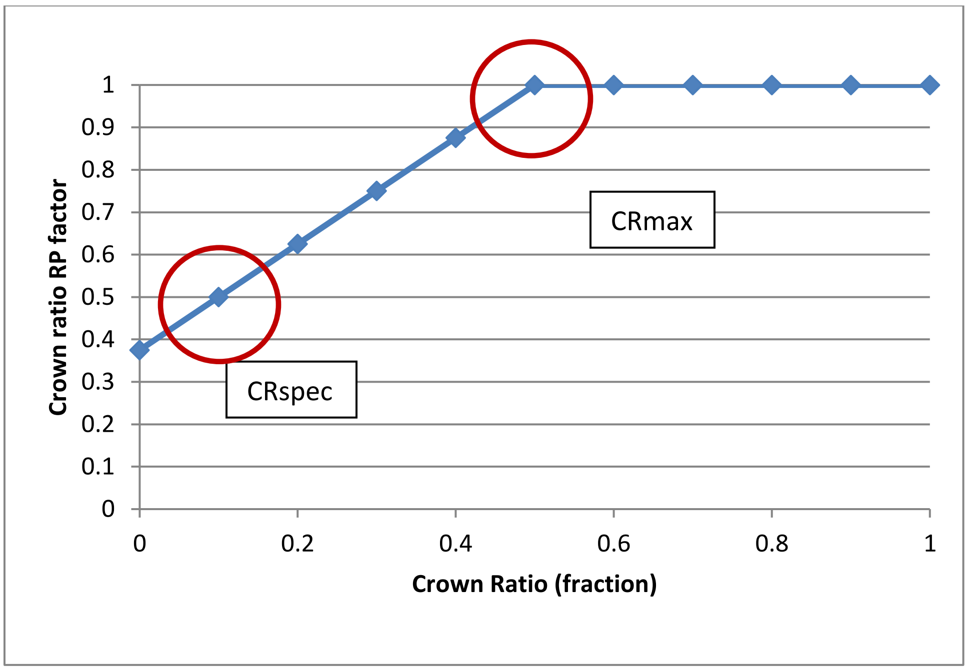


Figure 14-5: *Crown Ratio Factor* graph. CRmax is the point on this graph where the crown ratio RP factor = 1.0 (in this case around CR 0.5). CRspec is the user-defined value for crown ratio RP factor for a CR of 0.1. In this case, it is 0.5. A straight line connects CRspec and CRmax.

The calculation used in FuelCalc to calculate the crown ratio retention priority factor (CRfactor) is as follows:

$$CRfactor = MIN(1, \left(\frac{1 - CRspec}{CRmax - 0.1}\right)(CR - CRmax) + 1)$$

To eliminate crown ratio as a factor affecting retention priority, set CRspec to 1. Setting CRspec to 1 will result in a crown ratio retention priority factor of 1.0 for all trees.

Crown class retention priority factor inputs for FuelCalc's default thinning types are shown above in Figure 14-4.

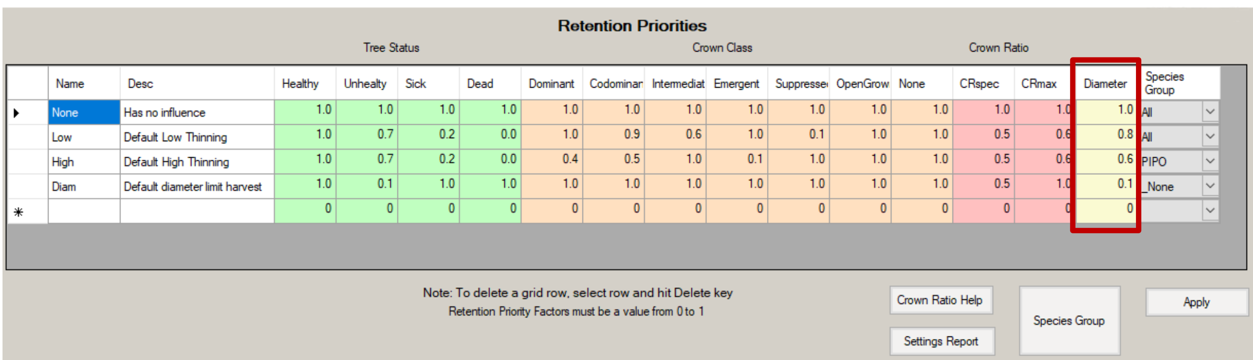
Diameter retention priority factor

Tree diameter at breast height (DBH) is a common factor affecting the desirability of a tree for retention after thinning (Fig. 14-6). In FuelCalc, DBH is used to compute a diameter retention priority factor for each tree in the Treelist. The first step is computing each tree's relative DBH (DBHrelative), which is calculated as the DBH of the tree divided by the maximum DBH of all trees in the Treelist (MaxDBH).

$$DBHrelative = \left(\frac{DBH}{MaxDBH}\right)$$

The result is a fraction between 0 and 1 (a value of 0 is possible only for a DBH = 0 cm). The next step is to calculate the diameter retention priority factor. The retention priority factor will always equal 1.0 for the largest tree (DBHrelative = 1), but a second input is needed to calculate the retention priority factor for smaller diameter trees. That input is the retention priority factor to use for the smallest tree (MinDBHfactor). The final diameter factor is calculated as shown below:

$$DBHfactor = (1 - MinDBHfactor) * \left(\frac{DBH}{MaxDBH}\right) + MinDBHfactor$$



Retention Priorities

	Name	Desc	Healthy	Unhealty	Sick	Dead	Dominant	Codominar	Intermediat	Emergent	Suppresse	OpenGrow	None	CRspec	CRmax	Diameter	Species Group
			Tree Status				Crown Class							Crown Ratio			
▸	None	Has no influence	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	All
	Low	Default Low Thinning	1.0	0.7	0.2	0.0	1.0	0.9	0.6	1.0	0.1	1.0	1.0	0.5	0.6	0.8	All
	High	Default High Thinning	1.0	0.7	0.2	0.0	0.4	0.5	1.0	0.1	1.0	1.0	1.0	0.5	0.6	0.6	PIPO
	Diam	Default diameter limit harvest	1.0	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	0.1	_None
*			0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Note: To delete a grid row, select row and hit Delete key
Retention Priority Factors must be a value from 0 to 1

Crown Ratio Help
Settings Report
Species Group
Apply

Figure 14-6: *Retention Priorities* table with Diameter in the red rectangle. The value in the Diameter field is the retention priority of a tree where DBH=0 inches (*MinDBHfactor*).

The result of the calculation of DBH retention priority factor is shown in below Figure 14-7 for a value of MinDBHpriority = 0.5. In the chart, the X-axis is DBHrelative (the ratio of the subject tree's DBH to the maximum DBH on the plot); the Y-axis is the calculated diameter retention priority factor. This calculation of a diameter retention priority factor means that a tree of half the maximum diameter will be given a diameter factor half-way between 1.0 and the specified MinDBHPriority. To eliminate diameter as a factor affecting retention priority set *Diameter* to 1.

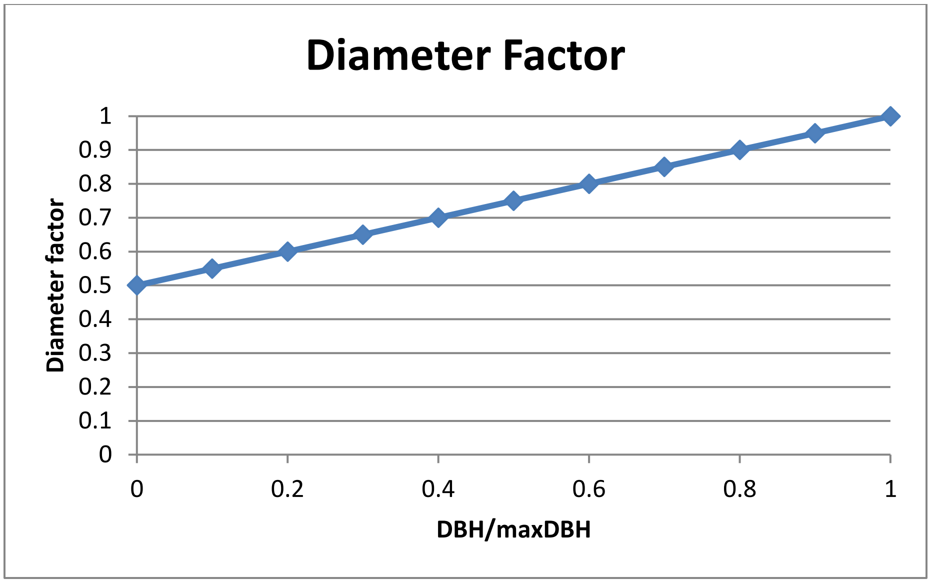


Figure 14-7: *Diameter Factor* graph showing the rate at which diameter factor rises as DBH/maxDBH increases.

Crown Ratio Help

Clicking this button provides a brief description of *CRspec*, *CRmax* and *Diameter*

Settings Report

Clicking this button provides a text report of the *Treatments*, *Retention Priorities* and *Species Groups* used in the currently selected project.

Apply

Clicking the apply buttons makes the modifications and additions to the *Treatments* and *Retention Priorities* available in the main interface.

Species Group

The Species Group window is available by clicking the *Species Group* button at the lower right of the *Settings* window. Click the File menu on the *Species Group* window to see the options for creating, saving and deleting species groups. The currently active species group is displayed in the dropdown field.

Tree species is the final factor affecting overall retention priority (Fig. 14-8). Species factors can be set separately for ranges of DBH values to allow for more flexibility in tree selection. Retention priority can be set from 0.0 and 1.0. Trees with low retention priority are removed first. There are also two special codes. Trees with retention priority of 0.0 will always be removed and trees with retention priority of 99 will always be retained. In the *Species Group* window, you can either select a value for all trees of a specific species regardless of size, or you can select one species and make several different size distinctions to remove trees of one size over another. For example, Figure 14-8 below illustrates species factors for three diameter ranges of Douglas-fir (PSME). The priority factor is set to 0 for trees less than 4 inches DBH, meaning that these trees will be the highest priority for removal. Trees between 4 and 16 inches DBH have a species priority factor of 0.7. Finally, Douglas-fir trees greater than or equal to 16 inches DBH are set to always be retained, even if that means the thinning target cannot be met.

> ***NOTE****: A good practice is to include a row for* _Other *species not specifically listed in the Species Group.*

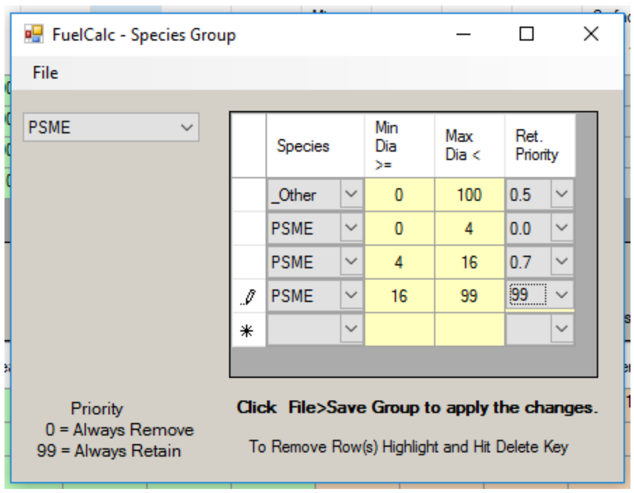


Figure 14-8: *Species Group* table with values set.

FuelCalc will apply the Species Group retention factors when the group is selected in the Species Group column of the *Retention Priorities* table. The overall retention priority for each tree is simply the product of the above factors (tree status, crown class, crown ratio, diameter, and species). The species priority factor code of 99 (always retain) supersedes a zero value for any of the other factors, so no trees of a given species and diameter range will be harvested if they are given a code of 99, regardless of other settings. If you want FuelCalc to use only the retention values in the Species Priority window set all cells in the new row of the Retention Priorities table to 1.

The File dropdown has options for the Species Groups: *New Group*, *Save Group*, *Save Group As*, *Delete Group*.

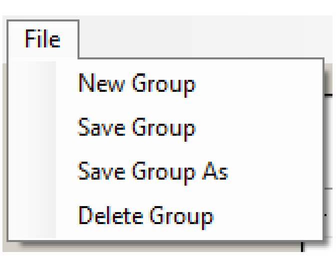


Figure 14.9: Species Group, File menu options

Option	Description
New Group	Creates a new group with one record for *_Other* species 0 to 100 dbh.
Save Group	Saves the selected Species Group
Save Group As	Duplicates the selected Species Group that can be renamed.
Delete group	Deleted the selected Species Group.

Table 14.1: Species Group, File menu option descriptions.

Run Batch Summary

You can automatically run all plots in the current project through FuelCalc using the treatment options you have set on the interface. The *Plot Input File*, *Tree Input File*, *Output File*, and *Error File* fields will be automatically filled out (Fig. 14-10). Click **Run** to begin processing. Use **Pause** and **Continue** to stop and start the execution. Click **Abort** to stop execution. Click the **Open Error File** button to view execution errors. The error file will describe the action taken. Records with errors are removed from the calculations. Records with substitutions are not removed from the calculations.

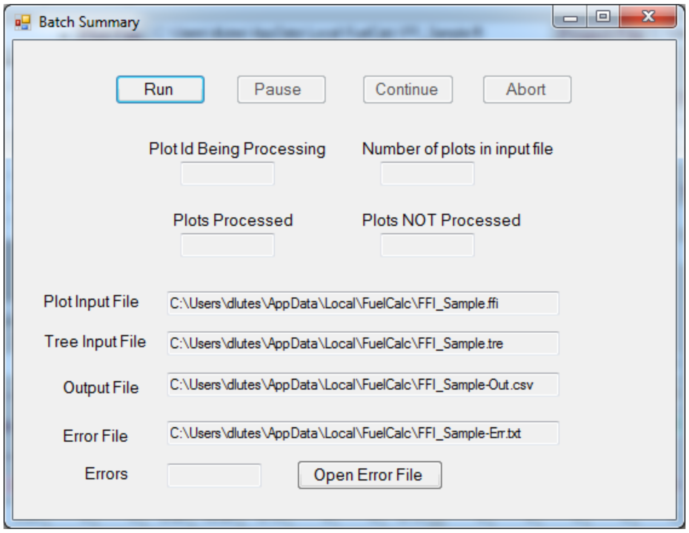


Figure 14-10: The Batch Summary screen

Note: *Before making a batch run, it is good practice to click the Summary Report Update button at the lower right of the main FuelCalc screen to capture the most recent changes made on the interface.*

Results are in a .csv file saved in your current working directory. Each row includes pre- and post-treatment fuel and stand conditions for a plot. Average values are reported in the last row of the spreadsheet. (Figure 14-11).

	A	B	C	D	E	F	G	H	I	J	K	L
1	PlotID	preCFL	postCFL	preCBD	postCBD	preCBH	postCBH	preSH	postSH	preTD	postTD	preSDI
2	Units	T/ac	T/ac	kg/m3	kg/m3	ft	ft	ft	ft	tpa	tpa	tpa
3	DylanCkR:	1.22	0.85	0.018	0.015	4	31	88	88	200	30.9	56.
4	DylanCkR:	1.56	0.89	0.021	0.012	10	19	109	109	100	43	103.
5	DylanCkR:	1.37	0.44	0.024	0.006	10	12	94	95	100	41	79.
6	DylanCkR:	0.55	0.36	0.011	0.008	12	29	76	78	100	43	52.
7	DylanCkR:	1.69	0.71	0.033	0.011	23	29	95	108	91.05	43.95	83.
8	DylanCkR:	0.33	0.14	0.009	0.004	14	19	70	73	91.05	42.95	37.
9	Average	1.12	0.57	0.019	0.009	12.17	23.17	88.67	91.83	113.68	40.8	68.

Figure 14-11: The plot summary is saved to a .csv file. Each row includes pre- and post-treatment fuel and stand conditions for a plot. Average values are included in the last row.

Show Batch Summary

View the output of the last stand summary you ran (Figure 14-12). The table reports the same information as the batch summary .csv file but is available directly in FuelCalc.

Batch Summary

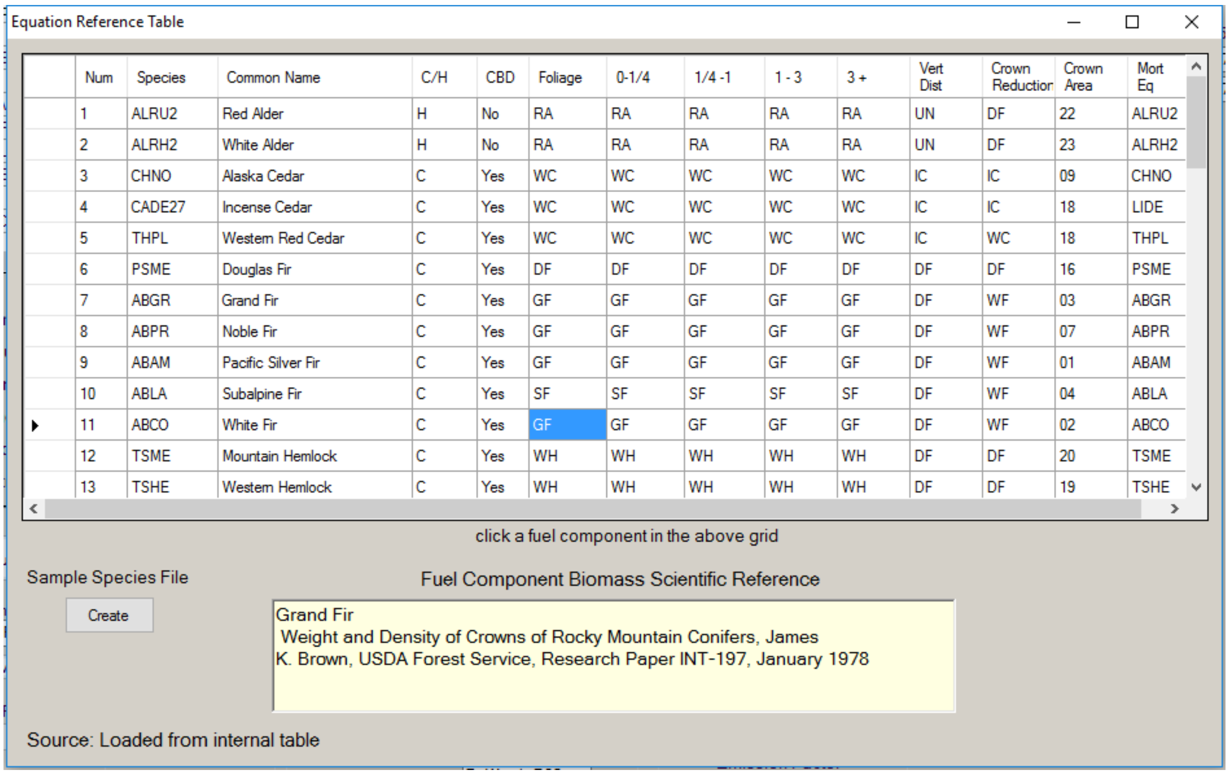
Plot	Pre Avail Fuel T/ac	Post Avail Fuel T/ac	Pre CBD kg/m3	Post CBD kg/m3	Pre CBH ft	Post CBH ft	Pre Stand Height ft	Post Stand Height ft	Pre Densit tpa	Post Densit tpa	Pre SDI tpa	Post SDI tpa	Pre Cover % tree	Post Cover % tree	Pre Basal Area ft2/ac	Post Basal Area ft2/ac	Pre QMD in	Post QMD in	P Q in
DylanCkRx08-...	0.33	0.14	0.009	0.004	14.0	19.0	70.0	73.0	91	43	38	22	9.2	5.7	18.6	11.3	6.13	6.95	
DylanCkRx06-...	1.69	0.71	0.033	0.011	23.0	29.0	95.0	108.0	91	44	84	39	22.4	11.0	51.3	24.6	10.16	10.14	1
DylanCkRx05-...	0.55	0.36	0.011	0.008	12.0	29.0	76.0	78.0	100	43	52	39	13.5	9.2	28.2	22.4	7.20	9.77	1
DylanCkRx04-...	1.37	0.44	0.024	0.006	10.0	12.0	94.0	95.0	100	41	80	35	21.6	9.1	47.3	22.3	9.31	9.98	1
DylanCkRx03-...	1.56	0.89	0.021	0.012	10.0	19.0	109.0	109.0	100	43	104	75	25.0	16.5	71.5	55.8	11.45	15.42	2
DylanCkRx01-...	1.22	0.85	0.018	0.015	4.0	31.0	88.0	88.0	200	31	57	34	16.2	8.3	30.1	19.9	5.25	10.87	1
Average	1.12	0.57	0.019	0.009	12.2	23.2	88.7	91.8	114	41	69	41	18.0	10.0	41.2	26.1	8.25	10.52	1

Figure 14-12: The batch summary that was run can be viewed directly in FuelCalc.

Equation Table

The equation table simply displays valid species in FuelCalc and the associated canopy load and load distribution equations.

Equation assignments cannot be modified in this table; however, there is an option for editing them discussed in *Appendix C*. See *Appendix D* for more information about how canopy loading is calculated. Click **Close** to close the table.



Num	Species	Common Name	C/H	CBD	Foliage	0-1/4	1/4 -1	1 - 3	3 +	Vert Dist	Crown Reduction	Crown Area	Mort Eq
1	ALRU2	Red Alder	H	No	RA	RA	RA	RA	RA	UN	DF	22	ALRU2
2	ALRH2	White Alder	H	No	RA	RA	RA	RA	RA	UN	DF	23	ALRH2
3	CHNO	Alaska Cedar	C	Yes	WC	WC	WC	WC	WC	IC	IC	09	CHNO
4	CADE27	Incense Cedar	C	Yes	WC	WC	WC	WC	WC	IC	IC	18	LIDE
5	THPL	Western Red Cedar	C	Yes	WC	WC	WC	WC	WC	IC	WC	18	THPL
6	PSME	Douglas Fir	C	Yes	DF	DF	DF	DF	DF	DF	DF	16	PSME
7	ABGR	Grand Fir	C	Yes	GF	GF	GF	GF	GF	DF	WF	03	ABGR
8	ABPR	Noble Fir	C	Yes	GF	GF	GF	GF	GF	DF	WF	07	ABPR
9	ABAM	Pacific Silver Fir	C	Yes	GF	GF	GF	GF	GF	DF	WF	01	ABAM
10	ABLA	Subalpine Fir	C	Yes	SF	SF	SF	SF	SF	DF	WF	04	ABLA
11	ABCO	White Fir	C	Yes	GF	GF	GF	GF	GF	DF	WF	02	ABCO
12	TSME	Mountain Hemlock	C	Yes	WH	WH	WH	WH	WH	DF	DF	20	TSME
13	TSHE	Western Hemlock	C	Yes	WH	WH	WH	WH	WH	DF	DF	19	TSHE

Figure 14-13. The equations used for calculating canopy fuel loading and distribution are displayed in the equations table.

Color Settings

This option lets you modify some of the FuelCalc user interface color settings.

Show Fuel Model

This option is used to toggle the **Fire Behavior Fuel Model Selector** section of the user interface on and off.

Treatment File

This option is used for creating the Treatment file used by the command line version of FuelCalc. The Treatment file can be created manually but this window (Fig. 14-14) makes it easier to set up the file.

Create - Brings all plots in the Project File into the grid.
Save - Saves the settings in CSV format that can be used by the command line batch program.
Import - Import and existing Treatment file.
Refresh - Updates the **Thin**, **Prune**, **Pile** and **Burn** checkboxes for all plots based on the user interface for those fields.

Set the Retention Priority and Treatment dropdowns and the Thin, Prune, Pile and Burn checkboxes as desired. The Retention Priorities and Treatments are created on the Settings window. The Project File includes the Thin, Prune, Pile and Burn settings.

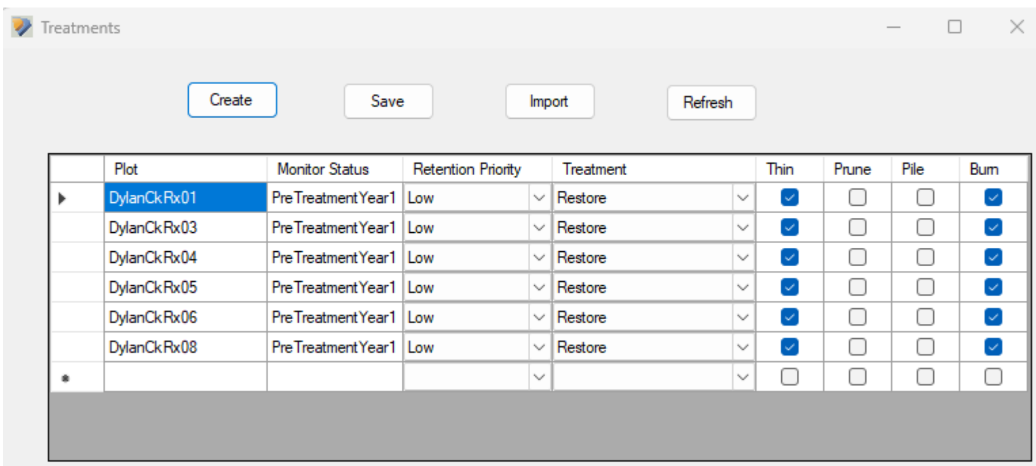


Figure 14-14. Example treatment file creator window.

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

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

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

.FFI	
Field name	**Description**
PlotId	FFI Macro plot identifier
Monitoring Status	FFI Monitoring status name
Monitoring Status Order	FFI Monitoring status order number (numbered sequentially when there are multiple monitoring statuses for one plot)
TotalDuffLoad[1]	Duff load (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol
DuffDepth	Duff Depth (in.). From Surface Fuels protocol and/or Biomass-Fuels protocol.
LitterLoad[1]	Litter load (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol.
LichenLoad[1]	Lichen load (t ac^{-1}). From Surface Fuels – Alaska protocol and/or the Biomass-Fuels protocol.
LiveMossLoad[1]	Live moss load (t ac^{-1}). From Surface Fuels – Alaska protocol and/or the Biomass-Fuels protocol
DeadMossLoad[1]	Dead moss (t ac^{-1}). From Surface Fuels – Alaska protocol and/or the Biomass-Fuels protocol.
OneHour[1]	1-hr (0 - <0.25 in) woody load (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol and/or Photoload protocol
TenHour[1]	10-hr (0.25 - <1.0 in) woody load (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol and/or Photoload protocol.
HundredHour[1]	100-hr (1.0 - <3.0 in) woody load (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol and/or Photoload protocol.
ThousandHourDc1Sz1[1]	Load of 3 - < 6 in. decay class 1 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[3] and/or Logs-Fixed Area protocol.
ThousandHourDc1Sz2[1]	Load of 6 - < 9 in. decay class 1 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[4] and/or Logs-Fixed Area protocol.
ThousandHourDc1Sz3[1]	Load of 9 - < 12 in. decay class 1 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[5] and/or Logs-Fixed Area protocol.
ThousandHourDc1Sz4[1]	Load of 12 - < 20 in. decay class 1 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[6] and/or Logs-Fixed Area protocol.
ThousandHourDc1Sz5[1]	Load of >= 20 in. decay class 1 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >20" class and/or Logs-Fixed Area protocol.

ThousandHourDc2Sz1[1]	Load of 3 - < 6 in. decay class 2 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[3] and/or Logs-Fixed Area protocol.
ThousandHourDc2Sz2[1]	Load of 6 - < 9 in. decay class 2 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[4] and/or Logs-Fixed Area protocol.
ThousandHourDc2Sz3[1]	Load of 9 - < 12 in. decay class 2 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[5] and/or Logs-Fixed Area protocol.
ThousandHourDc2Sz4[1]	Load of 12 - < 20 in. decay class 2 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[6] and/or Logs-Fixed Area protocol.
ThousandHourDc2Sz5[1]	Load of >= 20 in. decay class 2 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >20" class and/or Logs-Fixed Area protocol.
ThousandHourDc3Sz1[1]	Load of 3 - < 6 in. decay class 3 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[3] and/or Logs-Fixed Area protocol.
ThousandHourDc3Sz2[1]	Load of 6 - < 9 in. decay class 3 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[4] and/or Logs-Fixed Area protocol.
ThousandHourDc3Sz3[v]	Load of 9 - < 12 in. decay class 3 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[5] and/or Logs-Fixed Area protocol and/or Logs-Fixed Area protocol.
ThousandHourDc3Sz4[1]	Load of 12 - < 20 in. decay class 3 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[6] and/or Logs-Fixed Area protocol.
ThousandHourDc3Sz5[1]	Load of >= 20 in. decay class 3 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >20" class and/or Logs-Fixed Area protocol.
ThousandHourDc4Sz1[1]	Load of 3 - < 6 in. decay class 4 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[3] and/or Logs-Fixed Area protocol.
ThousandHourDc4Sz2[1]	Load of 6 - < 9 in. decay class 4 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[4] and/or Logs-Fixed Area protocol.
ThousandHourDc4Sz3[1]	Load of 9 - < 12 in. decay class 4 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[5] and/or Logs-Fixed Area protocol.
ThousandHourDc4Sz4[1]	Load of 12 - < 20 in. decay class 4 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[6] and/or Logs-Fixed Area protocol.
ThousandHourDc4Sz5[1]	Load of >= 20 in. decay class 4 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >20" class and/or Logs-Fixed Area protocol.
ThousandHourDc5Sz1[1]	Load of 3 - < 6 in. decay class 5 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[3] and/or Logs-Fixed Area protocol.
ThousandHourDc5Sz2[1]	Load of 6 - < 9 in. decay class 5 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >3" -9" class[4] and/or Logs-Fixed Area protocol.
ThousandHourDc5Sz3[1]	Load of 9 - < 12 in. decay class 5 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[5] and/or Logs-Fixed Area protocol.

ThousandHourDc5Sz4[1]	Load of 12 - < 20 in. decay class 5 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >9" -20" class[6].
ThousandHourDc5Sz5[1]	Load of >= 20 in. decay class 5 fuels (t ac^{-1}). From Surface Fuels protocol and/or the Biomass-Fuels protocol >20" class and/or Logs-Fixed Area protocol.
HerbLoadDead	Dead herb load (t ac^{-1}). From Surface Fuels-Vegetation protocol
HerbLoadLive[1]	Live herb load (t ac^{-1}). From Surface Fuels-Vegetation protocol and/or the Biomass-Fuels protocol and/or Photoload protocol.
ShrubLoadDead	Dead shrub load (t ac^{-1}). From Surface Fuels-Vegetation protocol
ShrubLoadLive[1]	Live shrub load (t ac^{-1}). From Surface Fuels-Vegetation protocol and/or the Biomass-Fuels protocol and/or Photoload protocol.
ShrubLiveSAV[2]	Not exported from FFI
HerbSAV[2]	Not exported from FFI
WoodySAVOneHour[2]	Not exported from FFI
FractionGroundAreaPileCovered[2]	Proportion of Sample Area covered by pile(s). From Surface Fuels-Piles protocol.
PileLoadWholePlot[1]	Load of piled fuels (t ac^{-1}). From Surface Fuels-Piles and/or Biomass Fuels protocol.
EmisSTSF[2]	Not exported from FFI
EmisDuffRSC[2]	Not exported from FFI
EmisCWDRSC[2]	Not exported from FFI

[1] If loading data for the same component exists in more than one protocol, the average of the values will be used in FuelCalc.

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

[3] FuelCalc 3"–6" class loading = Biomass-Fuels >3"-9"*0.265

[4] FuelCalc 6"–9" class loading = Biomass-Fuels >3"-9"*0.735

[5] FuelCalc 9"–12" class loading = Biomass-Fuels >9"-20"*0.301

[6] FuelCalc 12"–20" class loading = Biomass-Fuels >9"-20"*0.699

Table A-2: TRE file field names and descriptions. Files exported from FFI will include tree data from the Trees-Individuals method and, based on selections set in FFI, may include Saplings and Seedlings records. The first row of the file must include the label "PlotID".

.TRE	
Field name	**Description**
PlotId	Macro plot identifier
TreeSpecies	Tree species code (NRCS Code required)
TreeExpansionFactor	Representative tree density (trees ac^{-1})
Diameter[1]	Tree DBH (in.)
TreeHeight	Tree height (ft)
CrownBaseHeight[2]	Live crown base height (ft)
TreeStatus[3]	Tree status (L, H, U, S, D)
CrownClass[4]	Crown class (D, C, I, S, N)
Crown Ratio[5]	Crown ratio (0 – 100) (ideally, uncompressed crown ratio)
BoleCharHeight	Bole char height (ft)
CrownScorch%[6]	Crown scorch (%)
ScorchHeight	Scorch height (ft)
CKR	Cambium kill rating (0-4)
BeetleDamage[7]	Beetle damage (Y, N)
EquationType[8]	Equation type (CRNSCH, CRCABE, BOLCHR)
FlHt/ScHt	Flame height/scorch height (ft)

FS	Describes the value in the FlHt/ScHt field. Flame height (F) or scorch height (S).
Severity	Fire severity (L or blank)

[1] If values are entered in both the DBH and DRC fields in FFI then DBH will be exported. If the DBH field is null and DRC (inches) has a value then DBH=Exp(-0.35031 + (1.03991 * ln(DRC * 2.54)))/2.54. For trees <4.5' tall, DBH=0.1. DBH is converted back to DRC for NRCS codes linked to 2-letter FuelCalc codes in the sample-species.csv file. Equation from: *Chojnacky et al. 2013 Updated generalized biomass equations for North American tree species. Forestry 2014; 87, 129–151*

[2] This field is populated with values in the Live Crown Base Height or Crown Fuel Base Height field in the FFI Trees-Individual protocol. If crown height is missing then FuelCalc calculates Crown Base Height using height and crown ratio. For the Sapling and Seedling protocols, FuelCalc calculates Crown Base Height using the FFI Crown Ratio and height fields. Live Crown Base = 50% of height if other information is missing. Leave blank for dead trees.

[3] Tree status code of I (Injured) in FFI will be assigned the code S (Sick) in FuelCalc. Tree status code X (Not Assessed) in FFI will be assigned the code D (Dead) in FuelCalc. Tree status code L in FFI will be assigned code H in FuelCalc.

[4] Crown class code of SC (Subcanopy) in FFI will be assigned I (Intermediate) in FuelCalc. Class code of O (Open grown) in FFI will be assigned C (Codominant) in FuelCalc. Class code of E (Emergent) in FFI will be assigned D (Dominant) in FuelCalc. Class code of X (Not assessed) in FFI will be assigned N (None). Crown Class codes that are blank in the .TRE file (e.g., seedlings, saplings and snags) will be assigned N (None) in the FuelCalc user interface.

[5] If Crown Base Height is missing then Crown Base Height = Tree Height – (Tree Height * (Crown Ratio/100)).

[6] In the CRCABE equations, this value is set to equal either Crown Length Scorched, Crown Scorch or Crown Kill based on the species and mortality equation.

[7] If the Trees – Individuals, Damage Code 1, 2 or 3 fields equal 10000 or "INSE", then this field will be set to "Yes"; otherwise, it will be blank.

[8] This value is set based on data in the Trees-Individuals protocol

If the CKR field is not null then "Equation Type" is set to "CRCABE"
If the Char Height field is not null then "Equation Type" is set to "BOLCHR"
Otherwise "Equation Type" is set to "CRNSCH"

Appendix B: How FuelCalc selects the Fire Behavior Fuel Model

Selecting a standard fuel model from fuel load data is a two-step process. The first step is narrowing the range of fuel model choices to a reasonable number based on fire-carrying fuel type, climate type (which relates to extinction moisture content), and which set of standard fire behavior fuel models to choose from. Step two is selecting from the narrowed list based on a similarity index of fuelbed characteristics, such as fine fuel load, characteristic surface area to volume ratio, packing ratio, and bulk density. These characteristics can be calculated for both the measured/modeled fuel loads and for the standard fuel models.

Narrowing the fuel model choices

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

Fire-carrying fuel type

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

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

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

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

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

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

Climate type

Fuel models appropriate for humid and sub-humid climates have higher extinction moisture contents than fuel models for arid and semi-arid climates. Therefore, a different subset of fuel models is available for selection in the different climate types (with some overlap). Two climate types are available:

- Arid to semi-arid climates (low extinction moisture content)
- Humid to sub-humid climates (high extinction moisture content)

Fuel model set

The last piece of information needed is which set of standard fire behavior fuel model to use. Two complete sets are available: the original 13 fuel models (Albini 1976; Anderson 1982) and the 40 fuel models (Scott and Burgan 2005) (Table C-1). Although those sets were designed to stand alone, some people prefer to draw from among all 53 fuel models. FuelCalc allows three choices for fuel model set:

- Original 13
- 40 fuel models
- All 53 fuel models

The table below identifies the standard fuel models appropriate for each of the four fire-carrying fuel types, for both arid climates and for humid climates.

Table C-1: The standard fuel models appropriate for each of the four fuel types for both arid climates and for humid climates.

		Arid climate fuel models				Humid climate fuel models			
		GR	GS	SH/TU	TL/SB	GR	GS	SH/TU	TL/SB
Original 13 fuel models	1	X	X			X	X		
	2	X	X	X		X	X	X	
	3	X	X			X	X		
	4			X				X	
	5		X	X				X	
	6								
	7			X			X	X	
	8				X				X
	9				X				X
	10			X				X	
	11				X				X
	12				X				X
	13				X				X
New 40 fuel models	GR1	X				X			
	GR2	X	X						
	GR3					X	X		
	GR4	X	X						
	GR5					X	X		
	GR6					X	X		
	GR7	X							
	GR8					X			
	GR9					X			
	GS1		X						
	GS2		X						

	GS3						X		
	GS4						X		
	SH1		X	X			X		
	SH2		X	X					
	SH3						X	X	
	SH4						X	X	
	SH5			X					
	SH6							X	
	SH7			X					
	SH8							X	
	SH9							X	
	TU1			X				X	
	TU2							X	
	TU3							X	
	TU4			X					
	TU5			X					
	TL1				X				X
	TL2				X				X
	TL3				X				X
	TL4				X				X
	TL5				X				X
	TL6				X				X
	TL7				X				X
	TL8				X				X
	TL9				X				X
	SB1				X				X
	SB2				X				X
	SB3				X				X
	SB4				X				X

For example, appropriate fuel models for a grass-dominated fuelbed (GR) in arid climates include fuel models 1, 2, and 3 from the original 13; and GR1, GR2, GR4, and GR7 from the 40 fuel model set. For a grass fuel type in a humid climate, the same original 13 fuel models are available (1, 2, and 3), but the narrowed list from the set of 40 fuel models includes GR1, GR3, GR5, GR6, GR8, and GR9.

Depending on your preference, the final narrowed list could include fuel models from 1) only the 13 original fuel models, 2) only the set of 40 fuel models, or 3) both sets of fuel models.

Selecting a fuel model from the narrowed list

Once the list of potential fuel models has been narrowed from step 1, the next step is to compute a departure index comparing characteristics of the subject fuelbed to characteristics of each of the fuel models on the narrowed list. The departure of the fuelbed from each candidate fuel model is then used to select best one or two fuel models.

Fuelbed depth

Fuelbed depth is the fuel model parameter, but in reality the fire model is using that depth to compute bulk density and packing ratio; fuelbed depth itself if not a direct input to the Rothermel spread model. Spread rate and intensity is very sensitive to bulk density and packing ratio. In recognition of this, the procedure used to estimate fuelbed depth is really designed to estimate a reasonable bulk density—fuelbed depth is computed from that estimate.

Three intermediate quantities are needed in order to compute fuelbed depth for this custom fuel model: total fuel load (*TFL*), fine dead fuel load (*FDFL*) and fine fuel load (*FFL*). Total fuel load is the sum of litter, 1-h, 10-h, 100-h, live herbaceous and live woody load; fine dead fuel load is just litter+1-h load; and fine fuel load is the sum of the litter+1-h load, herbaceous load, and live woody load parameters.

The fuelbed depth and bulk density are directly related:

$$FuelBedDepth = \frac{TFL}{BD} * 0.04591$$

where TFL is the total fuel load (t ac^{-1}) and BD is fuelbed bulk density (lb ft^{-3}). The factor 0.04591 is a unit conversion factor.

Bulk density is the weighted-average of live and dead fuel bulk density values:

$$BD = BD_{live} + [WF * (BD_{dead} - BD_{live})]$$

where BD_{live} is the bulk density of the live fuel component of the fuelbed, BD_{dead} is the bulk density of the dead fuel component, and *WF* is a weighting factor that scales between BD_{live} and BD_{dead}. BD_{live} and BD_{dead} are user-specified constants for each simulation. Default BD_{live} is 0.10 lb ft^{-3}; default BD_{dead} is 0.75 lb ft^{-3}. The weighting factor (*WF*) is calculated as follows:

$$WF = \frac{FDFL}{FFL}$$

where *FDFL* and *FFL* are as defined above (t ac^{-1}). In other words, *WF* is the fraction of the fine fuel load that is dead. As used in the equation for *BD*, *WF* simply scales *BD* between the values for the live and dead fuel components. A fuelbed with no live fuel (*WF* = 1) will result in $BD = BD_{dead}$. A fuelbed with no fine dead fuel (*WF* = 0) will return $BD = BD_{live}$. A fuelbed for which the fine dead fuel load equals the fine live fuel load (*WF* = 0.5) will return a *BD* that is halfway between the values for BD_{live} and BD_{dead}.

Departure index

The departure index is the weighted average of the departure of three separate fuelbed characteristics: characteristic surface area to volume ratio (SAV), fuelbed bulk density (BD), and fine fuel load (FFL) Fine fuel load is the load of live and dead fuel less than 6 mm (0.25 in.) diameter. A normalized departure index is computed for each of those factors. The departure index (*DI*) is the square of the difference between the fuelbed characteristic and the fuel model characteristic, normalized by dividing by the standard deviation of the characteristic across all 53 standard fuel models. The final departure is a weighted average of the three characteristics. Bulk density and SAV are weighted equally (0.25 each); fine fuel load receives twice the weight of SAV and bulk density (0.50). The departure index is therefore defined as follows:

$$DI = 0.25 * \left(\frac{SAV_{fuelbed} - SAV_{fm}}{405.2}\right)^2 + 0.25 * \left(\frac{BD_{fuelbed} - BD_{fm}}{0.3992}\right)^2 + 0.50 * \left(\frac{FFL_{fuelbed} - FFL_{fm}}{3.051}\right)^2$$

where

$SAV_{fuelbed}$ is the *SAV* of the subject fuelbed (ft^{-1})

SAV_{fm} is the *SAV* of the subject standard fuel model (ft^{-1})

405.2 is the standard deviation of SAV of the 53 standard fuel models (ft^{-1})

$BD_{fuelbed}$ is the bulk density of the subject fuelbed (lb ft^{-3})

BD_{fm} is the bulk density of the subject standard fuel model (lb ft^{-3})

0.3992 is the standard deviation of the bulk density of the 53 standard fuel models (lb ft^{-3})

$FFL_{fuelbed}$ is the fine fuel load of the subject fuelbed (t ac^{-1})

FFL_{fm} is the fine fuel load of the subject standard fuel model (t a^{-1})

3.051 is the standard deviation of the fine fuel load of the 53 standard fuel models (t ac^{-1})

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

Choosing a standard fuel model

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

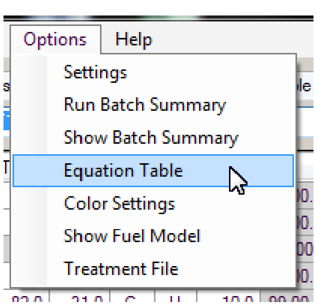
Appendix C: Adding and Editing Tree Species in FuelCalc

FuelCalc includes an internal table of all the species crown biomass equations used to calculate canopy fuels. However, users may want to modify the equations selected for a species or may want to add new species and assign existing FuelCalc equations to that species.

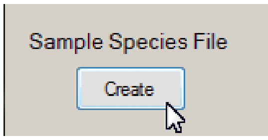
To facilitate using updated information FuelCalc looks for a file named *species.csv* when it first opens and, if the file exists in the ***C:\Users*\username*\AppData\Local\FuelCalc*** folder, then FuelCalc will use the crown biomass equations in that file rather than equations stored internally in the code.

The instructions below describe the steps used to create a file with new crown biomass assignments and/or new species.

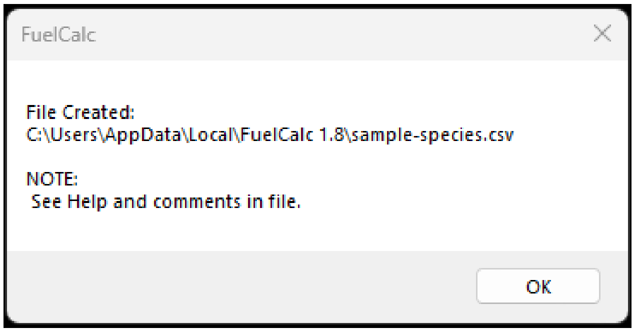
1) On the FuelCalc interface click **Options>Equation table**.



2) At the lower left click **Create** sample species file.



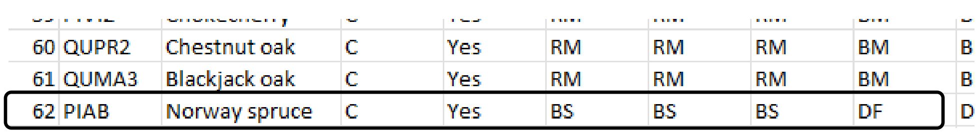
3) A file named *sample-species.csv* will be saved in: ***C:\Users*****username*****\AppData\Local\FuelCalcx.x.*** Click **OK**.



4) In Windows Explorer or My Computer navigate to the *sample-species.csv* file and double-click the filename to open in Excel.

5) The easiest way to add a species is to copy the row of a similar species and paste in the new row at the bottom.

6) Change the first three columns (Order Num, Species Code, and Common Name). The new species can then be assigned equation codes that are available in FuelCalc (Figure C-1). Two-letter species equation codes are defined in Appendix D.



60	QUPR2	Chestnut oak	C	Yes	RM	RM	RM	BM	B
61	QUMA3	Blackjack oak	C	Yes	RM	RM	RM	BM	B
62	PIAB	Norway spruce	C	Yes	BS	BS	BS	DF	D

Figure C-1: This example shows Norway spruce added in sample-species.csv by copying the black spruce record and renaming it. Now PIAB can be included in the FuelCalc canopy calculations and mortality simulations.

Table C-1. Column definitions for the species.csv file.

Title	Definition
Order Num	Sequential number.
Species Code	NRCS species code.
Common Name	Common name.
Conifer/Hard/PJ	This field is no longer used
Inc CBD	Include tree record with this species code in canopy fuel calculations: Yes or No.
Tot[1]	Two-letter species code for calculating total crown biomass.
Fol[1]	Two-letter species code for calculating foliage crown biomass.
Twg[1]	Two-letter species code for calculating small branch (0">0.25" diameter) crown biomass.

1in[1]	Two-letter species code for calculating 1 in. branch crown biomass.
3in[1]	Two-letter species code for calculating 3 in. branch crown biomass.
3+[1]	Two-letter species code for calculating 3+ in. branch crown biomass.
Vert Dist[1]	Two-letter species code for calculating vertical distribution of crown fuel.
Crown Reduc[1]	Two-letter species code for calculating reduction in crown biomass based on crown class.
Canopy Cover[1]	Equation number used to calculate the canopy cover. Don't change.
Bole Volume	Equation number used to calculate bole volume. Don't change.
FOFEM-Mort Spe-Code	NRCS species code used for calculating tree mortality. Valid codes are the species codes in *fof_spp.csv*. Refer to the FOFEM User Guide for more information about the mortality equations.

[1] See Appendix D for more information

By default, FuelCalc does not calculate CBD, CBH, or SH for hardwood trees because hardwood trees generally do not influence crown fire. By changing the entry in the *CBD* column from "No" to "Yes," the species will be included in the CBD, CBH, and SH calculations, and considered part of the available canopy.

NOTE: Many species (including hardwood trees) are assigned the FOFEM default mortality equation which is based on results from conifer mortality studies. See the Scientific Content section of the FOFEM User Guide for more information.

9) When you have finished making changes, save the file as *species.csv*.

10) Close and re-open **FuelCalc**.

11) Select **Options>Equation Table** and confirm the changes made in *species.csv* by checking the Equation Reference Table.

12) Remember to delete or change the name of *species.csv* if you want to go back to using the internal FuelCalc equations.

Appendix D: FuelCalc Calculation Notes

FuelCalc Biomass Equations

This appendix contains six subsections describing the biomass equation used in FuelCalc and the logic for computing crown and canopy biomass:

1. Crown weight equations
2. Crown weight proportion equations (foliage and small branch)
3. Vertical distribution
4. Crown class adjustment factors
5. Calculating canopy bulk density
6. Newer equations

7. Small tree equations
8. Canopy cover

The two character species identifiers (Id) that are shown in the equation lists are used internally in FuelCalc to identify equations. The species names (Name) are, for the most part, the names of the species for which the equations were originally developed. FuelCalc contains an internal species list that connects the species codes to equations using the Id.

Concerning other issues related to canopy bulk density measurements, please refer to the following source: *Reinhardt, E.D., and Crookston, N.L., Technical Editors. The Fire and Fuels Extension to the Forest Vegetation Simulator. Rocky Mountain Research Station RMRS-GTR-116. 2003. 218 p.*

Crown Weight Equations

Crown weight equations predict total canopy weight (lb). Total canopy weight is made up of all size class fuels. Most of the canopy weight equations are based on the original research papers listed in the "Source" column below.

Sources for additional crown equations are shown in the Newer Biomass Equation in FuelCalc.

Id = Species equation identifier, as used by FuelCalc
Name = Species common and scientific name
Source = Research paper
Code = Computer program source code that the equation was taken from
Equation = Weight equation as used in program source code

Id	Species Name	Source	Code	Equation
PP	Ponderosa Pine	Brn-78	BK	wt = exp(0.268 + 2.074 * ln(Dia))
GF	Grand Fir	Brn-78	BK	wt = exp(1.3094 + (1.6076 * ln(Dia)))
DF	Douglas Fir	Brn-78	BK	wt = exp(1.1368 + 1.5819 * ln(Dia)
LP	Lodgepole Pine	Brn-78	BK	wt = exp(0.1224 + 1.8820 * ln(Dia)
WL	Western Larch	Brn-78	BK	wt = exp(0.4373+ 1.6786 * ln(Dia)
SF	Subalpine Fir	Brn-78	BK	wt = (7.345 + (1.255 * Dia * Dia))
ES	Engelmann Spruce	Brn-78	BK	wt = exp(1.0404 + 1.7096 * ln(Dia)
WB	Whitebark Pine	Brn-78	BK	wt = (0.8371 * Dia * Dia) - 1
AL	Subalpine Larch			Uses Western Larch
WP	West. White Pine	Brn-78	BK	wt = exp(0.7276 + 1.5497* ln(dia))
WC	Western Redcedar	Brn-78	BK	wt = exp(0.8815 + 1.6389 * ln(Dia))
WH	Western Hemlock	Brn-78	BK	wt = exp(0.7218 + 1.7502 * ln(Dia))
PS	Southwest Ponderosa Pine			Uses ponderosa pine
BM	Bigleaf Maple	SL-83	SR	wt = exp(-0.0582 + 2.1505 * log(Dia))
MA	Pacific Madrone	SL-83	SR	wt = exp(-0.7881 + 2.4839 * log(Dia))
SE	Sequoia			Uses Western Redcedar
TO	Tanoak	SL-83	SR	wt = exp(-0.3169 + 2.2774 * log(Dia))
RA	Red Alder	SL-83	SR	wt = exp(-1.3290 + 2.6232 * log(Dia))
MH	Mountain Hemlock	Gh-79	SR	wt = exp(-3.8169 + 1.9756 * log (Dia * 2.54)) + exp(-5.2581 + 2.6045 * log (Dia * 2.54))
PY	Pinyon Pine	Gr-92	LG	See Pinyon Grier below
JP	Oneseed Juniper	Gr-92	LG	See Juniper Grier below

Crown Weight Proportion Equations (Foliage & Small Branch)

Equations use to predict the proportion of foliage and small branch biomass contained in the total canopy weight (lb). The combined weights of foliage and small branch makeup the available canopy fuel (ACF); in most cases, only fifty percent of small branch is included in the ACF.

Sources for additional crown equations are shown in the Newer Biomass Equation in FuelCalc.

Id = FuelCalc two-letter species equation identifier
Name = Species common and scientific name
Source = Research paper
Code = Computer program source code that the equation was taken from
Equation = Equation as used in program source code
pfol = Proportion of foliage
pb = Proportion of small branch (0 -> 1/4 inch) + pfol
NOTE: the weight (lb) of small branch material = pb - pfol
Dia = Diameter (in.)

Id	Species Name	Source	Code	Equation
PP	Ponderosa Pine	Brn-78	BK	pfol = 0.558 * exp(-0.0475 * Dia) pb = 0.625 * exp(-0.0511 * Dia)
GF	Grand Fir	Brn-78	BK	pfol = 1.0 / (1.592 + 0.0529 * Dia) pb = 1.0 / (1.15 + 0.0416 * Dia) If dia > 36, pfol = 0.286, pb = 0.378
DF	Douglas Fir	Brn-78	BK	pfol = 0.484 * exp(-0.021 * Dia) pb = 0.729 * exp(-0.0233 * Dia)
LP	Lodgepole Pine	Brn-78	BK	pfol = 0.493 – (0.0117 * Dia) pb = 0.777 – 0.0146 * Dia
WL	Western Larch	Brn-78	BK	pfol = 0.347 * exp(-0.0434 * Dia) pb = 0.745 * exp(-0.0362 * Dia)
SF	Subalpine Fir	Brn-78	BK	pfol = 0.597 * exp(-0.0425 * Dia) pb = 0.864 * exp(-0.0373 * Dia)
ES	Engelmann Spruce	Brn-78	BK	pfol = 0.578 * exp(-0.0325 * Dia) pb = 0.852 * exp(-0.0281 * Dia)
WB	Whitebark Pine	Brn-78	BK	pfol = 0.512 * exp(-0.0374 * Dia) pb = 0.864 * exp(-0.0585 * Dia)
AL	Subalpine Larch	Brn-78	BK	pfol = 0.512 * exp(-0.0374 * Dia) Uses whitebark pine pb = 0.745 * exp(-0.0362 * Dia) Uses western larch
WP	Western White Pine	Brn-78	BK	pfol = 0.550 * exp(-0.0345 * Dia) pb = 0.914 - 0.0978 * sqrt(Dia)
WC	Western Redcedar	Brn-78	BK	pfol = 0.6174 * exp(-0.02326 * Dia) pb = 0.7562 * exp(-0.02411 * Dia)
WH	Western Hemlock	Brn-78	BK	pfol = 0.547 * exp(-0.0370 * Dia) pb = 0.835 * exp(-0.0380 * Dia)
QA	Aspen	Brn-78	BK	pfol = 0.512 * exp(-0.0374 * Dia) Uses whitebark pine pb = 0.745 * exp(-0.0362 * Dia) Uses western larch
PS	Southwest Ponderosa Pine			Uses ponderosa pine
BM	Bigleaf Maple	SL-83	SR	pfol = 1.0 / (4.6762 + 0.1091 * pow (Dia,2.0390)) pb = 1.0 / (3.3212 + 0.0777 * pow (Dia,2.0496))
MA	Pacific Madrone	SL-83	SR	pfol = 1.0 / (1.6013 + 0.3591 * pow(Dia,1.3090)) pb = 1.0 / (1.0357 + 0.2263 * pow(Dia,1.3567))
SE	Sequoia	Brn-78	SR	pfol = 0.5474 * exp(-0.03697 * Dia) Uses western hemlock pb = 0.8352 * exp(-0.03802 * Dia) Uses western hemlock
TO	Tanoak	SL-83	SR	pfol = 1.0 / (1.7936 + 0.5952 * pow (Dia,0.7239)) pb = 1.0 / (0.9940 + 0.4229 * pow (Dia,0.6520))
RA	Red Alder	SL-83	SR	pfol = 1.0 / (2.7638 + 0.2155 * pow (Dia,1.3364)) pb = 1.0 / (1.286 + 0.1016 * pow (Dia,1.3525))

```
MH Mountain Hemlock    Brn-78  SR      if (Dia <= 40.0) pfol = 0.5474 * exp (-0.03697 * Dia)
       Uses western hemlock            pb  = 0.8352 * exp (-0.03802 * Dia)
                                       if (Dia > 40.0)  pfol = 0.125; pb  = 0.183
PY Pinyon Pine         Gr-92   LG      See Pinyon Grier below
JP Oneseed Juniper     Gr-92   LG      See Juniper Grier below
```

Canopy Weight and Proportion Equation Codes:

BK = Robert Keane, Missoula Fire Science Laboratory, Missoula, MT

SR = Stephanie Rebain, Rocky Mountain Research Station, Moscow, ID

LG = Larry Gangi, SEM LLC, Missoula, MT

TF = Tracy Frescino, Forest Inventory Analysis, Ogden, UT

Most of the canopy weight and proportion equations used by FuelCalc were taken directly from previously written software programs written by BK and SR. The exceptions are the Pinyon/Juniper equations that were researched and implemented by LG and TF.

Pinyon - Grier 1992, crown weight and proportion. Diameter (dia) is in centimeters, weight is in kilograms

```
Bole w/bark                  StemBark  = pow( 10.0,  (-2.588 + 2.955 * log10(diam)))
Twigs < 2.5 cm               BraSml = pow( 10.0,  (-1.613 + 2.088 * log10(diam)))
Foliage                      TotFol = pow( 10.0,  (-0.946 + 1.565 * log10(diam)))
Bole, branch & foliage       Total = pow( 10.0,  (-1.468 + 2.582 * log10(diam)))
Available Crown Fuel         ACF = TotFol + (0.33 * BraSml)
Total Crown Weight           CW = Total - StemBark;
Proportion of Foliage        pfol = ( TotFol / CW ): if pfol > 0.95 ;  pfol = 0.95
Proportion of Small Branch   pb = ACF / CW: if pb > 0.95; pb = 0.95
```

Juniper - Grier 1992, crown weight and proportion. Diameter (dia) is in centimeters, weight is in kilograms

```
Bole w/bark                  StemBark  = pow( 10.0, (-2.297 + 2.437 * log10(diam))
Twigs < 2.5 cm               BraSml    = pow( 10.0, (-1.476 + 1.787 * log10(diam))
Foliage - Young              FolYng  = pow( 10.0, (-1.358 + 1.841 * log10(diam))
Foliage - Mature             FolMat = pow( 10.0, (-0.862 + 1.399 * log10(diam))
Foliage - Average            Fol = (FolYng + FolMat) / 2.0
Bole, branch & foliage       Total     = pow( 10.0, (-1.157 + 2.086 * log10(diam))
Availabel Canopy Fuel        ACF = Fol + ( 0.25 * BraSml )
Total Canopy Weight          CW  = Total - StemBark
Proportion of Foliage        pfol = ( Fol / CW ): if pfol > 0.95;   pfol = 0.95
Proportion small branch      pb  = ( ACF / CW ): if pb > 0.95;  pb = 0.95
```

Canopy Weight and Proportion Equation Sources:

Brn-78: *Brown, JK. 1978. Weight and Density of Crowns of Rocky Mountain Conifers. USDA Forest Service, Research Paper INT-197.*

SL-83: *Snell, J. A. and S. N. Little, 1983: Predicting Crown Weight and Bole Volume of Five Western Hardwoods. PNW-GTR-151, 37 pp.*

Gh-79: *Gholz, H. L., C. C. Grier, A. G. Campbell, and A. T. Brown. 1979. Equations for estimating biomass and leaf area of plants in the Pacific Northwest. Oregon State University, Forestry Research Laboratory, Research Paper 41*

Gr-92: Grier. 1992. *Biomass distribution and productivity of Pinus edulis-Juniperus monosperma woodlands of north-central Arizona, 50 (1992) 331-350*

Vertical Distribution Equations

These equations are used to determine the amount of available canopy fuel that is contained in each layer of a tree's crown.

Id = FuelCalc two-letter species equation identifier
Name = Common Name
Equation = Equation as implemented in source code
pw = Proportion of weight (available canopy fuel)
ph = Fractional crown length (length from bottom crown) / (total length of crown)

```
Id      Name                       Equation
PP      Ponderosa               pw = (2.3637 * sqr(ph)) - (1.3637 * cube(ph))
DF      Douglas Fir             pw = (2.3284 * sqr(ph)) - (1.3284 * cube (ph))
LP      Lodgepole Pine          pw = (1.6045 * sqr(ph)) - (0.6045 * cube(ph))
IC      Incense/West. Red Ced. pw = (2.5395 * sqr(ph)) - (1.5395 * cube(ph))
PS      Ponderosa SW            pw = (0.1251 * ph) + (2.8072 * sqr(ph)) - (1.9322 * cube(ph))
WF      White fir               pw = ph
UN      Uniform                 pw = ph;       (default for hardwood species)
```

Vertical Distribution Equation Source:
Based on: *Reinhardt, E; Scott, J; Gray, K: Keane, R. 2006. Estimating canopy fuel characteristics in five conifer stands in the western United States using tree and stand measurements. Can. J. For. Res. 2803-2814.*
The vertical distribution equations were calculated by Kathy Gray using biomass data obtained by destructively sampling trees of different species at 5 study sites. To obtain the equations for the cumulative proportion of biomass at a given height, a nonlinear regression technique was used with proportion of crown as the independent variable and cumulative proportion of biomass as the dependent variable.

See the section below on *Calculating Canopy Bulk Densit*y for details on how these equations are used to distribute biomass into each vertical layer.

Crown Class Adjustment Factors (Crown Reduction)

These factors are used to reduce a tree's crown weight based on its crown class. Dom.=Dominant, Co-dom.=Co-dominant, Interm.=Intermediate, Supp.=Suppressed.

Code	Species	Source[1]	Dom.	Co-dom.	Interm.	Supp.	Other/none
WF	White fir	KG	0.85	0.85	0.35	0.3	0.5
PP	Ponderosa pine	KG	0.55	0.55	0.3	0.15	0.5
PS	SW ponderosa pine	KG	0.3	0.3	0.15	0.1	0.5
IC	Incense cedar	KG	1.1	1.1	0.75	0.4	0.5
DF	Douglas-fir	KG	1.15	1.15	1.15	0.75	0.5
LP	Lodgepole pine	KG	0.6	0.6	0.6	0.3	0.5
WL	Western larch	BK	1.0	0.45	0.3	0.2	0.5
WP	White pine	BK	0.8	0.9	0.6	0.35	0.7
WC	Western redcedar	BK	1.0	1.0	1.0	0.6	0.75
GF	Grand fir	BK	0.65	0.7	0.35	0.55	0.5
PJ	Pinyon & juniper	None	1.0	1.0	1.0	1.0	1.0

[1] Crown Class Adjustment Factor Sources:

Kathy Gray (KG) - *Reinhardt, E; Scott, J; Gray, K: Keane, R. 2006. Estimating canopy fuel characteristics in five conifer stands in the western United States using tree and stand measurements. Can. J. For. Res. 2803-2814.* Crown class factors were calculated by Kathy Gray to adjust the predicted biomass obtained from the equations for tree class. The tree class adjustments reported were the multipliers that minimized the average difference between the observed biomass of the tree and the predicted biomass of a tree using the biomass equations. The adjustments were applied to a tree by multiplying the predicted biomass by the specific adjustment for that particular tree class.

Bob Keane (BK) - *Keane, R.E., S.F. Arno, and J.K. Brown. 1989. Modeling cumulative fire effects in ponderosa pine/Douglas-fir forests. Ecology 71(1): 189-203*.

Keane, R.E., S.F. Arno, and J.K. Brown. 1989. FIRESUM -- an ecological process model for fire succession in western conifer forests. USDA Forest Service General Technical Report INT-266. 76 p.

Keane, Robert E., Penelope Morgan, Steven W. Running. 1996. Fire-BGC – a mechanistic ecological process model for simulating fire succession on coniferous forest landscapes of the Northern Rocky Mountains. Res. Paper INT-484. Ogden, UT: U.S. Department of Agriculture Forest Service. Intermountain Research Station. 122 p.

None - Currently there are no adjustment factors for Pinyon or Juniper so they are all set to 1.0.

Newer Biomass Equations in FuelCalc

This section contains new biomass formulas that have been added to the program. Existing FuelCalc vertical distribution formulas and canopy class factors needed to calculate canopy bulk density were then associated with each new species using a best-fit strategy.

The table below contains the species common names and the research papers from which their biomass formulas were taken. Most research papers contained only total crown and foliage biomass formulas; for these species, a best-fit twig biomass formula was chosen from the existing FuelCalc species formulas. Sources are identified below the table.

Species	Source
Northern Red Oak	Lom-81
Balsam Fir	Ker-108, twig Grand Fir Brn-78
Atlantic White Cedar	Ker-114, twig Western Redcedar Brn-78
Black Spruce	Ker-108, twig Grand Fir Brn-78
Red Spruce	Fre-134, twig Grand Fir Brn-78
Eastern White Pine	Ker-114, twig Grand Fir Brn-78
Eastern Hemlock	Ker-114, twig Western Hemlock Brn-78
Quaking Aspen-NS	Ker-108, twig Lom-78
Quaking Aspen-MN	Lom-78
Red Maple	Fre-134, twig Bigleaf Maple SL-83
Sugar Maple	Fre-134, twig Bigleaf Maple SL-83
Yellow Birch	Ker-114, twig Red Alder SL-83
Paper Birch	Ker-108, twig Red Alder SL-83, used Ker's White Birch
Pitch Pine	Duv-05
Loblolly Pine	Rog-16, twig Lodgepole Pine Brn-78
Giant Chinkapin	SL-83

Sources for new species

Lom-81:
Loomis, Robert M., Blank, Richard W. 1981. Estimating northern red oak crown component weights in the Northeastern United States. Research Paper NC-194. St. Paul, MN; U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station

Lom-78: *Loomis, Robert M., Roussopoulos, Peter J. 1978. Estimating aspen crown fuels in northeastern Minnesota. Research Paper NC-156. St. Paul, MN; U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station.*

Ker-108: *Ker, M.F. 1980. Tree Biomass equations for ten major species in Cumberland County, Nova Scotia. Maritime Forest Research Centre. Fredericton, New Brunswick. Inf. Rep. M-X-108. Canadian Forestry Service, Environment Canada.*

Ker-114: *Ker, M.F. 1980. Tree Biomass equations for seven species in southwestern New Brunswick. Maritime Forest Research Centre. Fredericton, New Brunswick, Rep. M-X-114, Canadian Forestry Service, Environment Canada*

Fre-134: *Freedman B, Duinker, and others. 1982. Forest biomass and nutrient studies in central Nova Scotia, Institute for Resource and Environmental Studies and Department of Biology, Dalhousie University, Halifax, Nova Scotia, B3H 4J1 Maritime Forest Research Centre Fredericton, New Brunswick, Report M-X-134*

Duv-05: *Duveneck, Matthew J. 2005. Characterizing Canopy Fuels as They Affect Fire Behavior in Pitch Pine (Pinus Rigida). MS Thesis, University of Massachusetts Amherst*

Rog-16: *Rogerson, T. 1964. Estimating foliage on loblolly pine. Res. Note SO-16. New Orleans, LA: U.S.*

Brn-78: *James K. Brown. 1978. Weight and Density of Crowns of Rocky Mountain Conifers, , USDA Forest Service, Research Paper INT-197.*

SL-83: *Snell, J. A. and S. N. Little, 1983. Predicting Crown Weight and Bole Volume of Five Western Hardwoods. PNW-GTR-151, 37 pp.*

Default Equation Table

The equation assignments stored in the internal table are displayed in the table below. The *Incl. CBD* column indicates whether or not crown and bole biomass for the associated species will be included in the crown biomass totals. By default, for hardwoods the field is set to *No*. You can modify the default setting by creating a custom equation file as described in Appendix C. Two-letter abbreviations are defined in the Crown weight equations, Crown weight proportion equations (foliage and small branch), Vertical distribution and Crown class adjustment factors sections above.

Common Name	Incl. CBD	Total	Fol.	Twig	1"	3"	3"+	Vert. Dist.	Crown Reduc.
Red Alder	No	RA	RA	RA	RA	RA	RA	UN	DF
White Alder	No	RA	RA	RA	RA	RA	RA	UN	DF
Alaska Cedar	Yes	WC	WC	WC	WC	WC	WC	IC	IC
Incense Cedar	Yes	WC	WC	WC	WC	WC	WC	IC	IC
Western Redcedar	Yes	WC	WC	WC	WC	WC	WC	IC	IC
Douglas Fir	Yes	DF	DF	DF	DF	DF	DF	DF	DF
Grand Fir	Yes	GF	GF	GF	GF	GF	GF	DF	WF
Noble Fir	Yes	GF	GF	GF	GF	GF	GF	DF	WF
Pacific Silver Fir	Yes	GF	GF	GF	GF	GF	GF	DF	WF
Subalpine Fir	Yes	SF	SF	SF	SF	SF	SF	DF	WF
White Fir	Yes	GF	GF	GF	GF	GF	GF	DF	WF
Mountain Hemlock	Yes	WH	WH	WH	WH	WH	WH	DF	DF
Western Hemlock	Yes	WH	WH	WH	WH	WH	WH	DF	DF
Rocky Mountain Juniper	Yes	JP	JP	JP	JP	JP	JP	DF	PJ
Utah Juniper	Yes	JP	JP	JP	JP	JP	JP	DF	PJ

Subalpine Larch	Yes	WL	WL	WL	WL	WL	WL	DF	WF
Western Larch	Yes	WL	WL	WL	WL	WL	WL	PP	PP
Madrone	No	MA	MA	MA	MA	MA	MA	UN	DF
Mountain Maple	No	BM	BM	BM	BM	BM	BM	UN	WF
Tanoak	No	TO	TO	TO	TO	TO	TO	UN	DF
Bristlecone Pine	Yes	LP	LP	LP	LP	LP	LP	LP	LP
Jeffrey Pine	Yes	PP	PP	PP	PP	PP	PP	PP	PP
Limber Pine	Yes	LP	LP	LP	LP	LP	LP	PP	PP
Lodgepole Pine	Yes	LP	LP	LP	LP	LP	LP	LP	LP
Ponderosa Pine	Yes	PP	PP	PP	PP	PP	PP	PP	PP
Ponderosa Pine SW	Yes	PP	PP	PP	PP	PP	PP	PS	PS
Sugar Pine	Yes	PP	PP	PP	PP	PP	PP	PP	PP
Western White Pine	Yes	WP	WP	WP	WP	WP	WP	LP	LP
Whitebark Pine	Yes	WB	WB	WB	WB	WB	WB	LP	LP
Colorado Pinyon	Yes	PY	PY	PY	PY	PY	PY	DF	PJ
Coast Redwood	Yes	WC	WC	WC	WC	WC	WC	DF	DF
Giant Sequoia	Yes	WC	WC	WC	WC	WC	WC	DF	DF
Blue Spruce	Yes	ES	ES	ES	ES	ES	ES	DF	DF
Brewer Spruce	Yes	ES	ES	ES	ES	ES	ES	DF	DF
Engelmann Spruce	Yes	ES	ES	ES	ES	ES	ES	DF	WF
Sitka Spruce	Yes	ES	ES	ES	ES	ES	ES	DF	DF
White Spruce	Yes	ES	ES	ES	ES	ES	ES	DF	DF
Pacific Yew	Yes	WC	WC	WC	WC	WC	WC	DF	WF
Quaking Aspen	No	QA	QA	QA	BM	BM	BM	UN	WF
Paper Birch	No	PB	PB	PB	RA	RA	RA	UN	DF
Yellow Birch	No	YB	YB	YB	RA	RA	RA	UN	DF
Atlantic White Cedar	Yes	AC	AC	AC	WC	WC	WC	IC	IC
Balsam Fir	Yes	BF	BF	BF	GF	GF	GF	DF	WF
Eastern Hemlock	Yes	EH	EH	EH	WH	WH	WH	DF	DF
Red Maple	No	RM	RM	RM	BM	BM	BM	UN	WF
Sugar Maple	No	SM	SM	SM	BM	BM	BM	UN	WF
Calif Black Oak	No	TO	TO	TO	TO	TO	TO	UN	DF
Giant Chinkapin	No	GC	GC	GC	GC	GC	GC	UN	DF
Northern Red Oak	No	RO	RO	RO	GC	GC	GC	UN	DF
Eastern White Pine	Yes	EP	EP	EP	DF	DF	DF	DF	DF
Loblolly Pine	Yes	LO	LO	LO	DF	DF	DF	DF	PP
Pitch Pine	Yes	PI	PI	PI	PP	PP	PP	PP	PP
Black Spruce	Yes	BS	BS	BS	DF	DF	DF	DF	DF
Red Spruce	Yes	RS	RS	RS	DF	DF	DF	DF	DF

Small Tree Biomass Equations

When tree dbh <u><</u>1" FuelCalc uses biomass calculated with equations from *Brown, J.K. 1978. Weight and Density of Crown of Rocky Mountain Conifers. Res. Pap. INT-RP-197. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 56 p.*

The tables below were created by first calculating whole tree weight using the equations in Brown 1978, table 6 (equations for predicting whole tree weight for trees <15' tall) and then calculating the component biomass using the equations in Brown 1978, table 19 (equations for predicting proportion of foliage and branch material for tree <15' tall). Component biomass for trees with dbh <u><</u>1" and greater than 10' tall are set at the values for a 10' tree (Wt = lbs tree^{-1}).

	1 foot						2 feet						3 feet					
Species	**Total Wt***	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**
Douglas-fir	0.030	0.011	0.005	0.011	0.002	0.000	0.200	0.076	0.036	0.076	0.012	0.000	0.560	0.213	0.101	0.213	0.034	0.000
Ponderosa pine	0.030	0.011	0.005	0.011	0.002	0.000	0.200	0.076	0.036	0.076	0.012	0.000	0.560	0.213	0.101	0.213	0.034	0.000
Spruce	0.030	0.015	0.006	0.007	0.002	0.000	0.200	0.102	0.042	0.046	0.010	0.000	0.560	0.286	0.118	0.129	0.028	0.000
Subalpine fir	0.030	0.015	0.006	0.007	0.002	0.000	0.200	0.102	0.042	0.046	0.010	0.000	0.560	0.286	0.118	0.129	0.028	0.000
Wester white pine	0.060	0.029	0.013	0.018	0.001	0.000	0.250	0.120	0.053	0.075	0.003	0.000	0.610	0.293	0.128	0.183	0.006	0.000
Grand fir	0.060	0.031	0.013	0.014	0.003	0.000	0.250	0.128	0.053	0.058	0.013	0.000	0.610	0.311	0.128	0.140	0.031	0.000
Whitebark/Limber pine	0.060	0.016	0.014	0.023	0.008	0.000	0.250	0.065	0.058	0.095	0.033	0.000	0.610	0.159	0.140	0.232	0.079	0.000
Western red cedar	0.020	0.010	0.004	0.005	0.001	0.000	0.130	0.066	0.027	0.030	0.007	0.000	0.340	0.173	0.071	0.078	0.017	0.000
Western larch	0.020	0.005	0.005	0.008	0.003	0.000	0.130	0.034	0.030	0.049	0.017	0.000	0.340	0.088	0.078	0.129	0.044	0.000
Lodgepole pine	0.020	0.008	0.004	0.008	0.001	0.000	0.130	0.049	0.023	0.049	0.008	0.000	0.340	0.129	0.061	0.129	0.020	0.000
Western hemlock	0.010	0.004	0.002	0.004	0.001	0.000	0.050	0.019	0.009	0.019	0.003	0.000	0.160	0.061	0.029	0.061	0.010	0.000

	4 feet						5 feet						6 feet					
Species	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**
Douglas-fir	1.180	0.448	0.212	0.448	0.071	0.000	2.090	0.648	0.293	0.481	0.669	0.000	3.330	1.032	0.466	0.766	1.066	0.000
Ponderosa pine	1.180	0.448	0.212	0.448	0.071	0.000	2.090	0.648	0.293	0.481	0.669	0.000	3.330	1.032	0.466	0.766	1.066	0.000
Spruce	1.180	0.602	0.248	0.271	0.059	0.000	2.090	0.836	0.334	0.355	0.543	0.000	3.330	1.332	0.533	0.566	0.866	0.000
Subalpine fir	1.180	0.602	0.248	0.271	0.059	0.000	2.090	0.836	0.334	0.355	0.543	0.000	3.330	1.332	0.533	0.566	0.866	0.000
Wester white pine	1.150	0.552	0.242	0.345	0.012	0.000	1.870	0.580	0.299	0.337	0.655	0.000	2.780	0.862	0.445	0.500	0.973	0.000
Grand fir	1.150	0.587	0.242	0.265	0.058	0.000	1.870	0.748	0.299	0.318	0.486	0.000	2.780	1.112	0.445	0.473	0.723	0.000
Whitebark/Limber pine	1.150	0.299	0.265	0.437	0.150	0.000	1.870	0.393	0.355	0.486	0.636	0.000	2.780	0.584	0.528	0.723	0.945	0.000
Western red cedar	0.690	0.352	0.145	0.159	0.035	0.000	1.170	0.468	0.187	0.199	0.304	0.000	1.820	0.728	0.291	0.309	0.473	0.000
Western larch	0.690	0.179	0.159	0.262	0.090	0.000	1.170	0.246	0.222	0.304	0.398	0.000	1.820	0.382	0.346	0.473	0.619	0.000
Lodgepole pine	0.690	0.262	0.124	0.262	0.041	0.000	1.170	0.363	0.164	0.269	0.374	0.000	1.820	0.564	0.255	0.419	0.582	0.000
Western hemlock	0.350	0.133	0.063	0.133	0.021	0.000	0.640	0.198	0.090	0.147	0.205	0.000	1.050	0.326	0.147	0.242	0.336	0.000

	7 feet						8 feet						9 feet					
Species	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**
Douglas-fir	4.940	1.531	0.692	1.136	1.581	0.000	6.950	2.155	0.973	1.599	2.224	0.000	9.390	2.911	1.315	2.160	3.005	0.000
Ponderosa pine	4.940	1.531	0.692	1.136	1.581	0.000	6.950	2.155	0.973	1.599	2.224	0.000	9.390	2.911	1.315	2.160	3.005	0.000
Spruce	4.940	1.976	0.790	0.840	1.284	0.000	6.950	2.780	1.112	1.182	1.807	0.000	9.390	3.756	1.502	1.596	2.441	0.000
Subalpine fir	4.940	1.976	0.790	0.840	1.284	0.000	6.950	2.780	1.112	1.182	1.807	0.000	9.390	3.756	1.502	1.596	2.441	0.000
Wester white pine	3.880	1.203	0.621	0.698	1.358	0.000	5.190	1.609	0.830	0.934	1.817	0.000	6.710	2.080	1.074	1.208	2.349	0.000
Grand fir	3.880	1.552	0.621	0.660	1.009	0.000	5.190	2.076	0.830	0.882	1.349	0.000	6.710	2.684	1.074	1.141	1.745	0.000
Whitebark/Limber pine	3.880	0.815	0.737	1.009	1.319	0.000	5.190	1.090	0.986	1.349	1.765	0.000	6.710	1.409	1.275	1.745	2.281	0.000
Western red cedar	2.640	1.056	0.422	0.449	0.686	0.000	3.650	1.460	0.584	0.621	0.949	0.000	4.840	1.936	0.774	0.823	1.258	0.000
Western larch	2.640	0.554	0.502	0.686	0.898	0.000	3.650	0.767	0.694	0.949	1.241	0.000	4.840	1.016	0.920	1.258	1.646	0.000
Lodgepole pine	2.640	0.818	0.370	0.607	0.845	0.000	3.650	1.132	0.511	0.840	1.168	0.000	4.840	1.500	0.678	1.113	1.549	0.000
Western hemlock	1.600	0.496	0.224	0.368	0.512	0.000	2.310	0.716	0.323	0.531	0.739	0.000	3.180	0.986	0.445	0.731	1.018	0.000

	10 feet					
Species	**Total Wt**	**Fol Wt**	**1hr Wt**	**10hr Wt**	**100hr Wt**	**1k hr Wt**
Douglas-fir	12.300	3.321	1.353	2.337	3.690	1.599
Ponderosa pine	12.300	3.321	1.353	2.337	3.690	1.599
Spruce	12.300	4.059	1.476	2.214	3.567	0.984
Subalpine fir	12.300	4.059	1.476	2.214	3.567	0.984
Wester white pine	8.430	2.108	1.012	1.265	3.119	0.927
Grand fir	8.430	2.782	1.012	1.517	2.445	0.674
Whitebark/Limber pine	8.430	1.265	1.180	1.349	3.709	0.927
Western red cedar	6.240	2.059	0.749	1.123	1.810	0.499
Western larch	6.240	0.936	0.874	0.998	2.746	0.686
Lodgepole pine	6.240	1.685	0.686	1.186	1.872	0.811
Western hemlock	4.240	1.145	0.466	0.806	1.272	0.551

Canopy Cover

Canopy Cover is calculated using crown width equations, which are then converted to crown area. The equations use species specific coefficients (see table below). Once crown cover is calculated for individual trees and then accumulated for the treelist, 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.CSV) in the installation folder for more information.

The overlap calculation is:

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

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

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

Eq no.	Species Code	A Coeff.	B Coeff.	Ratio Coeff.
1	"SF"	3.9723	0.5177	0.473
2	"WF"	3.8166	0.5229	0.452
3	"GF"	4.187	0.5341	0.489
4	"AF"	3.2348	0.5179	0.385
5	"RF"	3.1146	0.578	0.345
7	"NF"	3.0614	0.6276	0.32
8	"YC"	3.5341	0.5374	0.331

9	"C"	4.092	0.4912	0.412
10	"S"	3.6802	0.494	0.412
11	"LP"	2.4132	0.6403	0.298
12	"JP"	3.2367	0.6247	0.406
13	"SP"	3.061	0.6201	0.385
14	"WP"	3.4447	0.5185	0.476
15	"PP"	2.8541	0.64	0.407
16	"DF"	4.4215	0.5329	0.517
17	"RW"	4.4215	0.5329	0.517
18	"RC"	6.2318	0.4259	0.698
19	"WH"	5.4864	0.5144	0.533
20	"MH"	2.9372	0.5878	0.253
21	"BM"	7.5183	0.4461	0.815
22	"RA"	7.0806	0.4771	0.73
23	"WA"	7.0806	0.4771	0.73
24	"PB"	5.898	0.4841	0.601
25	"GC"	2.4922	0.8544	0.14
26	"AS"	4.091	0.5907	0.351
27	"CW"	7.5183	0.4461	0.815
28	"WO"	2.4922	0.8544	0.14
29	"J"	4.5859	0.4841	0.468
30	"LL"	2.1039	0.6758	0.207
31	"WB"	2.1606	0.6897	0.255
32	"KP"	2.1451	0.7132	0.248
33	"PY"	4.5859	0.4841	0.468
34	"DG"	2.4922	0.8544	0.14
35	"HT"	4.5859	0.4841	0.468
36	"CH"	4.5859	0.4841	0.468
37	"WI"	4.5859	0.4841	0.468
38	""	4.4215	0.5329	0.517

Calculating Canopy Bulk Density

Six basic steps are required to calculate canopy bulk density (CBD), canopy base height (CBH) and stand height (SH):

- Calculate a tree's total canopy weight (CW).
- Adjust the CW by applying the appropriate canopy class factor.
- Calculate available canopy fuel (ACF) from CW.
- Vertically distribute ACF into canopy layers.
- Repeat steps 1 to 4 for each tree and accumulate calculated values.
- Examine layers to determine CBD, CBH and SH.

1. Calculate the tree's total CW by using the Canopy Weight equation. Weight equations are species-specific, although some species use the same equation. Most weight equations are based on tree diameter, but a few equations include a crown ratio.

2. Adjust the calculated CW by applying the appropriate Canopy Class Factor according to the tree's canopy class (for example, dominant, codominant, etc.).

3. Calculate ACF using Proportion Equations.
Current equations in use are entirely based on tree diameter.

ACF = (pfol * CW) + ((pb * CW) * 0.5)

ACF = weight of foliage plus fifty percent of small branch
pfol = percent of foliage
pb = percent of small branch
small branch = less than 1/4 inch in diameter, sometimes referred to as twig

4. Vertically distribute the ACF into a crown layer array
For each layer [i] in the crown
CLA[i] = (ACF * (pw (ph([i+1])))) - (ACF * (pw (ph([i]))))

CLA[] = crown layer array
i = layer index, i-th layer in crown
ph = the height from the bottom of the crown up to the specified i-th layer, expressed as a percentage of total crown height
pw = percentage of total crown weight from the bottom of crown up to the specified percentage in height (ph)

Total crown height is the distance from the bottom of the crown to the top of the crown.

With the formula above, determining the ACF for layer[i] can be accomplished by calculating the ACF once for a height at the top layer[i] and once for height at the bottom of layer[i], then taking the difference to get the amount of ACF in layer[i]. Repeating this process for each layer in the tree crown results in the ACF for every layer.

Example to illustrate getting the ACF for layer 4:

i = 4
Layer width = 1 foot
Total crown height = 20 feet
ACF = 200 pounds
Vertical distribution equation:
*PP Ponderosa pw = (2.3637 * sqr(ph)) - (1.3637 * cube(ph))*

Initial Formula:
*CLA[i] = (ACF * (pw (ph([i+1])))) - (ACF * (pw (ph([i]))))*

The bounds of the 4th layer are 4 and 5 feet,
The initial formula with layer heights inserted is
*CLA[4] = (200 * (pw (ph(5)))) - (200 * (pw (ph(4))))*

Then the percentage in height that 5 feet is of a 20 foot crown is ph(5) or 0.25

Next the percentage of weight from bottom of crown to 5 feet is pw(0.25)
And using our PP Ponderosa equation and inserting 0.25.
*pw = (2.3637 * sqr(ph))   - (1.3637 * cube(ph))*
*0.13 = (2.3637 * sqr(0.25)) - (1.3637 * cube(0.25))*

Now multiply the percentage times ACF to get the predicted ACF from the bottom of the crown to a height of 5 feet.
*26 pounds = 0.13 * (200 pounds)*

Repeating the process for 4 feet, the height at the bottom for the 4th layer, obtains 16 pounds.

Finally take the difference of the two calculations (26-16), yielding 10 pound,s which is the ACF in the 4th layer.

5. Repeat steps 1 through 4 for each tree to accumulate the CW and ACF in the each crown layer.
6. Determine the maximum CBD, canopy base height (CBH) and stand height (SH) by examining the weight assigned to each layer in step 3.
CBD is the maximum value found, expressed as kilograms per cubic meter (kg m^{-3})
CBH is the height of the lowest layer containing a minimum value of 0.012 kg m^{-3}.
SH is the height of the highest layer containing a minimum value of 0.012 kg m^{-3}.

If CBD < 0.012, then CBH and SH are the lowest and highest layer, respectively, that exceed CBD*0.1.

Notes: Dead trees are not and should not be included in any type of FuelCalc's input; accordingly, they are not used in any calculations.
Hardwood tree crown weights are not included in ACF; therefore, they are not used to calculate CBD, CBH and SH. Hardwood trees can be included in canopy fuel calculations by setting the *Inc CBD* field to "Yes" in the sample-species.csv file.

Canopy cover equation citation

Crookston, N.L. and Stage, A.R. 1999. Percent canopy cover and stand structure statistics from the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-24. Ogden, UT: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 11 p.

Appendix E: FuelCalc Command Line Batch

FuelCalc can be run from the command line. Four input files are required. Examples of all these input files are provided with the installer and can be found in *C:\Users*\username*\AppData\Local\FuelCalc*.

Description	File format	Example
.FFI files	Comma delimited format	FFI_Sample.ffi
.TRE files with macro plots and tree data	Comma delimited format	FFI_Sample.tre
Treatment file	Comma delimited format	CLB_Treatment.csv
Project file	Space delimited format	FC_Sample.fcp

File Descriptions

.FFI

Includes macro plot names and fuels data. Described in Appendix A.

.TRE

Includes macro plots names and tree data. Described in Appendix A.

Treatment file

This comma delimited file includes a row for each macro plot. The fields in the table below are required for each macro plot. If the file is created using the *Options>Treatment File* menu item the file is named *Link-Treatment.csv*.

Field Name	Description
Plot	Macro plot name. Must correspond to a macro plot name in the .FFI and .TRE files
MonStat	Monitoring status name used to uniquely identify multiple visits to the same plot.
RetPri	Retention Priority name. Must correspond to a Retention Priority set described in the FuelCalc *Project* file
Treatment	Treatment settings. Must correspond to a Treatment set described in the FuelCalc *Project* file
Thin	Is a thinning treatment to be simulated? Valid values: Yes or No
Prune	Is a pruning treatment to be simulated? Valid values: Yes or No
Pile	Is a piling treatment to be simulated? Valid values: Yes or No
Burn	Is a burning treatment to be simulated? Valid values: Yes or No

Project file

The file has an FCP extension and it includes all information saved from the user interface including settings for Retention Priorities, Treatments, Thinning, Prune, Broadcast Burn, Pile and Fuel Model Selector. The Retention Priorities and Treatments listed in the *Treatment* file must be defined in the *Project* file.

Running a simulation from the DOS window

Open a command window. Type *CMD* in the Windows Search window and hit Enter. A command window will open.

In the command window, change the directory to the FuelCalc installation folder. This is usually *C:\users*\username*\AppData\Local\FuelCalc 1.8*, where *username* is your Windows username.

```
cd C:\users\username\AppData\Local\FuelCalc 1.8
```

Set the path to the FuelCalc installation folder by typing *CLB_Path* at the command prompt. This sets the path to the directory where *FC_GUI.EXE* is saved.

Example Path command: *set path=%path%;C:\Program Files\FuelCalc 1.8*

At the command prompt type *CLB_Run* to run a simulation that uses example files included with the FuelCalc installer. The Output filename must have a .csv extension and the Error/Warning filename a .txt extension.

Example Run command: *FC_GUI FFI_Sample.ffi FFI_Sample.tre CLB_Treatment.csv FC_Sample.fcp FFI_Sample-Out.csv FFI_Sample-Err.txt*

NOTE: Don't include spaces in filenames

FuelCalc will create the *output* and error files and put them in the same directory as the input files. Be sure to check the Error files for issues.

Check the error/warning file. For example, there is no field in FFI for sapling crown class so if your TRE file includes records in the Trees-Saplings method you will see a warning for every sapling that states the tree record was given a crown class of *None*. Warnings do not stop the simulation – they are just reported for information. Errors will stop the simulation.

Example Project file

The example includes documentation (in italics) for each section. Compare this example to the *FC_Sample.fcp* file found here: *C:\Users*\username*AppData\Local\FuelCalc1.8*

```
# ======================================================================================
# This is a sample project file for running a FuelCalc Command Line Batch
# Lines starting with a # followed by a blank character are comments
# Lines starting with a # not followed by a blank character are switches
# Switches are space delimited. Do not use blank characters in names or descriptions
# The switches in this file are a subset of those found in a FuelCalc project file
# All switches in this file are required when running FuelCalc from the command line
# ======================================================================================
# Canopy Bulk Density threshold - see FuelCalc User Guide for details
#CBDThreshold 0.012
# ----------------------
# Species Retention Priority Groups - define all groups used in the #RetPri below
# Number consecutively starting with -0
#            Name   Species  min dbh   max dbh   Ret Pri
#Species-0 All      _Other   0         100       99
#Species-1 PIPO     PIPO     0         100       99
#Species-2 PIPO     _Other   0         100       0.5
# ----------------------
# Retention Priority
# Number consecutively starting with -0
#          Name    Description                      Priorities – see Retention Priorities                  Species Group
#RetPri-0 None    Has_no_influence                 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0   All
#RetPri-1 Low     Default_Low_Thinning             1.0 0.7 0.2 0.0 1.0 0.9 0.6 1.0 0.1 1.0 1.0 0.5 0.6 0.8   All
#RetPri-2 High    Default_High_Thinning            1.0 0.7 0.2 0.0 0.4 0.5 1.0 0.1 1.0 1.0 1.0 0.5 0.6 0.6   PIPO
#RetPri-3 Diam    Default_diameter_limit_harvest 1.0 0.1 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.5 1.0 0.1 _None
# ----------------------
# Treatments number consecutively starting with -0
# The 10-hr moisture value is used for Broadcast burning AND calculating torching and crowing indexes
# See the BCBMoist setting below
#                Name       Treat. Type    Treatment settings - see Treatments
#Treatment-0 Restore    TreeDensity    200 90 4 2 20 0 8 0 0 0 0 0 10 12 14 30 InteriorWest Summer
# ----------------------
# This setting will only be used if there is no 10 Hour moisture value specified in the plot's assigned treatment
#BCBMoist Dry
# ----------------------
# Fuel Model Selector
#FMSModel All
#FMSClimate Arid
#FMSBedDep  20.0000
#FMSSAVGra 1800.0000
#FMSSAVShu 1500.0000
#FMSSAV1Hr 2000.0000
# ---------------------
#DecimalPrecision 2
#PlotFileType FFI
#PlotName TESTFOREST1_::_PreBurn
```

```
#Color1
#FuelModelShow Yes
#PlotFileName C:\Users\smokey\AppData\Local\FuelCalc$1.8\FFI_Sample.ffi
```

The 10-hr moisture setting in the Treatment file is used to set the moisture levels input to Nexus for calculating crowning and torching index.

	Percent Moisture used in Nexus					
Moisture, 10-hr (%)	1-hr	10-hr	100-hr	Live Herb	Live Shrub	Foliar[5]
0 $\leq$ 6[1]	3	4	5	30	60	100
6 $\leq$ 10[2]	6	7	8	60	90	100
10 $\leq$ 16[3]	9	10	11	90	120	100
>16[4]	12	13	14	120	120	100

[1] Dead fuel moisture = D1 and live fuel moisture = L1; in Scott and Burgan 2005
[2] Dead fuel moisture = D2 and live fuel moisture = L2; in Scott and Burgan 2005
[3] Dead fuel moisture = D3 and live fuel moisture = L3; in Scott and Burgan 2005
[4] Dead fuel moisture = D4 and live fuel moisture = L4; in Scott and Burgan 2005
[5] Nexus suggested default

Appendix F: Significant Version Changes

- Version 1.1: Added torching and crowning index calculations, added torching and crowning index into summary reports.
- Version 1.2: Added biomass equations for small trees (<1" DBH), modified batch run to allow stop/abort, modified installation folders for better performance in Windows 7 and Windows 8.
- Version 1.3: Added Crown Ratio field in TRE file and command line batch functionality.
- Version 1.4: Includes FOFEM 6.3.1 updates. Added command line batch.
- Version 1.5: Includes FOFEM 6.4 updates.
- Version 1.6: Includes FOFEM 6.5 updates, except bole char equations have not been added.
- Version 1.7: Minor bug fixes.
- Version 1.8: Includes FOFEM 6.9.4 updates, .NET Framework 4.7 update, updated tree volume library.