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The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation

Abstract

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The Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) simulates fuel dynamics and potential fire behavior over time, in the context of stand development and management. Existing models of fire behavior and fire effects were added to FVS to form the FFE extension. New submodels representing snag and fuel dynamics were created to complete the linkages. Additional outputs available from FFE include estimates of stored carbon and coarse woody debris.

This report contains four chapters: Chapter 1 states the purpose and chronicles some applications of the model. Chapter 2 details the model's content, documents links to the supporting science, and provides annotated examples of the outputs. Chapter 3 is a user's guide that presents options and examples of command usage. Chapter 4 describes how the model was customized for use in different geographic regions.

This document is meant to replace RMRS-GTR-116 (Reinhardt and Crookston 2003) and is continuously updated as the model is changed.

Keywords: FVS, FFE, forest fire, stand dynamics, FOFEM, BEHAVE, NEXUS, snags, coarse woody debris, carbon

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Model Availability and Support

USDA Forest Service, Forest Management Service Center, Fort Collins, CO, provides technical support and software distribution for the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS). The Forest Management Service Center (FMSC) may be contacted at the following:

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Collectively, the authors thank the following people. Albert R. Stage provided encouragement, attended workshops, and reviewed manuscripts. Jim Brown and Stage co-led this work at the beginning, found resources, and mentored our work. To a large degree the lifetime work from Brown and Stage is merged with this project and has been invaluable. The team received helpful reviews from Jane Kapler-Smith, Paul Langowski, David Atkins, Jamie Barbour, Paul Stancheff, and Casey Teske.

Numerous people participated in one or more workshops, held to specify the components of FFE, to calibrate it for specific regions, or to update the model with new information. The free flow of information and ideas at these workshops was key to the success and the adaptation of this model. A very large thanks goes out to all workshop participants.

Certain new model output would not have been possible without collaboration. Special thanks go to Kim Mellen-McLean for her input on snag dynamics and coarse woody debris output and to Coeli Hoover for her expertise in carbon modelling.

Lastly we must thank all of the FFE model users. Many users have found model bugs and given us suggestions on how the model could be improved. This feedback helps us make sure we are providing a tool that is useful to natural resource managers.

Table of Contents

Chapter 1
Purpose and Applications

Abstract: The Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) simulates fuel dynamics and potential fire behavior over time, in the context of stand development and management. This chapter provides an introduction to the model by illustrating its purpose and chronicling some of the applications it has supported.

Keywords: FVS, FFE, forest fire, stand dynamics, FOFEM, BEHAVE, NEXUS, snags, coarse woody debris.

1.1 Introduction

Fire is represented in the Forest Vegetation Simulator's (FVS) predictions of forest stand dynamics. Furthermore, long-term stand dynamics are now included in simulations of fires and fire effects. Fuel managers have a tool, the Fire and Fuels Extension to FVS (FFE-FVS), to evaluate the effectiveness of proposed fire and fuel management activities in the context of potential fire effects on short- and long-term stand dynamics, important to silviculture, wildlife habitat, and fuel hazard. In addition, the tracking of new ecosystem pools and attributes such as snags, coarse woody debris, and carbon make FVS more relevant to natural resource managers.

Adding all this to FVS was accomplished by programming an extension to FVS largely based on existing models of fire behavior and fire effects. New models that represent snag dynamics and down wood accumulation and decomposition were constructed to complete the system. The details of these components and their scientific support are the subject of Chapter 2 - Fire and Fuels Extension: Model Description. Chapter 3 - User's Guide/Keyword Manual presents options and examples of command usage. Chapter 4 - Variant Descriptions summarizes the changes made to customize the model for different geographic regions.

FFE-FVS is based on a huge legacy of research, generally dating to the middle of the 20th century. Contemporary contributors include many who attended meetings and workshops where a free flow of knowledge, data, and inspiration was recorded.

What follows in this paper is an example that demonstrates the kinds of outputs the model produces and the dynamic interactions between the fire, fuel, and tree growth components. Following the example, a summary of some of the applications recorded to date is presented. They document the range of the model's applicability from the stand to regional levels and include the use of the model in conjunction with other FVS extensions that represent insects and diseases.

1.2 An Example

The main use of FFE-FVS is to support fuel management and post fire treatment decisions in the context of other vegetation management concerns, including wildlife habitat, insect and pathogen hazards, and timber production. FFE-FVS displays measures of fire hazard as they change during the course of stand development and in response to management actions and other disturbances.

The following example displays a few of the many FFE-FVS outputs. It is taken from a Forest Inventory Analysis (FIA) plot on the Flathead National Forest in western Montana. The forest type is Douglas-fir although the potential type is classified as subalpine fir. While there is little species diversity, there is a great deal of variation in tree size, ranging from seedlings to trees over 30 inches in diameter.

Two simulation scenarios are offered. The first, named *Wildfire only*, includes a simulated wildfire in the year 2065 and was run with no other management actions. The second is like the first except that a series of prescribed fires (in years 2025 and 2045) was simulated prior to the wildfire and is therefore named *With prescribed fire*. A series of figures show the results of running these two scenarios. The variables were chosen to illustrate the relevance of the model outputs to various disciplines and to demonstrate the dynamic interactions between fire, fuel, and tree dynamics. There are many more variables that could be displayed and many more scenarios on many more stands could be run.

1.2.1 Output For Everyone: Stand Visualization

The Stand Visualization System (SVS, McGaughey 1997) can create images like the ones illustrated in Figure 1.2.1. The images show how the fire behavior differs during the wildfire under the two scenarios. In the *Wildfire only* case, the fire is burning in the crown, while the *With prescribed fire* case exhibits some torching. Images like these can be made for each time period of a simulation and viewed on computers as a time-lapse sequence showing the dynamic changes that take place in a stand. The software needed to construct these sequences is freely available and includes linkages to FVS.

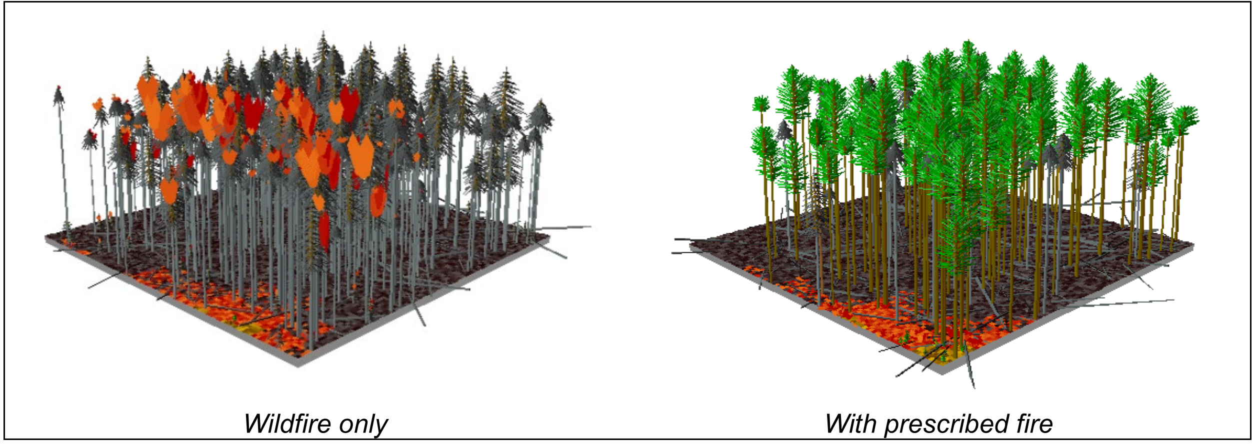
Wildfire only *With prescribed fire*

Figure 1.2.1 – Stand Visualization System (McGaughey 1997) images show how the fire behavior is different during the 2065 wildfire under the two scenarios. In the *Wildfire only* case (left), the fire is burning in the crown, while in the *With prescribed fire* case (right), only a surface fire is burning.

1.2.2 Outputs for Fire and Fuel Managers

The potential flame length indicates the expected fire intensity if a fire were to burn. It is computed over the duration of the simulation period using the same logic as used to simulate a fire except that no fire effects are included. Figure 1.2.2 illustrates that the *Wildfire only* case provides a very high potential flame length from the year 2005 on. Consequently, the wildfire simulated in year 2065 is classified as a crown fire and results in 100 percent tree mortality. Following the fire, the potential flame length dips sharply due to fuel consumption, and then increases because of the increase of dead surface fuels that accumulate immediately after the fire as a result of fire-caused tree mortality. In the *With prescribed fire* scenario, a pattern of reduction and increase in potential flame length follows the prescribed fires. There is also a sharp increase in the potential flame length at the end of that simulation when there is enough regeneration to drop the canopy base height very low.

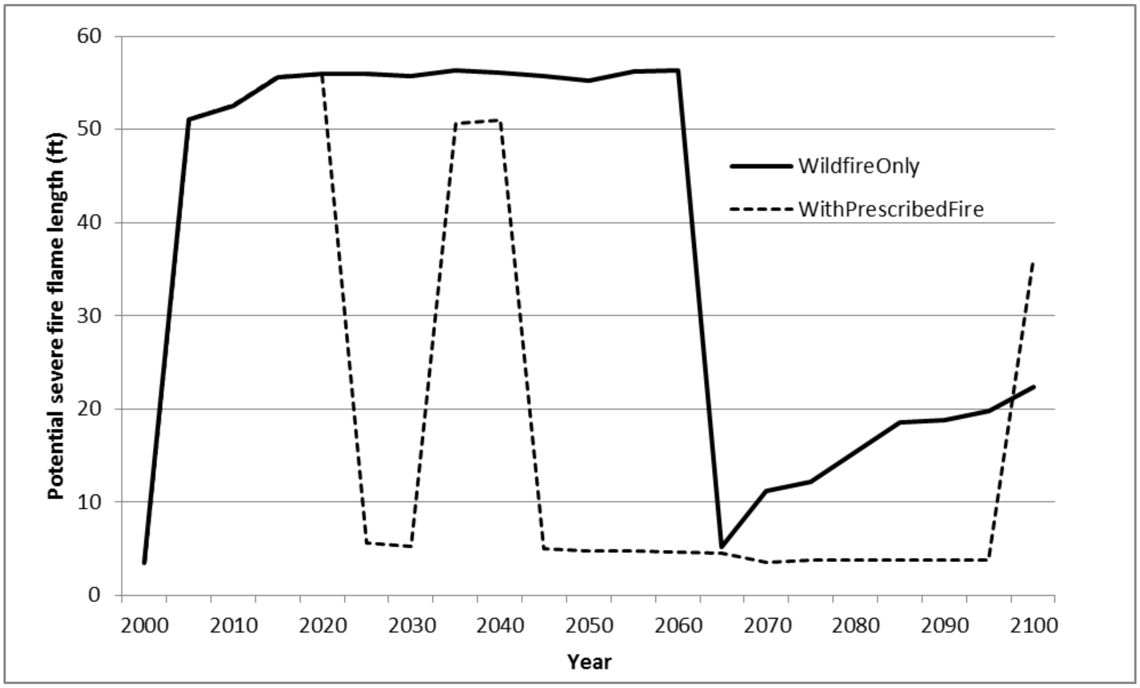

Figure 1.2.2 - The potential fire flame length for severe burning conditions is illustrated with both scenarios. The *With prescribed fire* scenario generally has a lower potential flame length in this example until the end of the simulation where it jumps to 35 feet. The large fluctuations in flame length from 2030 – 2050 are due to the estimated fire type varying between surface and conditional crown fire in these years.

Figure 1.2.3 shows changes in crowning index, the wind speed necessary to sustain crown fire. The series of prescribed fires in the *With prescribed fire* scenario maintain the crowning index at 15-20 miles per hour. In the *Wildfire only* case, after the wildfire in 2065, the crowning index is initially reported as -1 and then steeply increases due to the lack of overstory trees in which the fire can burn.

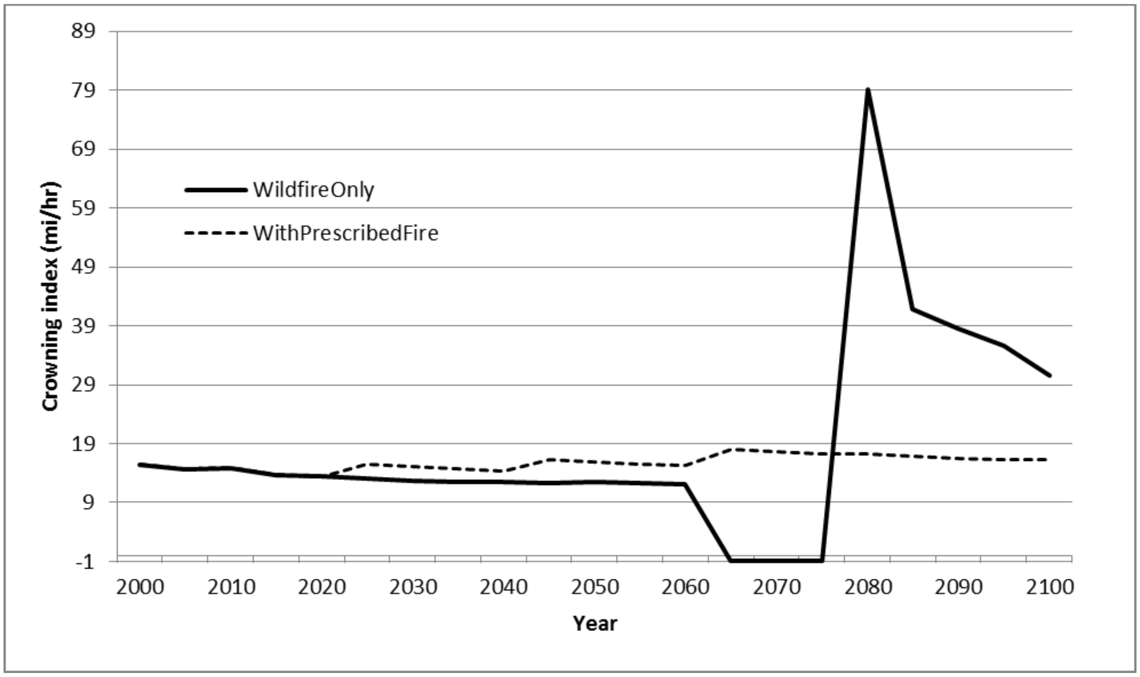

Figure 1.2.3 – The crowning index is one measure of crown fire hazard and is the windspeed needed to support an active crown fire. In this case, the crowning index is higher (less hazardous) when prescribed fire is included. In the wildfire only simulation, the crowning index increases after the wildfire as a result of the mortality and fuel consumption.

1.2.3 Outputs for Silviculturists, Fuel and Wildlife Managers

The surface fuel load in tons per acre is an indicator for fuel managers because generally, the more there is, the greater the fuel hazard. Figure 1.2.4 shows total weight of woody fuels summed over all size classes. To wildlife and vegetation managers, this fuel is considered down woody debris and that is often a valuable resource. The *Wildfire only* scenario shows consistently high fuel loads while the *With prescribed fire* scenario shows that surface fuels are reduced by the prescribed fires. In general, however, the reductions are short lived as the trees killed by the prescribed fires create surface dead material soon after each prescribed fire.

Snags are less important to fire behavior than down fuel yet can be important to wildlife habitat management (Figure 1.2.5). The *Wildfire only* scenario shows a slow, steady, increase in snag numbers with a peak after the wild fire. The *With prescribed fire* scenario shows an increase in large snags after each fire in 2025, 2045, and 2065.

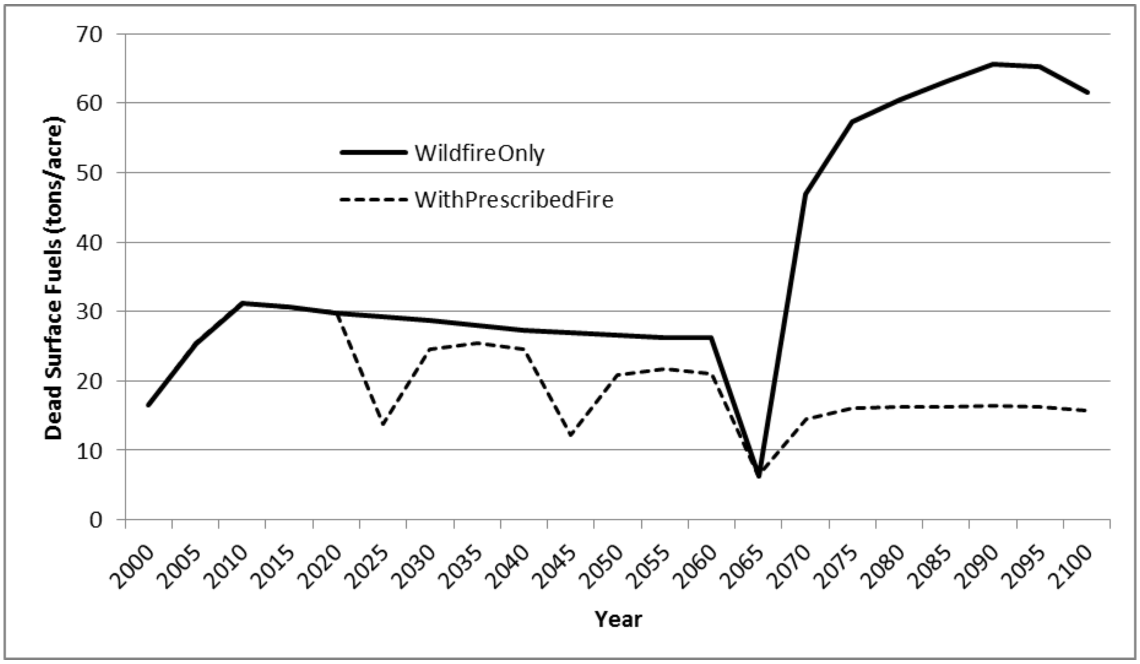

Figure 1.2.4 - Surface fuel loads are of interest to fuel managers. To wildlife and vegetation managers, this variable measures down woody debris. For the *Wildfire only* scenario, the model predicts surface fuel decomposition exceeds accumulation after the initial accumulation. A pulse of fuel accumulation is seen after the wildfire in 2065 as snags created by the fire start to fall down.

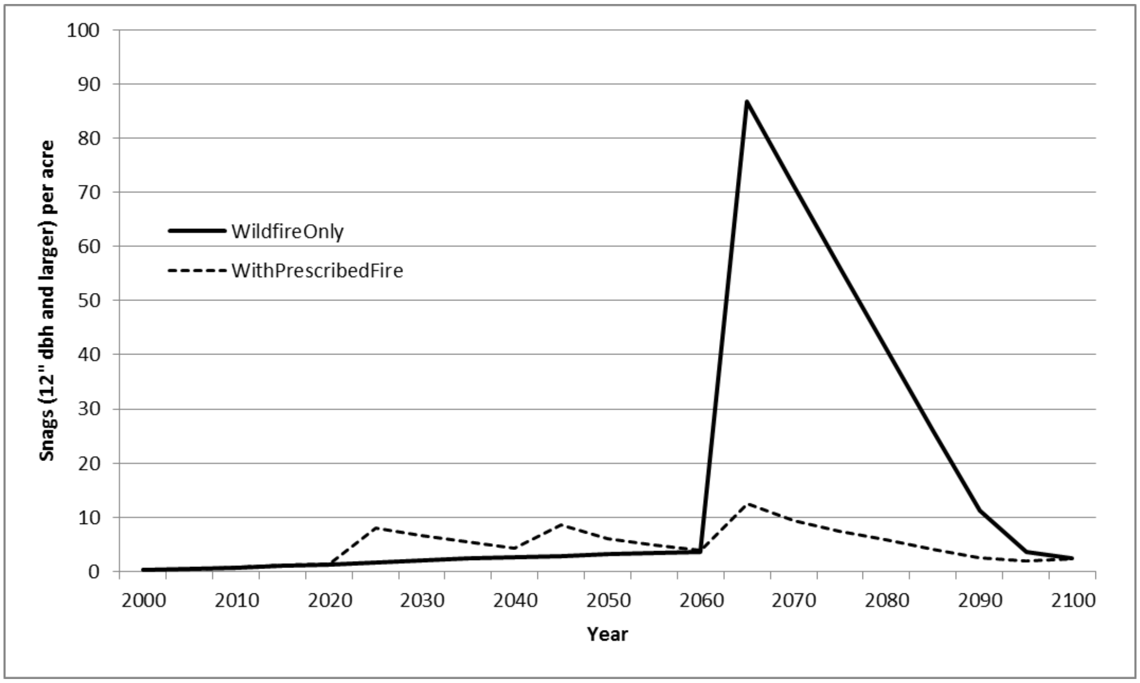

Figure 1.2.5 - The number of large snags per acre for the two scenarios.

Percent canopy cover for each of the scenarios is shown in Figure 1.2.6. Wildlife habitat managers and silviculturists use this variable to evaluate management alternatives. Thomas and others (1979) say that 70 percent canopy cover is an important level with respect to deer and elk habitat needs. While neither of the scenarios demonstrate 70 percent cover, it is clear that the

Wildfire only scenario shows high cover values for the simulated period up to the wildfire of 2065. In contrast, the *With prescribed fire* scenario shows reduced canopy cover, leaving the stand relatively open for most of the simulation period.

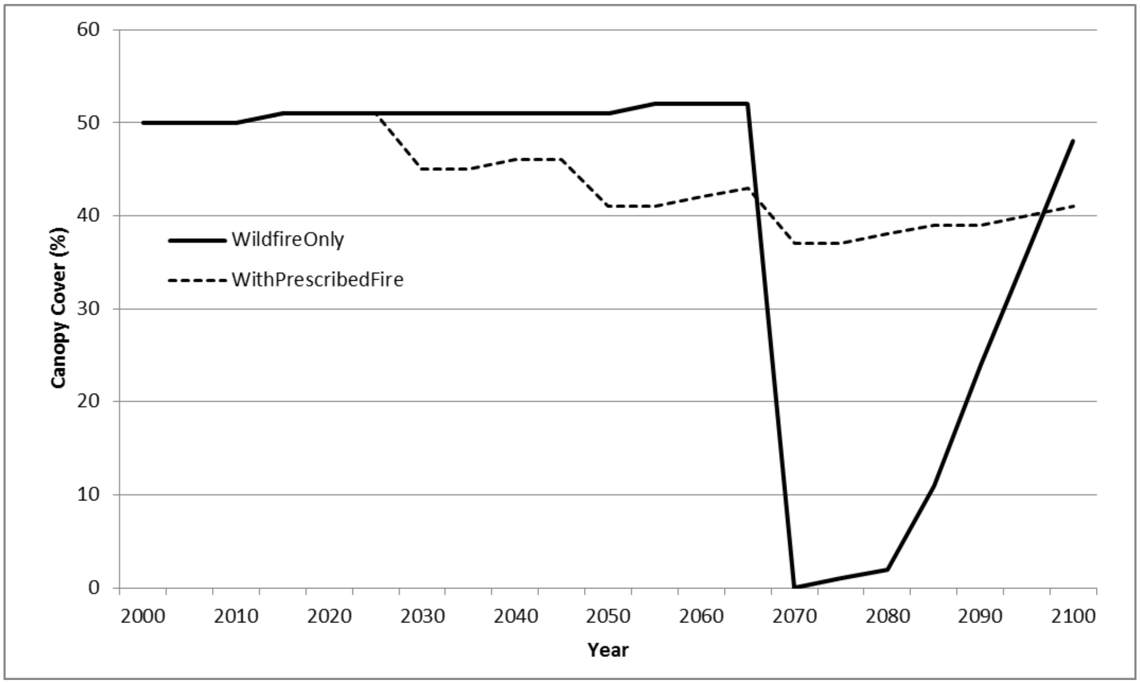

Figure 1.2.6 - Canopy cover is a key variable used in habitat assessments. The prescribed fires caused a steady reduction of this variable while the *Wildfire only* scenario provided significant cover until the wildfire of 2065.

1.2.4 Outputs For Silviculturists, Wildlife Managers, and Foresters

Top height (Figure 1.2.7) and volume (Figure 1.2.8) are key indicators for silviculturists and foresters. The simulations show that the average height of the largest trees is not greatly affected under the *With prescribed fire* scenario. The sequence of prescribed fires protects this vertical component of the stand from destruction by the wildfire of 2065. On the other hand, the prescribed fires cause a great deal of mortality and reduction in stocking resulting in a great loss in timber production. A plot of cubic volume over time (Figure 1.2.8) shows the model's ability to integrate growth, mortality, and fire processes showing how these processes affect productivity. There is no doubt that the *Wildfire only* scenario leads to the destruction of the timber in this stand in the 2065 wildfire while the *With prescribed fire* scenario left the stand capable of escaping the complete loss of timber.

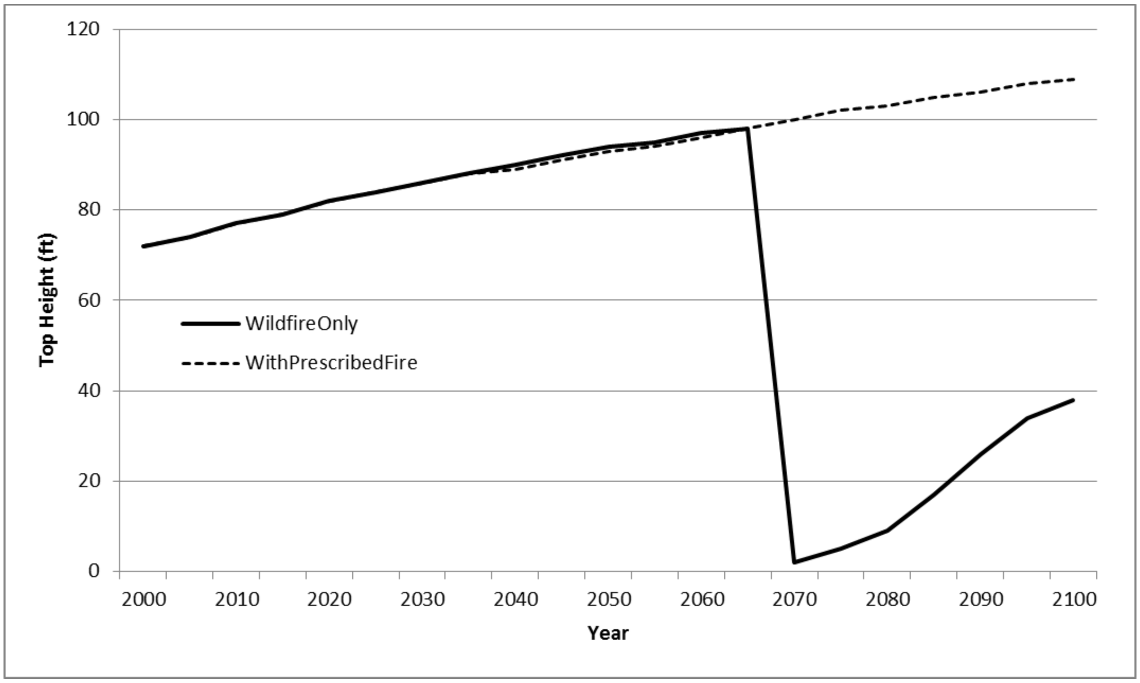

Figure 1.2.7 - Top height is the average height of the largest 40 trees per acres. The scenarios provide similar top heights until wildfire.

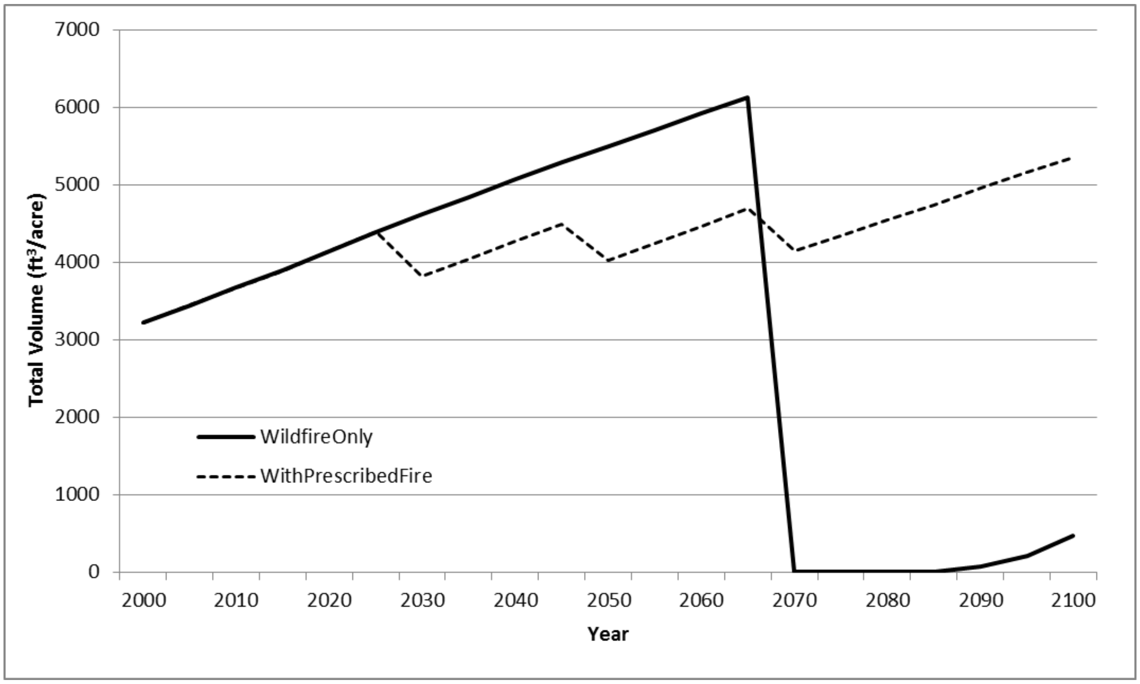

Figure 1.2.8 - The series of prescribed fires seriously reduced timber production as seen by this graph of cubic volume over time; this trend is similar when plotting board foot volume over time.

1.2.5 Summary of the Example

Structure, function, and composition of forest stands can be assessed for each management alternative using FFE-FVS. The base FVS model and FFE calculate many variables besides those shown in Figure 1.2.1 through Figure 1.2.8. The dynamic interactions between the model components are evident.

Different, perhaps better, management options could be run as well. The FFE-FVS system provides several options to manage the trees, snags, and simulate fuel treatments. The User's Guide (Chapter 3) lists them all.

1.3 Applications

FFE-FVS has proven useful to natural resource managers. It has been used to examine the effects of proposed management activies (including a no management option) on fuel loading, fire hazard, carbon storage, and snag levels. In some cases, it is used solely to provide other models, such as FARSITE, with estimates of variables such as canopy base height and canopy bulk density. It has been used throughout the country, for a variety of projects, from the stand-level to the landscape-level. Nearly every user of FVS uses FFE. Because it is impossible to keep track of every person and project using FFE, here is a small sample where model use was published. This list is by no means comprehensive and does not include the many unpublished analyses that use FFE.

- The Northern Region of the Forest Service (Atkins and Lundberg 2002) used FFE-FVS with Forest Inventory Assessment (FIA) data to characterize forest structure, fuel loads, potential fire hazard, and forest health conditions in Montana.
- Christensen and others (2002) used FFE-FVS to determine the effectiveness of several stand treatment options designed to reduce fire hazard both now and into the future. Long-term effects are reported in terms of the stocking, size, and species mix of stands and the size and species mix of trees and logs that might be removed for wood products.
- Ager and others (2007a) looked at thinning and fuel treatments and their effect on potential wildfire behavior, stand structure, species composition, and other characteristics over a 16,000-ha landscape in the wildland-urban interface in northeastern Oregon. Ager and others (2007b) further examined how thinning might affect bark beetle impacts, potential fire behavior, and their interactions the same landscape. This work used FFE-FVS along with the Parallel Processing Extension (PPE) and Westwide Pine Beetle Model (WPBM).
- Johnson and others (2007) used FFE to model six silvicultural options (no thinning; thinning from below to 50 trees per acre [tpa], 100 tpa, 200 tpa, and 300 tpa; and prescribed fire) in combination with three surface fuel treatments (no treatment, pile and burn, and prescribed fire). These alternatives were then compared in terms of their effect on surface fuels, fire hazard, potential fire behavior, and forest structure.
- Hurteau and North (2009) modeled the effects of eight fuel treatments on tree-based carbon storage and emissions with and without simulated wildfires.

1.4 Conclusions

FFE-FVS provides outputs of interest to several disciplines, has been successfully used in many applications, and can be linked to other models and tools. The science on which it is based and its limitations are the subjects of the next chapter in this document.

Chapter 2
Fire and Fuels Extension: Model Description

Abstract: The Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) is a model that simulates fuel dynamics and potential fire behavior over time, in the context of stand development and management. Existing models are used to represent forest stand development (the Forest Vegetation Simulator, Wykoff and others, 1982), fire behavior (Rothermel 1972, Van Wagner 1977, and Scott and Reinhardt 2001), and fire effects (Reinhardt and others 1997). These models are linked together with newly developed models of snag and fuel dynamics. Users can simulate fuel treatments including prescribed fire, thinning, and mechanical treatments. Wildland fires can also me modeled. Model output includes predicted fuel loadings over time, and measures of fire hazard including potential flame length, canopy base height, and canopy bulk density, torching and crowning indices, and potential stand mortality over the simulation period. If a prescribed fire or wildland fire is simulated, output also includes predicted fire behavior, fuel consumption, smoke production, and tree mortality. Additional output includes the amount of stored carbon and coarse woody debris.

Keywords: fire behavior, fire effects, stand dynamics, silviculture, fuel treatment, prescribed fire, potential wildfire behavior, fuel dynamics, carbon, coarse woody debris

2.1 Introduction

The Forest Vegetation Simulator (FVS) (Stage 1973; Wykoff and others 1982; Dixon 2002; Crookston and Dixon 2005) is used by forest managers throughout the United States and Canada to predict stand dynamics and the effects of various management actions on future forest conditions. It is an individual tree, distance-independent growth and yield model. The role of fire in ecosystem dynamics has not previously been explicitly represented in FVS. Other models have been developed to represent fuel dynamics with and without fire (Keane and others 1989), fire behavior (Albini 1976a,b; Rothermel 1972), and fire effects (Reinhardt and others 1997). These models, however, do not address the dynamics of vegetation management.

We developed the Fire and Fuels Extension to FVS (FFE-FVS) by integrating FVS with elements from existing models of fire behavior and fire effects. FFE-FVS predicts changes in stand and fuel characteristics over time and the behavior and impacts of fire. The model is not intended to predict the probability of fire or the spread of fire between stands.

The FVS simulates tree growth, tree mortality and regeneration, and the impacts of a wide range of silvicultural treatments. The Fire and Fuels Extension simulates fuel accumulation from stand dynamics and management activities, and the removal of fuel through decay, mechanical treatments and prescribed or wildfires. Various types of fuel are represented, including canopy fuel and surface fuel in various diameter classes. Fire behavior and fire effects such as fuel consumption, tree mortality and smoke production are modeled. Model output describes fuel characteristics, stand structure, snags, and potential fire behavior over time and provides a basis for comparing proposed fuel treatments.

Where possible, FFE-FVS uses existing models and algorithms to simulate fires. To predict fire intensity, it uses Rothermel's fire behavior model as implemented by Albini (1976a) in FIREMOD and subsequently by Andrews (1986) in Behave. The onset of crowning is predicted using approaches developed by Van Wagner (1977) and Scott and Reinhardt (2001). The model uses methods from FOFEM (Reinhardt and others 1997) for predicting tree mortality, fuel consumption and smoke production. Methods for simulating fuel accumulation and decay and snag dynamics were developed for FFE-FVS using information described in detail in sections 2.3 and 2.4 of this chapter.

The model does not simulate fire spread or the probability of fire. It calculates potential fire intensity over time, under user-defined conditions, as a measure of the fire hazard of stand and fuel conditions. It also allows the user to schedule or simulate a fire or series of fires at given points in time or when certain stand conditions are reached. When a fire is simulated, the model computes its intensity, its effects on different stand components and the associated emissions.

This document describes the model processes and assumptions in detail for the Northern Idaho variant, the first variant expanded to include FFE, and one which has now been retired and replaced by the Inland Empire variant. The details and default development relationships for other variants are given in Chapter 4.

Examples of FFE-FVS output in this document use the same example stand as Chapter 1: a Douglas-fir stand in western Montana that is burned with a wildfire in 2065.

2.2 Model Structure

The Fire and Fuels Extension includes three major submodels:

1) A snag model for tracking and simulating decay and fall down of standing dead trees.
2) A fuel model that simulates the accumulation (through litterfall and other sources) and decomposition of surface fuel; tracks canopy fuel characteristics, and selects fire behavior fuel models. Carbon in various pools is also tracked.
3) A fire model that simulates fire intensity and fire effects on trees, snags, and fuel as well as smoke production and mineral soil exposure.

As with all of FVS, users interact with FFE using keywords specific to FVS and to FFE. Once FFE is invoked, the snag and fuel components are automatically present. Users can simulate fires or request fuel treatments using keywords. Many FFE-specific characteristics are linked to the Event Monitor (Crookston 1990). This allows users to request the simulation of events or management actions, such as fuel treatment, if certain stand or fuel conditions are predicted by the model.

FVS passes control to FFE in every growth cycle (Figure 2.2.1). Some parts of FFE operate on an annual time step within the FVS cycle (normally representing 5 or 10-year time steps). All simulation results relevant to FVS, such as fire effects on tree mortality, are passed back to FVS at the end of the cycle. Figure 2.2.2 illustrates the general scheme of FFE-FVS. FVS uses a tree list to represent a stand. For each tree in the list, FVS stores several attributes including dbh, height, crown ratio, and the number of trees per acre represented by the sample tree. Similarly, FFE tracks snags using a snag list, which carries attributes specific to snags (see section 2.3.1). Snags are created through mortality and gradually break apart and fall, thus contributing to the surface fuel.

```
Read all keywords and the tree list (sample-based collection of individual trees that represent a stand).
Establish initial snag and fuel conditions

For Each Growth Cycle
        Apply stand management (thinning and salvage)

        Estimate normal growth and mortality for each sample tree

        Apply FFE management activities (pileburns, fuelmoves, and simulated fires)

        Print all FFE reports and set FFE event monitor variables and functions

        For each year in the Growth Cycle
                Update condition of snags
                Update fuel pools (decay)
                Update fuel pools (litterfall, crown breakage, snag crown additions)
        End annual loop

        Call Establishment Model
        Update Stand Attributes (and apply the possibly altered mortality rates)
        Add new mortality to snag pools
        Display Indicators
End Growth Cycle Loop
```

Figure 2.2.1 - Order of calculations in FFE, including sections of FVS.

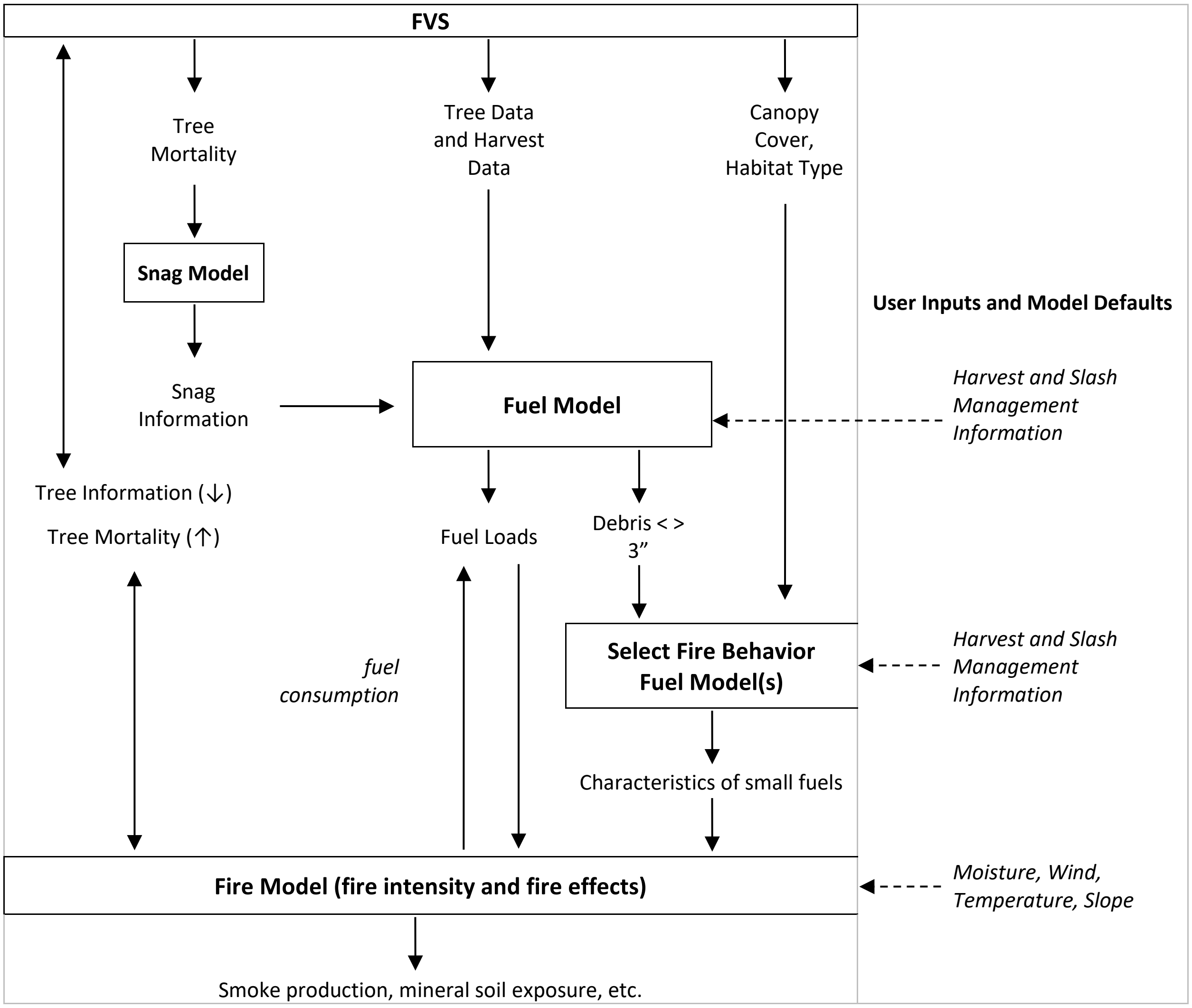

Figure 2.2.2 - Scheme of the FFE-FVS Model. The boxes in this figure show the major submodels of FFE. Arrows indicate the flow of information between submodels. See text for further explanation.

Fuel is tracked in a number of fuel pools (section 2.4.1) representing the quantity of fuel in different size classes. Fuel pools can be initialized by the user, or FFE will estimate initial loadings from the cover type, canopy cover, and other variables. The fuel pools are updated by simulating input and decomposition. The simulated fuel loadings, along with the habitat type, canopy cover, and other variables are used to select one or more fire behavior fuel models (Anderson 1982) that most closely represent fuel conditions (section 2.4.8). These fire behavior fuel models are used to predict fire behavior rather than the simulated fuel loadings because of the extreme sensitivity of the fire behavior model to fuel parameters we cannot easily track in FFE, in particular surface area to volume ratio and fuel bed depth.

Surface fire intensity is predicted using Rothermel’s model (Rothermel 1972; Albini 1976a) for each of the selected fire behavior fuel models. The predicted fire behavior for the models is then combined in a weighted average (section 2.5.4). The weighted average and canopy fuel characteristics are used to determine whether crown fire occurs. Fire intensity, expressed as flame length, and fire type (surface, passive, conditional, or active) are used as indicators of the fire hazard of the fuel and stand conditions. They are also used to calculate the effects of a simulated fire [i.e., fuel consumption, smoke production, tree mortality, mineral soil exposure, etc. (section 2.5.5)].

2.3 Snag Submodel

2.3.1 Overview

The snag submodel tracks the breakage, decay and fall-down of the boles of standing dead trees. The term "snag" throughout is used only to refer to standing dead trees; once they have fallen, they are modeled as surface fuel. The foliage and branches of snags also fall and contribute to surface fuel, as described in section 2.4.4.

Snags are represented in the model using a snag list. Each list element, called a snag record, represents a group or class of snags. These are snags of the same species, that died in the same simulation cycle or year, and that are in the same diameter and height class. The snags in each record are described by the following characteristics:

- Diameter class - Snags are grouped into two-inch diameter classes, based on their dbh at the time of death. The largest class represents all snags with a dbh of 36" or more.
- Species - Tree species.
- Height at death - Average height of the trees in that record at the time of death (for the initially-hard and initially-soft snags separately). If the height of otherwise similar trees differs by more than 20 feet, two records are created (section 2.3.3). This allows the model to follow these height differences in the simulation of snag dynamics.
- Current height - Average current height of the snags in the record, again for initially-hard and initially-soft snags separately. The height will decrease over time as the snags start to break apart (section 2.3.4).
- Years since death - Number of years since the death of the tree (i.e., the time since the snag was created).
- Decay status - Decay status: hard or soft. Soft snags are more decayed and are assumed to have 80% of the wood density of hard snags.
- Density - Number of stems per acre represented by this record. This will decrease as snags of this record start to fall down (section 2.3.6).

Only four of the characteristics will change over time (current height, years since death, decay status, and density). The simulated change in height as snags age allows the corresponding reduction in volume to be calculated (using the diameter at time of death).

In some of the variants covering Oregon, Washington, and Alaska (PN, WC, EC, SO, BM, and AK), the snag dynamics were modified based on the work of Kim Mellen-McLean, USFS Pacific Northwest Regional Wildlife Ecologist and described in Rebain (2008).

2.3.2 Initialization

Snags can be initialized in the model using two options. Snags can be included in the input FVS tree list along with live trees by recording the species, dbh, and height information and a code indicating that the tree is dead. At present, all trees initialized in this manner are assumed to have died 5 years before the inventory year - the FVS tree history codes are not used to estimate snag age. By default, these snags are hard, but the **SNAGPSFT** keyword can be used to change this assumption.

Snag records can also be created using the **SNAGINIT** keyword. Each of the snag characteristics described above, except decay status, can be defined using this keyword. These snags are also assumed to be hard, unless the user has changed the default using the **SNAGPSFT** keyword.

During a model simulation, snags may be created through base FVS-predicted mortality (every simulation cycle), fire-caused mortality (in the year of fire) (see section 2.5.5), and some management actions (see section 2.3.7).

2.3.3 Creation and Maintenance of Snag Records

The model uses snag records to represent groups of snags that die in the same simulation cycle or year, belong to the same species, dbh class, and are within a 20-foot height range. When new snags are created, the model determines the height range of snags of the same species and dbh class. If height varies by more than 20 feet, two records are created for snags of that species and dbh class. Thus, some of the variability in initial snag heights is maintained in the model. In all cases, the density-weighted average height and average dbh of all the snags in each record are used as the attributes.

Snag records are eliminated once all snags in the record have fallen (section 2.3.6), when the record contains fewer than 0.0002 snags/acre (equivalent to one-hundredth of one snag in a 50 acre stand), or when the current height of the snags in the record is less than 1.5 feet. Any remaining snag material in these records is added to the surface fuel with the other fallen snags.

Currently the number of snag records in FFE is limited to 2000. If a new snag record is needed and all of the snag records are already in use, then the model must search for a snag record to over-write. The model first searches the snag records created in all previous years to determine which contains the fewest snags. If this record contains fewer snags than the new record would have if all the new snags were in the same height group, then the existing snags are knocked over and the record is used by the new snags. If not, then the model determines which snag record already created this year has the fewest snags. Again, if this record contains fewer snags than the new record would have, the snags are placed on the ground and the new snags are used instead. If at this point no record has been found for the new snags, then these snags are placed on the ground.

2.3.4 Height Loss

As snags age, their tops break off and fall to the ground, decreasing the snag height. In the model, this process slows with time, as the remaining top of the tree becomes wider at each successive breakpoint. We assume breakage occurs at a faster rate until half of the initial height has been lost, then occurs at a slower rate. All species use the same pattern of breakage, but the rates differ between them (Figure 2.3.1). In addition, initially-soft snags lose height twice as quickly as initially-hard snags. This difference in height loss is under user-control.

The basic equations for snag breakage are:

$$HT_t = HT_0 \left(1 - 0.0228mx\right)^t \qquad if \ \left(1 - 0.0228mx\right)^t > 0.5$$

$$HT_t = 0.5\, HT_0 \left(1 - 0.01mx\right)^{t-y} \qquad if \ \left(1 - 0.0228mx\right)^t \leq 0.5$$

where:

t = number of years since death
y = number of years after death when half of the initial height has been lost
Ht_t = height of the snag at t years after death
HT_0 = height of the snag at death
m = multiplier used to change the base rate for different species
x = multiplier used to accelerate the rate of breakage of initially-soft snags (default values are x=1 for initially hard snags, and x=2 for initially soft snags)

These equations are defined such that, with m=1, snags lose 2.28% of their current height each year until they have lost 50% of their original height in about 30 years. After that, the remaining breakage occurs at a rate of 1% per year. The switch from the faster rate to the slower rate occurs when 50% of the initial height of the snag has been lost (Table 2.3.1).

Snags are considered surface fuel if they are less than 1.5 feet in height. At this point, the amount of material represented by the remaining bole is transferred to the appropriate surface fuel pools and the record is eliminated from the snag list.

Using the **SNAGBRK** keyword, users can control the breakage rates for each species by defining the time it takes for a given amount to break. The model translates these times into the parameter m.

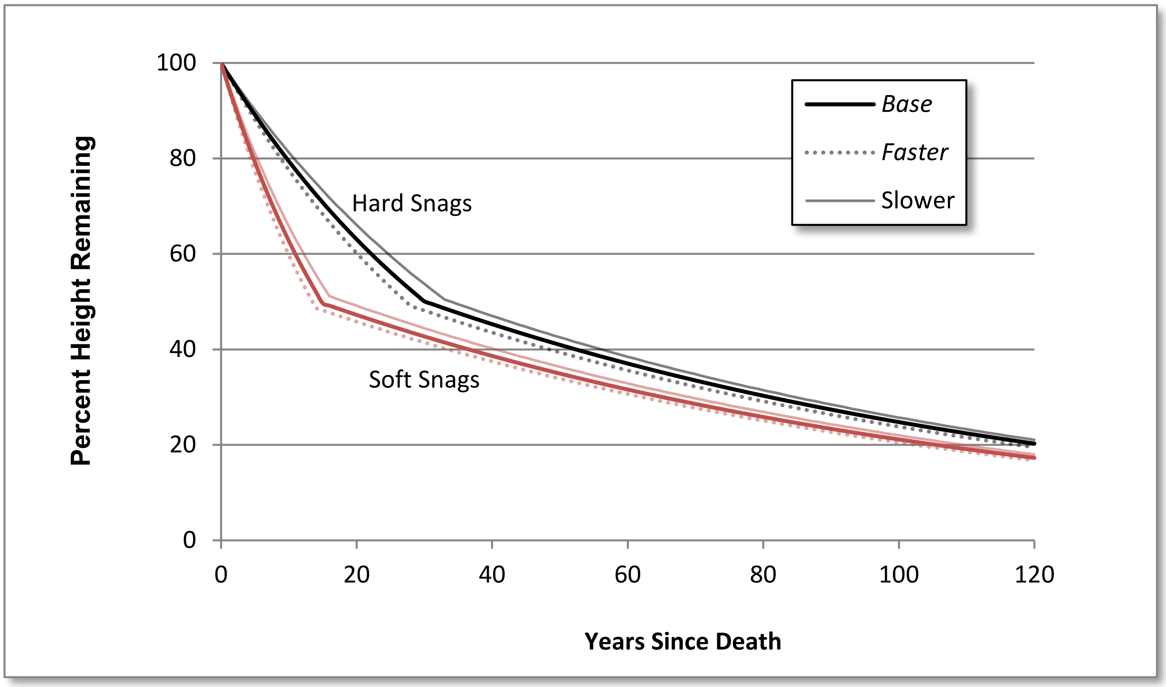

Figure 2.3.1 - Comparison between patterns of height loss for initially hard or soft snags with the three different sets of default rates.

Table 2.3.1 - Comparison between height loss for different species. The “Years to 50% height loss” is the number of years after death required for 50% of the original height to be lost. This is the time at which the simulated breakage

rate switches from the faster rate to the slower rate (for example, 2.28 percent to 1 percent). The “Multiplier” is the value used by default on the initially defined percentages. The “% of height after 100 years” gives the percent of the initial height that is still remaining on standing snags after 100 years.

			Years to 50% Height Loss		% of Height After 100 Years	
	Species	**Multiplier**	**Hard**	**Soft**	**Hard**	**Soft**
Base	Ponderosa pine, Other	1.0	30	14	25	21
Faster	Grand fir, Western hemlock, Western redcedar, Lodgepole pine, Engelmann spruce, Subalpine fir	1.1	27	13	22	19
Slower	White pine, Western larch, Douglas-fir	0.9	33	16	27	2

2.3.5 Decay

Decay is the process by which snags become softer. In the snag model, there are only two stages of decay: hard and soft. Newly created snags are classified as “hard” in the model, unless otherwise specified by the user. Over time, these snags decay until eventually they are considered “soft”. Soft snags experience more rapid height loss in the model (section 2.3.4). Debris originating from soft snags decays faster than debris from hard snags (section 2.3.5).

All hard snags, assuming that they remain standing, will eventually become soft snags. The rate of this decay depends on the diameter of the tree at the time of death and its species. The basic decay rate is based on a linear approximation of some rates for Douglas-fir snags (Bruce Marcot, USFS, Portland, OR, unpubl. data, 1995), and has the form:

$$DecayTime = m(1.24\,dbh + 13.82)$$

where:

$DecayTime$ = number of years it takes for a hard snag to become soft (that is, the time from death to transition to soft)

dbh = diameter at breast height (in inches) of the snag at the time of death

m = multiplier used to scale the equation to increase or decrease the decay rate for different species

The default decay rate of each species is assigned using a scaling multiplier of 0.9, 1.0, or 1.1 (Figure 2.3.2). The scaling value, *m*, used for each species can be changed using the **SNAGDCAY** keyword.

2.3.6 Falldown

Standing snags will eventually fall. In the model, fall rates vary based on species, size, and whether the snag was present during a fire. With one exception, the rates do not depend on snag age or decay status. As with the breakage and decay rates, a basic set of rates is defined. These rates are based on a linear approximation of data for ponderosa pine snags (Bruce Marcot, USFS, Portland, OR, unpubl. data, 1995), with a modification to ensure that some large snags remain standing for 100 years.

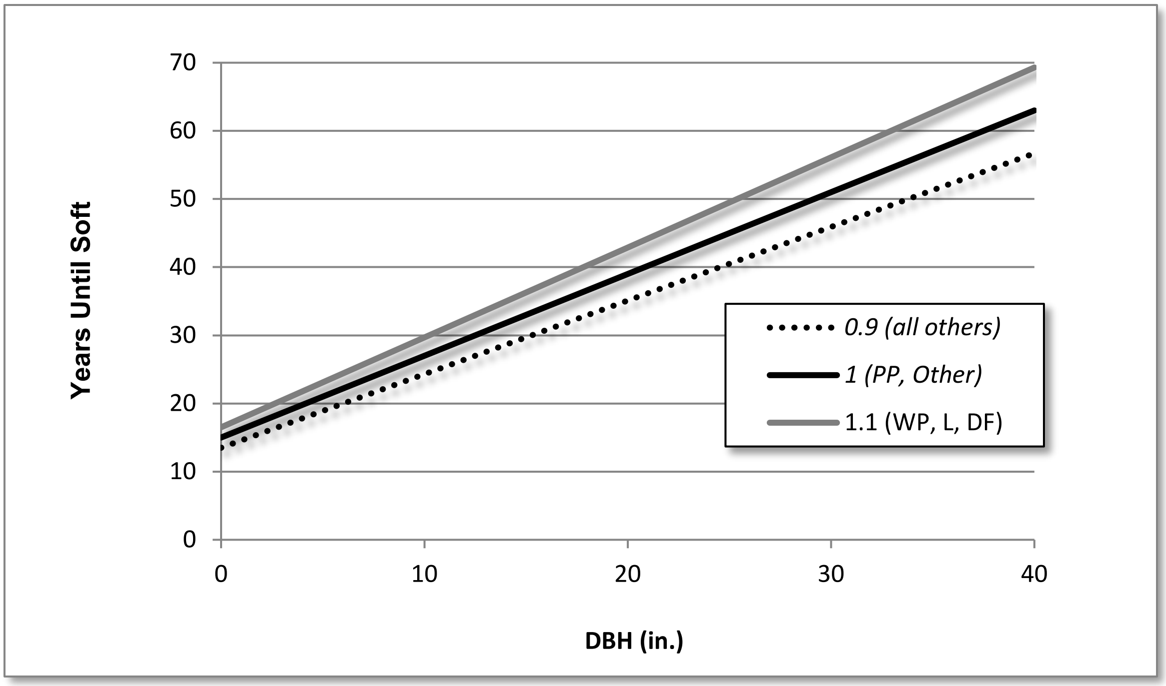

Figure 2.3.2 - Number of years until decay for the different default rates and a range of dbh. A multiplier less than 1 decreases the amount of time until decay (that is, the snag decays faster) while multipliers greater than 1 increase the amount of time before decay (that is, the snag decays slower).

For all snags less than 18 inches, and for all but the last 5% of snags over 18 inches, the number of snags in a record that fall each year is calculated as:

$$R = -0.001679d + 0.064311$$

$$F = mRN_0$$

where:

R = rate of fall (Figure 2.3.3); for records with a dbh > 32.3 inches, this rate is set to 0.01
d = initial diameter at breast height in inches of the snag
$N0$ = initial density (stems/acre) of snags in the record
m = multiplier that can be used to change the rate of fall
F = density of snags (stems/acre) that fall each year from that record

For the last 5% of snags over 18 inches, the number of snags falling each year is:

$$F = \frac{0.05}{A-T} N_0$$

where:

F = density of snags (stems/acre) that fall each year from that record
A = maximum number of years that snags will remain standing (i.e. the time when all snags will have fallen)
T = time when 95% of the snags had fallen
$N0$ = initial density (stems/acre) of snags in the record

This is the only exception to the rule that the fall rates do not depend on age. This equation ensures that some large snags persist throughout the period of time A, but that none persist beyond this time. By default, ponderosa pine snags fall at the rate calculated with m=1 and with a maximum persistence time of 100 years for snags over 18 inches. All other species are assumed to fall either 10% faster or 10% slower. Similarly, the maximum persistence time for snags over 18 inches is also assumed to be either 10% longer, or 10% shorter (

Table 2.3.4). Figure 2.3.4 compares the effect of the three fall rates for large and small snags. The user can specify both the normal fall-rate multiplier m and the persistence time A for each species using the keyword **SNAGFALL**.

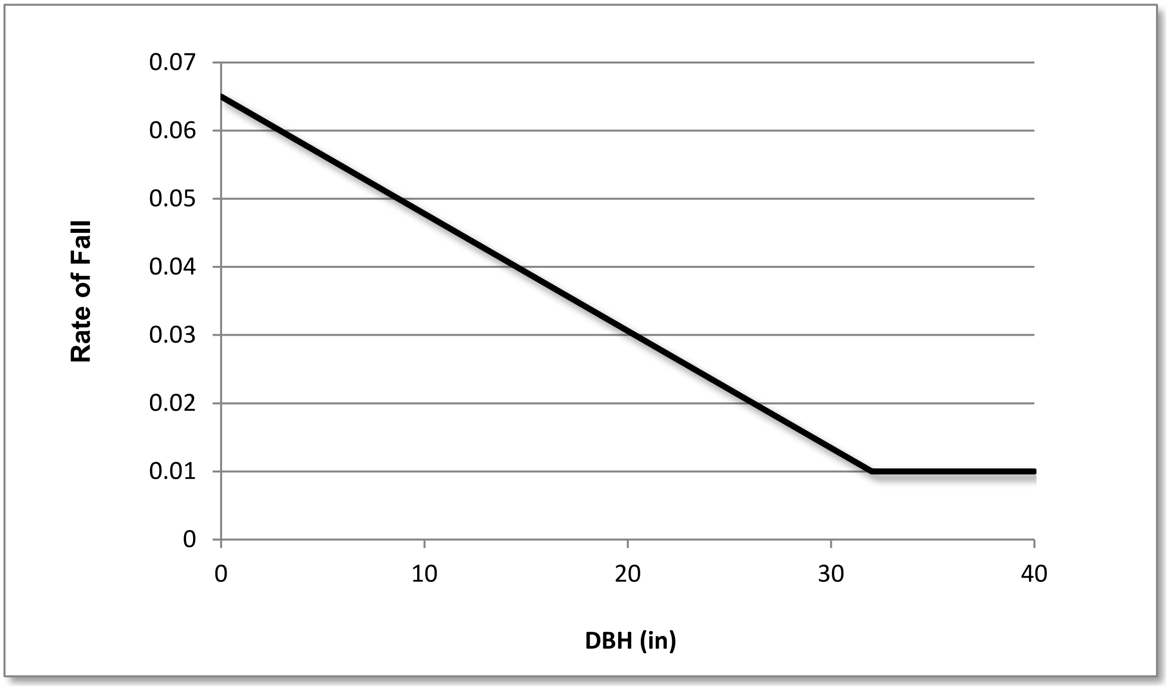

Figure 2.3.3 - The rate of fall of small snags and the first 95 percent of large snags.

Fires that exceed a threshold scorch height (by default 0 ft) increase the fall rates of previously existing soft snags and small snags (Figure 2.3.5). After a fire, all soft snags and 90% of hard snags smaller than 12 inches dbh will fall within seven years. Snags that would already fall in less than seven years, will still fall at their "pre-burn" rate. Large, hard snags are unaffected by fires. These parameters may all be controlled by the user using the keyword **SNAGPBN**.

Table 2.3.2 - Default snag fall rate modifiers for different species. Ponderosa pine is the base species. Species that are assumed to fall faster have a higher multiplier and a shorter maximum persistence time. The opposite is true for the species with slower falling snags. Species "other" was assigned to the base rate values because it is not known which species will be included in "other".

	Species	Multiplier (*m*)	Maximum Persistence Time (years, *A*)
Base	Ponderosa pine, Other	1.0	100
Faster	Grand fir, Western hemlock, Western redcedar, Lodgepole pine, Engelmann spruce, Subalpine fir	1.1	90
Slower	White pine, Western larch, Douglas-fir	0.9	110

Figure 2.3.4 - Percent of large and small snags standing as a function of years since death. The last 5 percent of large snags, or those greater than 18” dbh, remain for a long period of time, while small snags fall at a consistent rate. Fall rates decrease with increasing dbh and differ between species (see Table 2.3.2).

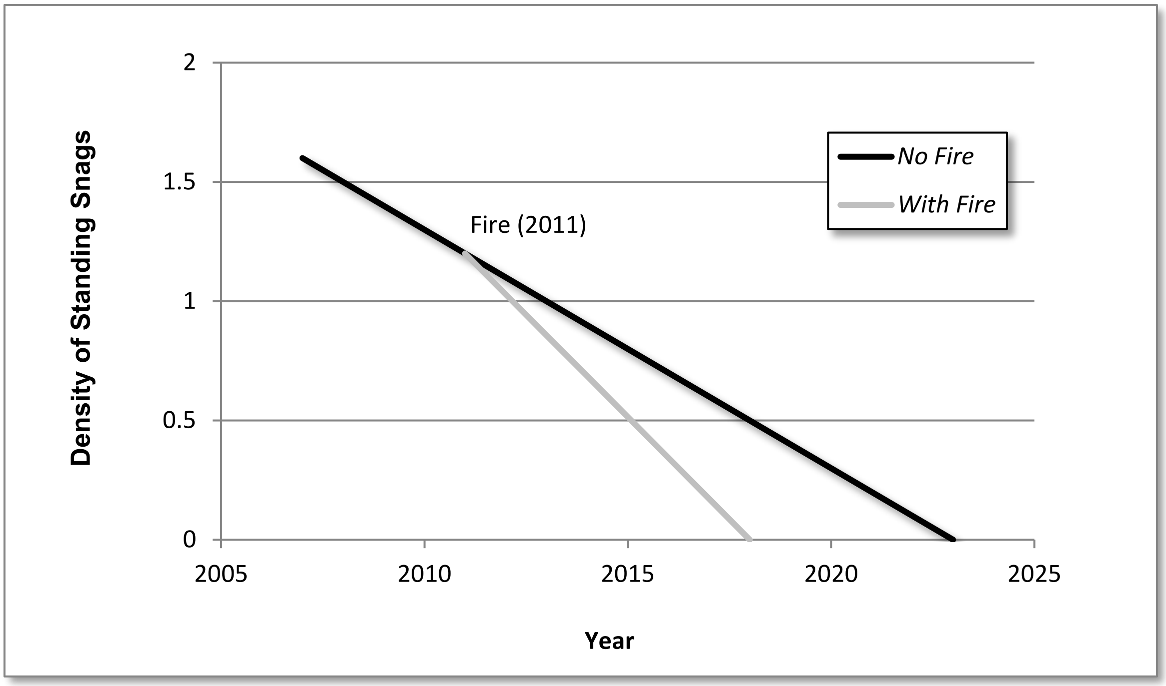

Figure 2.3.5 - Effect of fire on the fall rate of a sample snag record. The example record contains 6.8” GF snags that were created in 2006. The graph shows the density of the snags without a fire in 2011.

2.3.7 Management

Snags can be created by using the base FVS model keyword **FIXMORT** or by using **YARDLOSS** in conjuction with a thinning keyword. Snag removal is simulated using the FFE keywords **SALVAGE** and **SALVSP**. Users can select snags to salvage based on time since death, size (dbh at death), decay status (hard/soft), and species. Salvage operations are processed before base model management options and before fires are simulated. Thus, if a user specifies that all new snags be removed, any snags created using the **YARDLOSS** or **FIXMORT** keywords in the current year will not be eligible for removal, and those created from a fire in the current year have not yet been produced, and cannot be salvaged either. In this case, inserting a cycle break for the following year with the **CYCLEAT** keyword and scheduling the **SALVAGE** for that year WILL capture the snags created via **YARDLOSS**, **FIXMORT**, and **SIMFIRE**. Note that the FFE **SALVAGE** keyword removes snags from the snag list maintained by FFE.

The amount of the salvage is printed in two places: as the last field (on the second line) in the activity summary (volume/acre removed in total cuft/acre in the western variants and merchantable cuft/acre in the eastern variants), and in the column “standing removed” in the detailed fuel report (tons/acre removed; section 2.4.10). The size and species distribution of the salvage can also be inferred to some degree through changes in snags reported in the summary and detailed snag outputs (section 2.3.8). More detailed breakdown of salvage amounts are currently available through the event monitor functions **SalvVol** and **Snags**.

2.3.8 Output

Information about snags in the model can be important for determining wildlife values or other non-timber indicators. Two snag output reports can be produced by the model—detailed or summary.

Detailed Snag Report: The detailed snag report produces information about snags (**SNAGOUT** keyword). The detailed snag report is produced after all management is simulated, but before any of the other processes such as snag fall and decay are simulated. The report summarizes the snag records by species into up to six user-defined diameter size classes. The report provides the following information on these summary records (Table 2.3.3):

Year	The simulation year of the report
Species	The two-letter species code of the species being reported
DBH cl	Value between 1 and 6 indicating the user-defined size class of the snags in this record
Death dbh	The average diameter (inches) at the time of death of snags that are aggregated into this record
Curr height	Current height (in feet)
Hard	Average height of currently hard snags aggregated into the record
Soft	Average height of currently soft snags aggregated into the record
Curr volume	Current volume in ft^3/acre. Estimated from the original height of the snags, the current height, and diameter at time of death. Separated into hard, soft, and total (sum between hard and soft) volume.
Year died	The year the record was created (the year the tree died)
Density	Number of snags per acre. Separated into hard, soft, and total (sum between hard and soft) snags per acre.

Table 2.3.3 - Example detailed snag report. In this example, snags were only reported for the year 2008. The stand contains hard Douglas –fir (DF), western larch (WL), and lodgepole pine (LP) snags that had died in 2004 and 1999, as well as some soft lodgepole snags that had died in 1983.

```
ESTIMATED SNAG CHARACTERISTICS, STAND ID=300290024601
 -------------------------------------------------------------------------
             DEATH CURR HEIGHT CURR VOLUME (FT3)        DENSITY (#/ACRE)
         DBH  DBH  ----(FT)--- ----------------- YEAR --------------------
 YEAR SP  CL  (IN)  HARD  SOFT  HARD  SOFT TOTAL DIED  HARD   SOFT   TOTAL
 -------------------------------------------------------------------------

 2008 WL   1   2.0  22.0   0.0     0     0     0 2004    5.4    0.0    5.4
 2008 DF   1   4.8  35.8   0.0    55     0    55 2004   17.7    0.0   17.7
 2008 DF   2  13.5  72.3   0.0     2     0     2 2004    0.1    0.0    0.1
 2008 DF   3  21.0  79.3   0.0     6     0     6 2004    0.1    0.0    0.1
 2008 DF   6  38.1  92.5   0.0     2     0     2 2004    0.0    0.0    0.0
 2008 LP   1   6.4  64.1   0.0    25     0    25 2004    3.1    0.0    3.1
 2008 WL   1   1.8  18.6   0.0     0     0     0 1999    6.4    0.0    6.4
 2008 DF   1   4.4  29.5   0.0    53     0    53 1999   21.4    0.0   21.4
 2008 DF   2  13.4  62.7   0.0     2     0     2 1999    0.1    0.0    0.1
 2008 DF   3  20.6  69.5   0.0     7     0     7 1999    0.1    0.0    0.1
 2008 DF   6  37.9  82.2   0.0     2     0     2 1999    0.0    0.0    0.0
 2008 LP   1   6.1  54.5   0.0    28     0    28 1999    4.1    0.0    4.1
 2008 LP   1   6.9   0.0  41.2     0   257   257 1983    0.0   33.8   33.8
```

The default size class boundaries for reporting are at 12", 18", 24", 30", 36", and >36" dbh at death. These values can be changed with the **SNAGCLS** keyword. The report only lists species and size classes that are present in the reporting year. Classes with low densities (less than .05 trees/acre) show densities of .0 in this report. By default, the detailed snag report is written to the *.chp output file (I/O file reference number 13), and this can be adjusted on the **SNAGOUT** keyword.

Each line in the report may represent more than one snag record because for reporting purposes snags are grouped into larger diameter size classes. Within each class, all reported values are averages of the characteristics of each snag record. This averaging means that some reported values may change between years in a counter-intuitive fashion as records within the class lose height or numbers at different rates.

Table 2.3.4 shows a selection of output for 3 inventory snags that were created in 2005. In this case, we start the simulation with 3 types of snags – Douglas-fir in dbh class 1, Douglas-fir in dbh class 4, and ponderosa pine in dbh class 1. Although the dbh of a particular snag record does not change during the simulation, the average dbh and height in the reported class increases over time because the smaller snag records included in the class fall faster (and thus contribute less to the average) than the larger snag records in the reporting class. By 2040 the two snag records in dbh class 1 disappear as those smaller snags all fall down. The amount of the largest snags, the Douglas-fir in dbh class 4, decrease over time as some fall down; a small number move to the soft snag category.

Table 2.3.4 - Sample output from the detailed snag report showing a selection of reports about some inventory snags that died in 2005. Death dbh is the average dbh of snags combined in a given record.

		Dbh	Death	Height		Total Volume			Year	Density		
Year	**Sp**	**cls**	**dbh**	**hard**	**soft**	**hard**	**soft**	**total**	**Died**	**hard**	**soft**	**Total**
2010	DF	1	8.0	8.0	0.0	14	0	14	2005	8.19	0.00	8.19
2010	DF	4	25.0	50.0	0.0	22	0	22	2005	0.42	0.00	0.42
2010	PP	1	9.5	42.0	0.0	24	0	24	2005	2.90	0.00	2.90
2020	DF	1	8.0	6.5	0.0	7	0	7	2005	4.44	0.00	4.44
2020	DF	4	25.0	40.6	0.0	18	0	18	2005	0.33	0.00	0.33
2020	PP	1	9.5	33.3	0.0	12	0	12	2005	1.50	0.00	1.50
2030	DF	1	8.0	5.3	0.0	0	0	0	2005	0.69	0.00	0.69
2030	DF	4	25.0	33.0	0.0	12	0	12	2005	0.25	0.00	0.25
2030	PP	1	9.5	26.5	0.0	0	0	0	2005	0.10	0.00	0.10
2040	DF	4	25.0	26.8	0.0	7	0	7	2005	0.17	0.00	0.17
2050	DF	4	25.0	23.4	0.0	3	0	3	2005	0.08	0.00	0.08
2060	DF	4	25.0	0.0	21.4	0	0	0	2005	0.00	0.02	0.02
2070	DF	4	25.0	0.0	19.5	0	0	0	2005	0.00	0.02	0.02
2080	DF	4	25.0	0.0	17.8	0	0	0	2005	0.00	0.01	0.01
2090	DF	4	25.0	0.0	16.3	0	0	0	2005	0.00	0.01	0.01
2100	DF	4	25.0	0.0	14.9	0	0	0	2005	0.00	0.01	0.01

Snag records can be created at harvesting, after a fire, or from natural mortality applied at cycle boundaries. They can only be removed through falling or salvage. From cycle to cycle, there will be regular changes from height-loss and falling. Dramatic changes such as fire mortality or salvage should be relatively easy to distinguish. Any newly created snags should correspond to other reports: the fire mortality information (section 2.5.7) or the distribution of harvested trees from the base model.

Summary Snag Report: The detailed snag report contains a large amount of information typically required only for detailed analyses. A summary snag report can be requested using the keyword **SNAGSUM**. It is produced after all management is simulated, but before any of the other processes such as snag fall and decay are simulated, and contains the total density of snags that are larger than the given diameter. In Table 2.3.5 for example, the first column lists all snags, the second column gives the density of all snags greater than 12" diameter, etc. With the exception of a distinction between hard and soft snags, this table contains no other distinguishing information about species, heights, volumes, or age.

The sizes classes are the same ones that are used in the detailed snag output report, and can be defined by the user with **SNAGCLS** keyword. If the detailed snag report and the summary snag report are both printed in the same year, the total densities reported in both tables should be the same.

Table 2.3.5 - Example output from the summary snag report. In this example, most snags are hard, but some soft snags are present in 2050 through 2100. These snags were previously hard. Each column of each snag type also contains the snags in the larger size classes to the right. Thus, in 2030, there are 379.2 snags/acre total (greater than 0”), of which 116.0 snags/acre are $\geq$ 12”. Initially, most of the snags are small (< 12”), however, the 2030 wildfire killed a number of larger trees. These show up in 2030 because this report, like all the other FFE reports, is printed after all management and activities in that year. The hard snag total, soft snag total and grand total columns report snags for all sizes (DBH >0”) regardless of size class designations.

```
---------------------------------------------- SNAG SUMMARY REPORT (BASED ON STOCKABLE AREA) ---------------------
 STAND ID: 01160805050023                MGMT ID: NONE
       --------------- HARD SNAGS/ACRE ----------------  --------------- SOFT SNAGS/ACRE ----------------   GRAND
YEAR    >=00"  >=12"  >=18"  >=24"  >=30"  >=36"  TOTAL   >=00"  >=12"  >=18"  >=24"  >=30"  >=36"  TOTAL   TOTAL
----   ------ ------ ------ ------ ------ ------ ------  ------ ------ ------ ------ ------ ------ ------  ------
2010      9.2    1.7    1.7    0.0    0.0    0.0    9.2     0.0    0.0    0.0    0.0    0.0    0.0    0.0     9.2
2020     70.4    6.0    2.6    0.1    0.0    0.0   70.4     0.0    0.0    0.0    0.0    0.0    0.0    0.0    70.4
2030    379.2  116.0   52.3    7.8    0.8    0.0  379.2     0.0    0.0    0.0    0.0    0.0    0.0    0.0   379.2
2035    143.6   96.3   45.0    7.0    0.7    0.0  143.6     0.0    0.0    0.0    0.0    0.0    0.0    0.0   143.6
2040     76.5   76.5   37.7    6.3    0.7    0.0   76.5     0.0    0.0    0.0    0.0    0.0    0.0    0.0    76.5
2050     37.9   37.9   23.5    4.8    0.6    0.0   37.9     0.1    0.1    0.1    0.0    0.0    0.0    0.1    38.0
2060     31.1   10.1    9.8    3.4    0.5    0.0   31.1     0.1    0.1    0.1    0.0    0.0    0.0    0.1    31.2
2070     22.1    3.6    3.6    1.9    0.4    0.0   22.1     0.4    0.4    0.4    0.0    0.0    0.0    0.4    22.5
2080     37.9    0.8    0.8    0.8    0.4    0.0   37.9     1.9    1.9    1.9    0.2    0.0    0.0    1.9    39.8
2090     35.9    0.2    0.0    0.0    0.0    0.0   35.9     2.0    2.0    2.0    0.6    0.3    0.0    2.0    37.9
2100     35.4    1.1    0.0    0.0    0.0    0.0   35.4     1.5    1.5    1.5    0.4    0.2    0.0    1.5    36.9
```

2.4 Fuel Submodel

2.4.1 Overview

The fuel submodel tracks stand biomass and accounts for the dynamics of all nonliving biomass derived from above-ground sources in the stand. It receives input from live trees (litterfall, crown lifting and breakage), snags (either breaking up or falling over), and harvest activity, (Figure 2.4.1) and simulates decay over time using a simple constant proportional loss model. Litter, duff, and nine size classes of woody fuel are modeled (Table 2.4.1). The fuel submodel simulates decay dynamics based on up to four species-dependent decay rates, and accounts for differences attributable to the hard or soft condition of the input from snag boles and snag material (Table 2.4.1).

Some of the decaying material from the above classes moves into a duff pool. Duff does not use different species-dependent decay rates, and, like litter, is not stratified as hard or soft. Thus, a single decay rate is used for all duff material.

The fuel submodel also tracks the biomass of aboveground live tree components (crown and bole) as well as a nominal measure of live herbs and shrubs in the stand (see section 2.4.6).

Canopy fuel characteristics are tracked as indicators and for use in predicting fire behavior (section 2.4.7).

Surface fuel loads are often important indicators of fire hazard and wildlife habitat. They are used in FFE to select predefined fire behavior fuel models used for calculating fire intensity (section 2.4.8).

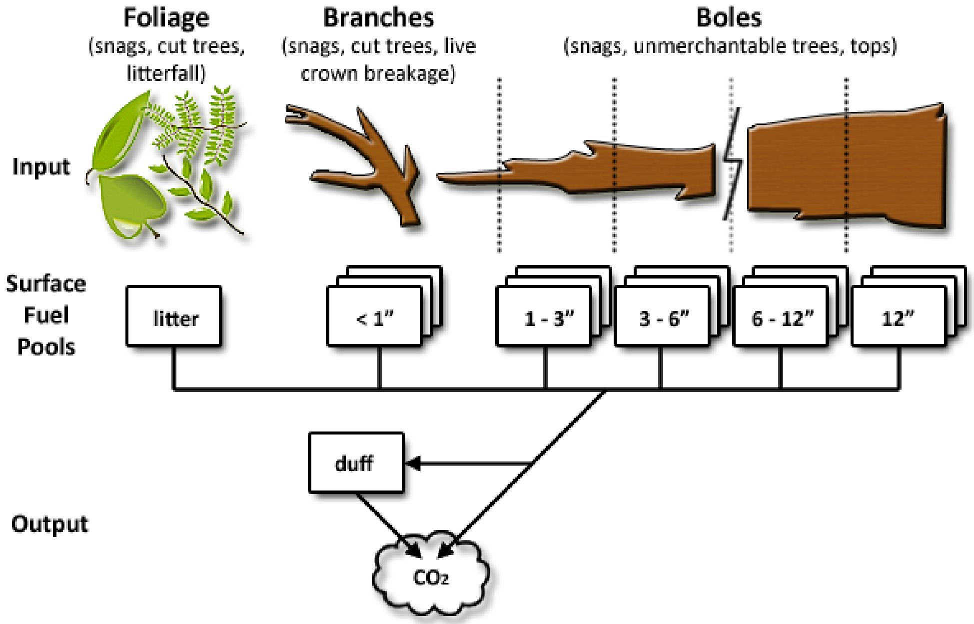

Figure 2.4.1 - Flow of material within the fuel model. Material enters the various size classes, decays and goes either to duff pool or to air (which is not tracked in this model). Not all size classes are shown in the figure. See Table 2.4.1 for additional information on each size class.

Table 2.4.1 - Fuel pools may be characterized by a combination of the following attributes.

Fuel Characteristics		
Size Class	**Decay Rate**	**Initial Decay Status**
Duff		
Litter	Very Fast	Hard
diam < 0.25”	Fast	Soft
0.25” < diam < 1”	Slow	
1” < diam < 3”	Very Slow	
3” < diam < 6”		
6” < diam < 12”		
12” < diam < 20”		
20” < diam < 35”		
35” < diam < 50”		
diam > 50”		

2.4.2 Initialization

Fuel loads can be initialized with the keywords **FUELINIT** and **FUELSOFT**. If the user does not specify initial fuel loads, the model sets them based on the dominant cover type in the stand and the percent canopy cover (Table 2.4.2; Jim Brown, pers. comm. 1995). When the model simulation is started from a tree list, the cover type is set to the species with the highest total basal area. If there are no trees in the stand, the cover type is defined as the major climax species in the stand's given habitat type (Cooper and others 1991; Pfister and others 1977), because those were likely the tree species that created the existing fuel pools. The rules and values used to determine default initial fuel loads by size class vary greatly between FVS variants.

Dead surface fuels can also be initialized by including this information in the StandInit table of an input FVS database. In addition to entering initial fuel loadings (tons/acre) directly, users can initialize their surface fuel loads by specifying a representative fuels photo series photo. This can be done with the FFE keyword **FUELFOTO** or by including this information in the StandInit table of an input FVS database.

The amount and distribution of fuel in an actual forest stand is highly dependent on the stand's history. For example, a stand generated after stand-replacing fire will have different fuel than one generated after a clear cut. This variation is not captured by the model's default initial values, so we recommend initializing fuel loadings to appropriate values rather than using model defaults whenever possible.

During a simulation, woody debris from each tree is assigned a fuel decay rate class based on species (Table 2.4.3). At initialization, once the total amount of fuel in each size class has been established, it is apportioned between the various decay rate classes using the relative amounts of basal area of each tree species present in the stand. If there are no trees in the stand, all fuel is placed into the decay class corresponding to the cover type determined above.

Table 2.4.2 - Default initial fuel loadings (tons/acre), by size class, based on the cover type of the stand. If there are trees present at the time of initialization, values in row "E" (for "established") will be used, while if there are no trees (in other words, a bare ground simulation), the canopy cover is less than 10 percent, or all trees are smaller than 1" dbh, the values in row "I" (for "Initializing") will be used. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

Species		**Size Class (in)**							
		< 0.25	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
western larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
western hemlock	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western redcedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
other	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0

Table 2.4.3 - Decay class and wood density of the tree species found in the Northern Idaho (NI) FVS variant. The density values are for oven-dry wood. See section 2.4.5 for the decay rates associated with each decay rate class.

Species	Decay Rate Class	Density lb/ft3
White pine	4	22.5
Western Larch	3	29.9
Douglas-fir	3	28.1
Grand fir	4	21.8
Western hemlock	4	26.2
Western Redcedar	2	19.3
Lodgepole pine	4	23.7
Engelmann Spruce	4	20.6
Subalpine fir	4	19.3
Ponderosa pine	4	23.7
Mountain hemlock & other	4	26.2

2.4.3 Estimation of Tree Material

The boles and crowns of both live trees and snags contribute to the surface fuel pools in FFE. Therefore, the estimation of the amount of bole and crown material on each live tree has a large impact on fuel amounts and dynamics. The following two sections describe how these amounts are calculated. Section 2.4.4 describes how the material moves from the standing pools to the surface pools.

Estimation of Bole Material: FFE uses an FVS subroutine to determine the volume of wood in each bole. In the case of live trees and hard snags, the resulting bole volumes are converted to biomass using wood density values calculated from Table 4-3a and Equation 3-5 of the Wood Handbook (Forest Products Laboratory 1999) and shown in Table 2.4.3. The boles of soft snags are assumed to have only 80% of the density of hard snags. All biomass is tracked and reported as dry weight.

When tree boles become surface fuel (as described below), the bole material is partitioned among the size classes shown in Table 2.4.1. The partitioning is done by approximating bole shape as a cone of the specified total height and diameter at breast height. Using this approximation, the length of the bole at each diameter-class breakpoint is determined. These lengths are then used, together with the base FVS model volume routine, to determine bole volume between each breakpoint. No attempt is made to simulate the physical fragmentation or actual piece lengths of boles. The material in each portion of the bole is simply assigned to the appropriate size class at the time the bole falls.

The material from each bole is also assigned a decay rate based on its tree species, as shown in Table 2.4.3. Model users may change the decay rate assignments for each species with the keyword **FUELPOOL**. The model also classifies the down material from each snag bole according to its decay status at the time it falls (hard or soft).

Estimation of Tree Crown Components: FFE estimates the amount of crown material on each tree using the equations in Brown and Johnston (1976). These equations estimate the total dry weight of live and dead material in each crown, as well as the proportions of that material in foliage, 0-0.25", 0.25-1", 1-3", and over 3" diameter branchwood.

According to Brown and Johnston's equations, the total amount of crown material and the partitioning of that material among size classes depends on the following variables: tree species, dbh, height, crown ratio, and the tree's dominance position in the stand. FFE classifies the dominance of trees based on their height. Trees above the 60th percentile (i.e., the tallest 40%) are considered dominant or co-dominant. If a tree is below the 60th percentile, it is assumed to be intermediate or suppressed. The crowns of trees classified as species 11 ("other") are estimated from Brown and Johnston's equations for western hemlock.

When crown material becomes surface fuel, all foliage is classified as litter and the other crown components enter the appropriate fuel pools based on size and species. As recommended by Jim Brown, USFS, Missoula, MT (pers. comm., 1995), the branch material over 3" is all classified as 3-6" fuel. Fallen crown material is also classified into different pools based on the decay rate of the tree species from which it originates, and whether it originates from a live tree/hard snag or a soft snag.

Except in the case of fire-scorched trees, the amount of crown material associated with each live tree is calculated in every FVS cycle based on the current attributes of the tree record. For one cycle after a tree has been scorched by fire, the amount of crown material associated with that tree is held static at the level remaining immediately after the fire (as described in section 2.5.5).

2.4.4 Sources of Woody Fuel and Litter

Every year, some material is transferred from the crowns and boles of live trees and snags into the appropriate fuel pools. This transfer is based on tree growth and mortality, snag fall and breakage, fires, and management. The following sections describe each of these processes in more detail.

Annual Litterfall: FFE simulates annual foliage litterfall from each live tree using data from Keane and others (1989) on foliage lifespan. The model assumes that 100% of the current foliage will fall during the specified leaf lifespan, so that the average proportion of foliage falling each year can be approximated from the inverse of the leaf lifespan. This gives the following equation for annual litterfall from each tree:

$$Litterfall = \frac{Foliage\,Weight}{Leaf\ \ Lifespan}$$

where:

Litterfall = weight of litter (lbs/year) to fall from this tree in each year of the FVS cycle

FoliageWeight = current weight of foliage on this tree (lbs)

Leaf Lifespan = expected foliage lifespan (years) for this tree species (Table 2.4.4)

In accounting for litterfall, the amount of foliage remaining on the tree is not reduced as we assume that the dropped material is replaced by new growth each year.

Table 2.4.4 - Leaf lifespan data used in calculation annual litterfall. Data shown are from Keane and others (1989). Where this source did not provide data for a species that occurs in the Northern Idaho FVS variant, data from another species were substituted as shown in the table.

Species	Leaf Lifespan (years)
White pine	data from ponderosa pine
Western larch	1
Douglas-fir	5
Grand fir	7
Western hemlock	data from Douglas-fir
Western redcedar	data from Douglas-fir
Lodgepole pine	3
Engelmann spruce	6
Subalpine fir	7
Ponderosa pine	4
other	data from ponderosa pine

Crown Lifting: FFE simulates the die-back of lower branches as a tree grows and the crown lifts. The model assumes that a portion of the woody crown material that was present in the previous cycle has now died and will fall during the current cycle. The amount is estimated from the ratio of the change in height of the base of the crown to the previous total length of the crown. As shown in Figure 2.4.2, this is equivalent to assuming that the crown is cylindrical in shape with crown material evenly distributed throughout this space. In reality, crowns may be broader across the bottom with crown material less dense in this space. Because these factors tend to cancel each other out, the model's simple approximation should not systematically bias the timing of debris inputs.

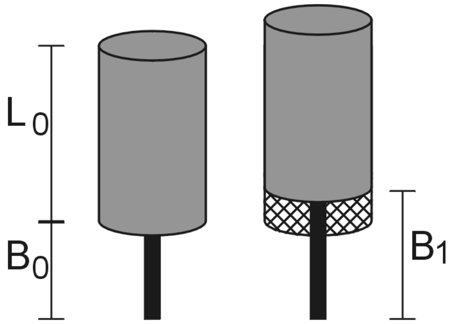

Figure 2.4.2 - Simulation of crown lifting. B_0 is the height of the base of the crown in the previous FVS cycle, B_1 is the height of the base of the crown in the current cycle, and L_0 is the length of the crown in the previous cycle. FFE assumes that all crown material in the space vacated by the lifting crown – the cross-hatched area in the figure – has died and will fall during the current cycle.

The woody crown material that has died as a result of crown lifting is assumed to fall at a constant rate during the current FVS cycle. In reality, some material might not fall until later time periods but there would also be older material from earlier time periods falling in the current year; the two effects would largely cancel each other out. Mathematically, the amount of material of each size class (excluding foliage) that will fall due to crown lifting in each year of the cycle is calculated as:

$$Annual\ Fall_i = \frac{B_1 - B_0}{L_0}\left(\frac{W_{oi}}{Cycle\ Length}\right)$$

where:

$Annual\ Fall_i$ = weight of material (lb/acre/year) in size class *i* to fall from this tree in each year of the current cycle

B_0 = height of the base of the crown (ft) of this tree in the previous FVS cycle

B_1 = height of the base of the crown (ft) of this tree in the current FVS cycle

L_0 = length of the crown (ft) in the previous FVS cycle

W_{0i} = weight of crown material (lb/acre) in size class *i* in the previous FVS cycle

$Cycle\ Length$ = length of the current FVS cycle (years)

The crown material that falls due to crown lifting is assumed to be “hard” when it is added to the surface fuel pools.

The current crown weight is not reduced as a result of these calculations. Current crown weight is a function of the tree characteristics as described above.

Background Crown Breakage: Crown material on live trees may fall as a result of normal background breakage due to snow, wind, disease, or fall-down of adjacent stems. FFE simulates this breakage by adding a small, constant proportion of each crown component to the debris pools each year. This proportion is set to 1% per year and is not under user control. The material is all assumed to be hard when it enters the surface fuel pools. Current crown weight is not reduced as a result of the loss of this material, as it is assumed that new growth replaces it.

Snag Breakage & Crown Loss: FFE models the breakage and fall-down of snags as described in section 2.3. As each snag breaks or falls naturally, the fallen bole is partitioned into the appropriate size classes and decay rate classes as described in section 2.4.3. The material from each snag is classified as “hard” or “soft” depending on the current decay status of the snag.

Table 2.4.5 - Rate of crown loss for snags of different species. Data on the amount of each crown component remaining 5 years after death were estimated from a field handbook (Division of Forest Economics 1961). “-“ indicates no data were available. The estimated time to 100 percent loss was derived from the available data, with subsequent modifications as requested during model review.

	Amount remaining 5 years after death (data)				Estimated time to 100% loss (years)			
Snag Species	Foliage	Twigs	Branches	Large Limbs	Foliage	Twigs 0-1”	Branches 1-3”	Large Limbs >3”
Western white pine	0%	< 75%	-	“numerous” limbs gone	2	5	15	15
Ponderosa pine	0%	< 50%	< 50%	“falling”	2	5	10	10
Engelmann spruce	0%	< 30%	< 50%	“falling”	2	5	10	10
Douglas-fir	0%	< 50%	< 75%	“falling”	2	5	15	15
Western hemlock	-	-	-	-	2	5	15	15
Grand fir (True firs)	0%	< 50%	< 75%	“falling”	2	5	15	15
Subalpine fir (True firs)	0%	< 50%	< 75%	“falling”	2	5	15	15
Western larch	-	-	-	-	2	5	15	15
Lodgepole pine	0%	< 75%	< 75%	-	2	5	15	15
Western redcedar	0%	< 60%	-	“some” limbs falling	2	5	20	20
Other	-	-	-	-	2	5	15	15

Over time, the crowns of snags will also fall and contribute to surface fuel pools. The rate at which this happens is estimated in the model from available data on the amount of foliage, twigs and limbs remaining five years after death (Table 2.4.5). The model uses the estimated time to 100% loss to calculate a constant fall-down rate following the death of the snag. For example, 100% loss in 10 years means that 10% of the material will be scheduled to fall each year for the next 10 years. One exception is that the model calculates the time by which a snag will become soft, since soft snags are assumed to have already lost all their branches. The model will cause the material to fall over whichever time frame is shorter: the time to 100% lost or the time to turn soft.

The fall of snag crown material is scheduled at the time each snag record is created. That is, all of the snag crown material is put into the appropriate pools (based on size and decay-rate class) and scheduled to be added to down fuel pools over succeeding years – pools of "debris-in-waiting". In this way, the need to store explicit crown data for each snag record is avoided. When snag records are created during model initialization, FFE schedules only the portion of crown material expected to fall after the start of the simulation. When a salvage operation occurs in the stand, a proportion of the material scheduled to fall in all future years is brought down early and added to fuel pools in the year of the salvage. The proportion brought down is equal to the proportion of total snag volume that was removed by the salvage operation. Similarly, when crown fires occur, a proportion of this material is removed (not added to down fuel) to simulate its consumption in the fire. The proportion removed is set equal to the proportion of the stand in which crown fire occurred, for foliage and one-half the 0-0.25" branchwood only. Larger branches are not consumed.

All snag crown material is considered hard at the time that it falls, since snags are assumed to have lost all their branches by the time they become soft.

Scorched Crowns: As described in section 2.5.5 on fire effects, FFE simulates the consumption by fire of a portion of small diameter crown material below the scorch height on surviving trees. All crown material below the scorch height that is not consumed in the fire is assumed to have been killed and to fall over the following years in the same manner as is described for snags in the previous section.

Slash: Harvest activity can result in an increase in surface fuel through the creation of slash. Slash is created when crown material from harvested trees is left in the stand, as well as when sub-merchantable or damaged trees are felled and left in the stand. The **YARDLOSS** keyword allows model users to specify a proportion of crown material from harvested trees to be left in the stand. The keyword also allows users to specify a proportion of "harvested" live trees to be left in the stand, and whether these stems are left as standing snags or felled. By default, FFE assumes that all harvested boles are removed from the stand, but that the associated crown material is left in the stand.

Pruning: When pruning in simulated in FVS, two things happen. First, length of the tree crowns is reduced based on the amount that was pruned off. FFE also calculates the biomass of the pruned material and adds it to the debris pools.

2.4.5 Decay Rates

Decay of surface fuel is simulated in annual timesteps. By default, two percent of the decayed matter from each fuel pool is added to the duff compartment while the remaining biomass is lost as CO2 and is not tracked by the model. Pools decay according to the equation:

$$Fuel_{t+1} = Fuel_t\left(1 - r\right)$$

where:

Fuel = weight of fuel in a given pool
t = year (and *t* + 1 is the following year)
r = decay rate from Table 2.4.6

The default decay rates for each size class are based on Abbott and Crossley (1982; Table 2.4.6). Users can change the decay rates using two different keywords: **FUELDCAY** and **FUELMULT**. These change the decay rate for a specific pool, or apply a multiplier to the rates in all pools. The default amount of the lost material that becomes duff is the same for each size class, but can be controlled with the **DUFFPROD** keyword.

FFE can accommodate up to 57 unique decay rates based on size class, decay rate classes, and the hard/soft status of input debris (Table 2.4.1). By default far fewer decay rates are used, decay rate classes are often not used, and decay is usually based almost solely on the size class. The one exception is a differential decay rate assigned to soft debris (debris originating from soft snags or that has become soft over time). Because this material is less physically cohesive, it is considered more susceptible to decay, and each size class is assigned a rate 10% higher than that shown in Table 2.4.6 for the corresponding size class of hard material. The hard/soft attribute applies only to woody fuel; litter and duff are always classified as hard for the purpose of calculating decay.

Table 2.4.6 - Default annual losses due to decay and the proportion of the loss that becomes duff for each species of the size class, litter and duff components. These loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Size Class Component	Annual Loss Rate	Proportion of Loss Becoming Duff
diam < 0.25"	0.12	0.02
0.25" ≤ diam < 1"		
1" ≤ diam < 3"	0.09	
3" ≤ diam < 6"	0.015	
6" ≤ diam < 12"		
diam ≥ 12"		
Litter	0.5	
Duff	0.002	0

FFE also transitions surface fuel from a hard to a soft state. The rate at which this happens is based on the specific decay rate for that size and decay rate class and the time it takes to reach 64% of its original density (Kim Mellen-McLean, personal communication). Specifically, we determine the number of years it would take that surface fuel to become soft (reach 64% of its original density) and then use the inverse as the proportion that moves from the hard class to soft class each year:

$$ToSoft = \log(1 - r) / \log(0.64)$$

where:

ToSoft = proportion of the hard class moving to the soft class each year

r = decay rate for that size and decay rate class

2.4.6 Live Surface Fuel

FFE does not dynamically simulate amounts of live fuel such as herbs and shrubs, but it does represent them with cover-type and density-specific values. The total fuel load of these materials is felt to be roughly constant in a stand (after canopy closure). Understory herbaceous vegetation is often stimulated by fire. The rapid increase in herb biomass will compensate for the slower recovery of shrub biomass.

The values used for the herbs and shrubs are determined from a combination of percent cover and the dominant species in the stand, as determined by basal area. The actual values are based on those used in FOFEM (Reinhardt and others 1997) and modified by Jim Brown, USFS, Missoula, MT (pers. comm., 1995; Table 2.4.7). If there are no trees at the beginning of the simulation, the cover type is determined from the major climax species in the stand's habitat type (Cooper and others 1991; Pfister and others 1977), as is done for the initial fuel levels. Otherwise, the assumed cover type is either the current one calculated from the dominant basal area in the stand, or the last one that was used in the stand if the stand was recently fully cut. The values for herbs and shrubs are calculated each cycle, but will only change if the percent cover or species composition of the overstory changes (from a fire, harvesting, planting, growth, or mortality).

Users cannot change the amount of live fuel or the rules by which the live fuel loads are assigned. The rules and default values differ between the FVS variants.

Table 2.4.7 - Default fuel loading (tons/acre) for herbs and shrubs based on cover type. If trees are present, and the cover is 60 percent or higher, the two columns labeled "E" (for "Established") will be used, while if there are no trees (that is, a bare ground simulation), or the cover is less than 10 percent, the values in the two columns labeled "I" (for "Initializing") will be used. If the cover is between 10 and 60 percent, a linear interpolation between the "E" and "I" columns will be used.

	Herbs		Shrubs	
	E	I	E	I
Western white pine, Grand fir	0.15	0.3	0.1	2.0
Douglas-fir, Western larch, Western hemlock, Western redcedar	0.2	0.4	0.2	2.0
Lodgepole pine	0.2	0.4	0.1	1.0
Englemann spruce, Subalpine fir, other	0.15	0.3	0.2	2.0
Ponderosa pine	0.2	0.25	0.25	0.1

2.4.7 Canopy Fuels

Canopy fuel characteristics, including the stand-level canopy base height and canopy bulk density, are calculated as described in Scott and Reinhardt (2001). The model usually assumes that the amount of crown on each tree is evenly distributed along the crown's length – with the exception being ponderosa pine in the CR, EM, IE, KT, and NI variants. The model sums the total weight of foliage and fine branchwood (one-half the 0-1/4 inch diameter branchwood) from all live conifers trees at least 6 feet tall in 1-foot height increments from the ground to the top of the tallest tree. It then calculates the 13-foot running mean weight of crown in each section (Figure 2.4.3). Canopy bulk density is the highest average value. Canopy base height is the lowest height at which a 3-foot running mean is greater than 30 lbs/acre/foot (.011kg/m3). Dead trees are not included in the canopy fuels calculations. By default, hardwoods and trees less than 6 feet tall are not included in this calculation because they are considered part of the surface fuel complex. Trees over 6' tall may contribute canopy fuels between the ground and 6' however, so it is possible to have canopy base heights of less than 6 feet.

You can use the FFE keyword **CANCALC** to include hardwoods or smaller trees in the canopy fuel calculations and to change the cutoff value that is used to set the canopy base height. Canopy fuels profile information – the density of foliage and fine branchwood at various heights above the ground – can be exported to an FVS output database using the FFE keyword **CANFPROF.**

2.4.8 Fire Behavior Fuel Models

Predicted fuel loads are important indicators of potential fire behavior and effects. However, most applications of Rothermel's fire behavior model (e.g. Andrews 1986, Finney 1998) use predefined fire behavior fuel models (Anderson 1982, Scott and Burgan 2005) rather than actual or estimated fuel loads. 53 of these models are in widespread use (Table 2.4.8), and some regions have customized additional models. Each fuel model is typically used to represent a range of fuel conditions in which fire behavior may be expected to respond similarly to changes in fuel moisture, wind and slope. The models are named descriptively (e.g., timber litter and understory; medium logging slash), and define values for a number of parameters that are difficult to measure in the stand and that are not tracked in FFE. These parameters include fuel characteristics such as: surface-to-volume ratio, depth, moisture of extinction, heat of combustion, dry density, total mineral content, and silica-free mineral content (Table 2.4.8). Rothermel's fire behavior model uses these parameters to calculate surface fire behavior. Users can change the parameters of existing fuel models, or enter their own customized fire model using the keyword **DEFULMOD**.

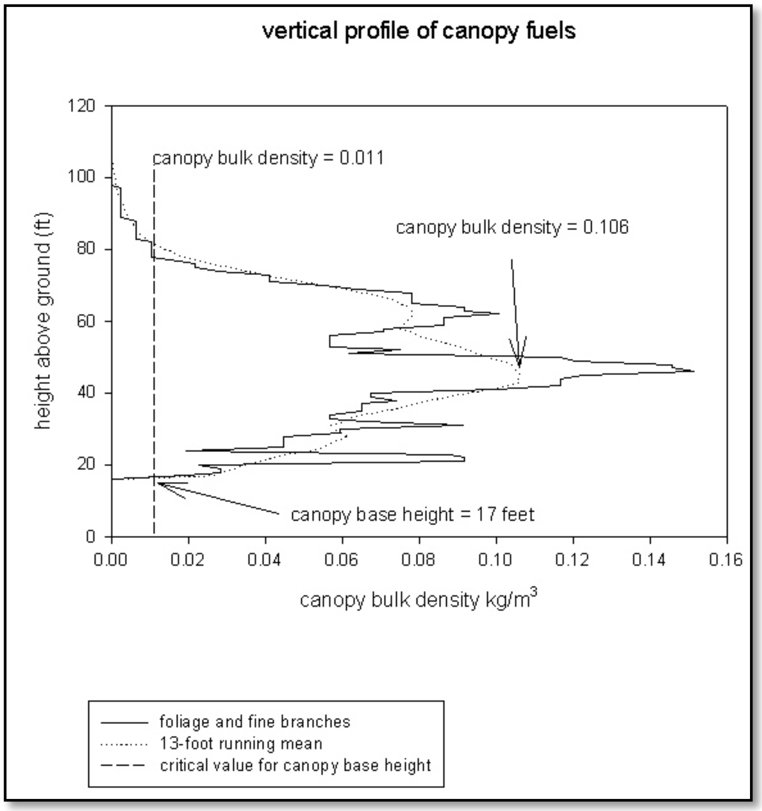

Figure 2.4.3 - Canopy fuel characteristics are determined by examining the vertical distribution of canopy fuels. Canopy bulk density is defined as the maximum of the 13-foot running mean of 1-foot deep layers. Canopy base height is defined as the lowest height at which the canopy bulk density exceeds 0.011 kg/m^3.

FFE simulates fuel loadings by size class over time, but does not use these loadings directly as inputs to the fire behavior model. Instead, FFE uses the loadings and other stand characteristics to select one or more of the stylized fuel models that best represent the fuel. The rules used to select the fire behavior fuel models vary greatly among the geographic variants of FFE-FVS.

FFE can use the fire behavior fuel models in two ways: static or dynamic. The static option selects the single model that best represents current conditions. Once the fuel model is selected, its parameters are used to calculate fire behavior. This approach, while useful in many applications, has a disadvantage when simulating changes in fuel and potential fire behavior over time. Since there are a small number of fire behavior fuel models, as fuel changes over time the same model may be selected and predicted fire behavior remain constant. At the time step when another fuel model is selected there may be dramatic changes in fire behavior with only a tiny change in simulated fuel conditions. A more reasonable result is a gradual change in predicted fire behavior corresponding to the gradual changes in fuel.

Table 2.4.8 - Parameter values for the fire behavior fuel models (Anderson 1982, Scott and Burgan 2005). Fire Behavior Fuel Models 14, 25, and 26 are customized fuel models.

			Fuel Load (lbs/ft2)						SAV Ratio (1/ft)[b]					
Fuel model Code	**Fuel model number**	**Name**	**1-hr**	**10-hr**	**100-hr**	**Live herb**	**Live woody**	**Fuel model type[a]**	**1-hr**	**Live herb**	**Live woody**	**Fuel bed depth (ft)**	**Dead fuel extinction moisture (percent)**	**Heat Content (BTU/lb)[c]**
-	1	Short grass	0.034	0.000	0.000	0.000	0.000	N/A	3500	9999	1500	1	12	8000
-	2	Timber (grass & understory)	0.092	0.046	0.023	0.023	0.000	static	3000	1500	9999	1	15	8000
-	3	Tall grass	0.138	0.000	0.000	0.000	0.000	N/A	1500	9999	1500	2.5	25	8000
-	4	Chaparral	0.230	0.184	0.092	0.000	0.230	N/A	2000	9999	1500	6	20	8000
-	5	Brush	0.046	0.023	0.000	0.000	0.092	N/A	2000	9999	1500	2	20	8000
-	6	Dormant brush, hardwood slash	0.069	0.115	0.092	0.000	0.000	N/A	1750	9999	1550	2.5	25	8000
-	7	Southern rough	0.052	0.086	0.069	0.000	0.017	N/A	1750	9999	1550	2.5	40	8000
-	8	Closed timber litter	0.069	0.046	0.115	0.000	0.000	N/A	2000	9999	1500	0.2	30	8000
-	9	Hardwood litter	0.134	0.019	0.007	0.000	0.000	N/A	2500	9999	1500	0.2	25	8000
-	10	Timber (litter & understory)	0.138	0.092	0.230	0.000	0.092	N/A	2000	9999	1500	1	25	8000
-	11	Light logging slash	0.069	0.207	0.253	0.000	0.000	N/A	1500	9999	1500	1	15	8000
-	12	Light-medium logging slash	0.184	0.644	0.759	0.000	0.000	N/A	1500	9999	1500	2.3	20	8000
-	13	Medium logging slash	0.322	1.058	1.288	0.000	0.000	N/A	1500	9999	1500	3	25	8000
-	14	Heavy logging slash	0.126	0.426	0.506	0.000	0.000	N/A	1500	9999	1500	1.8	20	8000
-	25	Plantation older than 25 years	0.069	0.069	0.092	0.000	0.207	N/A	2000	9999	1500	3.5	25	8000
-	26	Modified FM 4	0.1242	0.1242	0.0828	0.000	0.1656	N/A	2000	9999	1500	3.6	25	8000
GR1	101	Short, sparse dry climate grass	0.005	0.000	0.000	0.014	0.000	dynamic	2200	2000	9999	0.4	15	8000
GR2	102	Low load, dry climate grass	0.005	0.000	0.000	0.046	0.000	dynamic	2000	1800	9999	1	15	8000
GR3	103	Low load, very coarse, humid climate grass	0.005	0.018	0.000	0.069	0.000	dynamic	1500	1300	9999	2	30	8000
GR4	104	Moderate load, dry climate grass	0.011	0.000	0.000	0.087	0.000	dynamic	2000	1800	9999	2	15	8000
GR5	105	Low load, humid climate grass	0.018	0.000	0.000	0.115	0.000	dynamic	1800	1600	9999	1.5	40	8000
GR6	106	Moderate load, humid climate grass	0.005	0.000	0.000	0.156	0.000	dynamic	2200	2000	9999	1.5	40	9000
GR7	107	High load, dry climate grass	0.046	0.000	0.000	0.248	0.000	dynamic	2000	1800	9999	3	15	8000
GR8	108	High load, very coarse, humid climate grass	0.023	0.046	0.000	0.335	0.000	dynamic	1500	1300	9999	4	30	8000
GR9	109	Very high load, humid climate grass	0.046	0.046	0.000	0.413	0.000	dynamic	1800	1600	9999	5	40	8000
GS1	121	Low load, dry climate grass-shrub	0.009	0.000	0.000	0.023	0.030	dynamic	2000	1800	1800	0.9	15	8000
GS2	122	Moderate load, dry climate grass-shrub	0.023	0.023	0.000	0.028	0.046	dynamic	2000	1800	1800	1.5	15	8000
GS3	123	Moderate load, humid climate grass-shrub	0.014	0.011	0.000	0.067	0.057	dynamic	1800	1600	1600	1.8	40	8000
GS4	124	High load, humid climate grass-shrub	0.087	0.014	0.005	0.156	0.326	dynamic	1800	1600	1600	2.1	40	8000
SH1	141	Low load, dry climate shrub	0.011	0.011	0.000	0.007	0.060	dynamic	2000	1800	1600	1	15	8000
SH2	142	Moderate load, dry climate shrub	0.062	0.110	0.034	0.000	0.177	N/A	2000	9999	1600	1	15	8000
SH3	143	Moderate load, humid climate shrub	0.021	0.138	0.000	0.000	0.285	N/A	1600	9999	1400	2.4	40	8000
SH4	144	Low load, humid climate timber-shrub	0.039	0.053	0.009	0.000	0.117	N/A	2000	1800	1600	3	30	8000
SH5	145	High load, dry climate shrub	0.165	0.096	0.000	0.000	0.133	N/A	750	9999	1600	6	15	8000
SH6	146	Low load, humid climate shrub	0.133	0.067	0.000	0.000	0.064	N/A	750	9999	1600	2	30	8000
SH7	147	Very high load, dry climate shrub	0.161	0.243	0.101	0.000	0.156	N/A	750	9999	1600	6	15	8000
SH8	148	High load, humid climate shrub	0.094	0.156	0.039	0.000	0.200	N/A	750	9999	1600	3	40	8000
SH9	149	Very high load, humid climate shrub	0.207	0.112	0.000	0.071	0.321	dynamic	750	1800	1500	4.4	40	8000
TU1	161	Low load, dry climate timber-grass-shrub	0.009	0.041	0.069	0.009	0.041	dynamic	2000	1800	1600	0.6	20	8000
TU2	162	Moderate load, humid climate timber-shrub	0.044	0.083	0.057	0.000	0.009	N/A	2000	9999	1600	1	30	8000
TU3	163	Moderate load, humid climate timber-grass-shrub	0.051	0.007	0.011	0.030	0.051	dynamic	1800	1600	1400	1.3	30	8000
TU4	164	Dwarf conifer with understory	0.207	0.000	0.000	0.000	0.092	N/A	2300	9999	2000	0.5	12	8000
TU5	165	Very high load, dry climate timber-shrub	0.184	0.184	0.138	0.000	0.138	N/A	1500	9999	750	1	25	8000
TL1	181	Low load, compact conifer litter	0.046	0.101	0.165	0.000	0.000	N/A	2000	9999	9999	0.2	30	8000
TL2	182	Low load, broadleaf litter	0.064	0.106	0.101	0.000	0.000	N/A	2000	9999	9999	0.2	25	8000
TL3	183	Moderate load, conifer litter	0.023	0.101	0.129	0.000	0.000	N/A	2000	9999	9999	0.3	20	8000
TL4	184	Small downed logs	0.023	0.069	0.193	0.000	0.000	N/A	2000	9999	9999	0.4	25	8000
TL5	185	High load, conifer litter	0.053	0.115	0.202	0.000	0.000	N/A	2000	9999	1600	0.6	25	8000
TL6	186	Moderate load, broadleaf litter	0.110	0.055	0.055	0.000	0.000	N/A	2000	9999	9999	0.3	25	8000
TL7	187	Large downed logs	0.014	0.064	0.372	0.000	0.000	N/A	2000	9999	9999	0.4	25	8000
TL8	188	Long-Needle litter	0.266	0.064	0.051	0.000	0.000	N/A	1800	9999	9999	0.3	35	8000
TL9	189	Very high load, broadleaf litter	0.305	0.152	0.191	0.000	0.000	N/A	1800	9999	1600	0.6	25	8000
SB1	201	Low load, activity fuel	0.069	0.138	0.505	0.000	0.000	N/A	2000	9999	9999	1	25	8000
SB2	202	Moderate load, activity fuel or low load, blowdown	0.207	0.195	0.184	0.000	0.000	N/A	2000	9999	9999	1	25	8000
SB3	203	High load, activity fuel or moderate load, blowdown	0.253	0.126	0.138	0.000	0.000	N/A	2000	9999	9999	1.2	25	8000
SB4	204	High load, blowdown	0.241	0.161	0.241	0.000	0.000	N/A	2000	9999	9999	2.7	25	8000

[a] Fuel model type does not apply to fuel models without live herbaceous load.

[b] The value 9999 was assigned in cases where there is no load in a particular fuel class or category. The value is assumed to be 109 for 10-hr fuel, and 30 for 100-hr fuel.

[c] The same heat content value was applied to both live and dead fuel categories.

As a result, we developed the dynamic option for selecting fuel models. The dynamic method selects two or more fuel models based on fuel loads and other stand characteristics, calculates the resulting fire behavior for each fuel model, and takes a weighted average of the results.

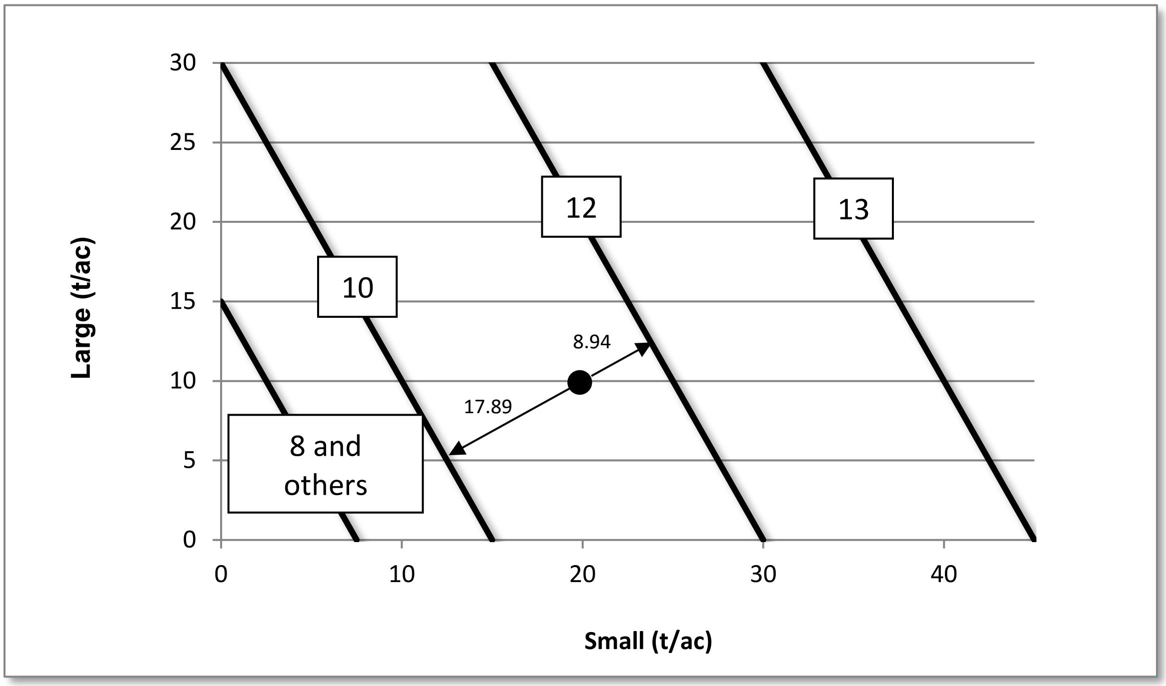

Figure 2.4.4 - An example of dynamic fuel modeling, based on large and small woody surface fuel. The lines here correspond to fuel models for natural fuel in closed stands for many habitat types, with the fuel model number shown on the line. The point shown below here will result in an interpolation using Fuel Models 10 and 12, as described in the text.

The selection of the fuel models and their weights depends on stand conditions, including fuel loads. For example, fuel loads might place the stand somewhere in the diagram in Figure 2.4.4. The model computes the shortest distance to each of the nearest neighboring fuel model lines. For combinations of fuel found in the upper right corner in the example, there will be only one nearest neighbor (Fuel Model 13, in Figure 2.4.4). Typically though, there will be two neighbors. Once the distance to each neighboring fuel model is known, the influence of each fuel model is calculated by using the inverse of the distance from the fuel model line to the current condition as a weight. In Figure 2.4.4, the distance from the sample point (small = 20; large = 10) to neighboring Fuel Model 12 is 8.94 units; the distance to Fuel Model 10 is 17.89 units. The resulting fire behavior will be more like Fuel Model 12, which is nearer than Fuel Model 10, but the contributions of both models will be present. The weights of the two models, W10 and W12 can be calculated in this example as:

$$W_{10} = \frac{1/17.89}{(1/17.89)+(1/8.84)} = 0.33$$

$$W_{12} = \frac{1/8.94}{(1/17.89)+(1/8.84)} = 0.67$$

where:

W_{10} = weight for Fuel Model 10
W_{12} = weight for Fuel Model 12

In this example, fire intensity will be computed as a weighted average of the intensity predicted using Fuel Model 10 (33.3%) and Fuel Model 12 (66.7%).

In more complex examples, it is possible to define fuel model lines that are not parallel (as in the example) or that are horizontal or vertical. In these cases, the interpolation searches to the left and right of the sample point, and then searches above and below the sample point. Based on these searches, between one and four unique neighboring models may be found, and the same weighting system will be used to compute the influence of the neighboring models. In the NI variant, however, the fuel model lines are oriented similarly to the ones shown in this example.

Fuel loads provide the system for weighting when woody surface fuels dominate the fuel complex. In situations where woody fuels are sparse and litter, shrubs or herbaceous fuels dominate, a similar distance-based weighting system is used based most often on the amount of canopy coverage.

The benefit of the dynamic approach is that the calculated potential fire intensity varies continuously as fuel conditions change in the stand. Figure 2.4.5 shows the flame length predicted by different small (0-3”) and large (3”+) woody fuel loads using the static and dynamic approaches.

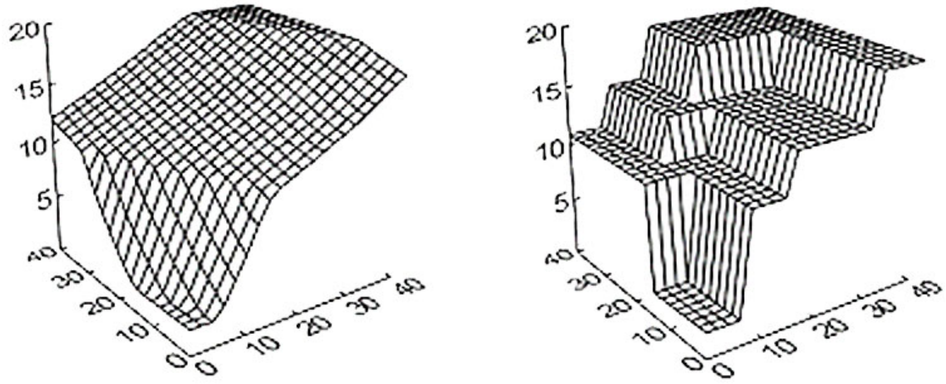

Figure 2.4.5 - Example of predicted flame length over a range of small and large woody fuels (tons/acre). Predictions using the dynamic option are on the left, and predictions using the static option are on the right.

Users can choose whether to use the static or the dynamic standard fuel models using the keyword **STATFUEL**. They cannot, however, change the definition of the fuel regions or lines (i.e., the fuel levels at which different fuel models apply). These definitions are customized in the development of regional variants of FFE.

The logic used by FFE to select fire behavior fuel model(s) varies between FFE variants and is one of the main differences between FFE variants. Complete selection logic for each variant is contained in chapter 4. Users can also set fuel model(s) using the keyword **FUELMODL** or by including it in the StandInit table of an FVS input database.

Certain common features are present in most variants, however. In most cases, different selection logic is used for natural and activity fuels (fuels resulting from harvesting within the last five years), and for high and low woody fuel loads. Most variants use the same logic for activity fuels and when woody debris is abundant. In these cases, the fuel model depends only on the amount of small (<3") and large (>3") fuel in the stand, and whether the fuel is “natural” or “activity” (Figure 2.4.5).

At low natural fuel loads in the Northern Idaho variant, the fuel model depends on habitat type and canopy cover. The habitat types are divided into dry grassy types, dry shrubby types, and all other habitat types. For the dry grassy and shrubby types, the fuel model choice is further defined by the canopy cover of the stand (Table 2.4.9). The rules for choosing a fire behavior fuel model at low fuel loads vary widely between FFE variants.

Table 2.4.9 - Rules for determining the Fuel Model at low woody fuel loads. For stands that are between the percent cover values listed below, the fire behavior will be based on a combination of the two fuel models (unless the static option is being used).

Habitat Type	Percent Cover	Fuel Model
Ponderosa pine / bluebunch wheatgrass (130)	<20	1
	>60	9
Ponderosa pine / common snowberry (170)	<20	2
Douglas-fir / common snowberry (310)	>60	9
Other	any	8

2.4.9 Management

Management can affect surface and canopy fuel in different ways, either directly or indirectly. FFE-FVS allows simulation of a full range of thinning treatments, prescribed fire, and mechanical fuel treatments. When thinning is simulated using base model keywords, FFE can simulate creation of activity fuel (see section 2.4.4). Thinning also changes canopy fuel characteristics – amount of canopy fuel, canopy base height, and canopy bulk density. Other surface fuel treatments are specific to FFE and do not interact with base model thinning keywords. These management options include treatments that affect fuel depth, reduce fuel loading, or reduce fuel size.

Methods Affecting Fuel Depth: Several harvest methods can be simulated as well as different types of mechanical slash treatments. Harvesting and mechanical fuel treatment methods are specified with the **FUELTRET** keyword, used in conjunction with base model thinning keywords. The base model thinning keywords and **YARDLOSS** specifications determine the volume harvested and the quantity of logging residue left on site. The harvesting and mechanical fuel treatment methods only affect the depth of the logging residue and overall fuel depth. In FFE, fuel depth affects fire intensity but not fuel consumption.

Three harvesting options are available in FFE:

1) Ground based (including cat skidding and line skidding)
2) High lead (including skyline)
3) Precommercial or helicopter

Any other type of harvesting is assumed to have no impact on fuel depth.

Two general types of slash treatments are also available:

1) Trampling / crushing / chopping / chipping; and

2) Flailing / lopping.

No other type of slash treatment (excluding burns which are discussed in section 2.5) impacts fuel depth. The slash treatments specified here have no impact on the actual size distribution of fuels. Treatments affecting size must be simulated differently (see below).

The harvest method and slash treatment are used to determine a multiplier for fuel depth (Table 2.4.10). If no activity is specified at the time of a harvest, no multiplier will be applied (i.e., fuel depth will not be changed). The multiplier can be changed with the keyword **FUELTRET**.

Table 2.4.10 - Default fuel depth multipliers based on harvest type and slash treatment method.

	Slash Treatment Type		
Harvest Method	**None**	**Flailing etc.**	**Trampling etc.**
Ground based	1.0	0.83	0.75
High lead	1.3	0.83	0.75
Precommercial	1.6	0.83	0.75

Multipliers are applied for five years following a stand entry. After that time, fuel from activities is assumed to have the same depth as natural fuel.

Methods Affecting Fuel Loads: Burning fuel to reduce fuel loadings is a common practice. Broadcast burning, piling and burning fuel, and jackpot burning are discussed in section 2.5.3.

Fuel loads can also be manually increased or decreased with the **FUELMOVE** keyword to simulate treatments involving fuel removals or to ensure that fuel levels are at some predetermined level.

Methods Affecting Fuel Size: Chipping or other treatments that reduce fuel size can be simulated independently of any harvesting action in the model. They move material from the larger fuel classes to the smaller fuel classes, without reducing fuel loads or affecting fuel depth. These treatments are scheduled using the **FUELMOVE** keyword.

2.4.10 Output

Using the keyword **FUELOUT**, the user can request the detailed fuel report, a table describing fuel in specific years or at specific intervals. The report contains information about surface fuel and standing dead and live fuel, consumed fuel, and removed fuel (Table 2.4.11). All values, including the live components, are given in dry weight, tons/acre. All fuel is included in this table, as are all removals except decay. The following is a short description of the columns in the output table.

Year	The simulation year of the report
Surface Fuel	Reported in tons/acre. Dead surface fuels are separated by diameter class. The >3” column is a sum of the three following columns. Live surface fuels are separated into herbs and shrubs, and the Surf Total column is the sum of all surface fuels (dead and live).
Standing Wood	Reported in tons/acre. Dead fuels are reported in two size classes: small diameter snags and branches (0-3”), and larger diameter snags and branches (>3” inches). Live fuels are separated into foliage, 0-3” size class and >3” size class branch and stem wood.
Total Biomass	Total (tons per acre) of all standing wood and surface fuels.

Total Consumption	Total amount of fuel (not including live trees) that was consumed in a fire. In most years, this column will be zero, but if a fire was simulated this value is that same as reported in the fuel consumption report (section 2.5.7). Consumption will not be shown if it occurs in a year where no output is requested.
Biomass Removed	Amount of wood that was harvested (live or dead) in tons per acre. This includes removals from thinnings as well as salvage operations and surface fuel removed with the FUELMOVE keyword.

Table 2.4.11 - Example detailed fuel report. Notice that a fire in 2065 consumed surface fuel and killed trees (moved standing live biomass to standing dead). Notice also the sharp increase in surface woody fuels in 2070. This is a result of fire-killed trees breaking up and falling down. For the 0-3” fuels this peak is short-lived because smaller materials fall quickly and begin to decompose. The >3” material continues to accumulate over the remainder of the simulation period, as standing dead tree boles slowly fall over. By comparing the columns showing surface fuel and standing dead, the process of dead wood falling to the forest floor can be tracked.

```
-------------------------------------------------------------------------------------------------------------------------
                                         ******  FIRE MODEL VERSION 1.0 ******
                                                   ALL FUELS REPORT
-------------------------------------------------------------------------------------------------------------------------
                                                   ESTIMATED FUEL LOADINGS
                     SURFACE FUEL (TONS/ACRE)                          STANDING WOOD (TONS/ACRE)
     ----------------------------------------------------------  -----------------------------------
                    DEAD FUEL                     LIVE               DEAD            LIVE
     ----------------------------------------- ---------- SURF   -----------   ---------------        TOTAL TOTAL BIOMASS
YEAR LITT.  DUFF  0-3"   >3"  3-6" 6-12"  >12" HERB SHRUB TOTAL   0-3"   >3"   FOL  0-3"   >3" TOTAL BIOMASS CONS REMOVED
-------------------------------------------------------------------------------------------------------------------------
1993  1.25   9.0   3.1   7.2   3.8   3.4   0.0 0.24  0.57  21.3   0.00  23.4   4.8   9.6    40    78    99      0     0
1995  1.78   9.0   3.1   9.2   5.1   4.1   0.0 0.24  0.57  23.9   0.00  20.5   4.8   9.6    40    75    99      0     0
2000  2.11   9.0   4.2  14.1   8.3   5.8   0.0 0.24  0.56  30.3   0.86  15.0   4.9  10.6    44    76   106      0     0
2005  2.12   9.1   7.2  19.0  11.6   7.4   0.0 0.24  0.56  38.3   0.64   8.4   5.0  10.8    47    72   111      0     0
2010  2.15   9.3   7.5  22.9  14.0   8.8   0.1 0.24  0.55  42.6   0.69   3.4   5.1  11.2    50    71   113      0     0
2015  2.34   9.4   7.2  22.3  13.6   8.6   0.1 0.24  0.54  42.0   0.70   3.5   5.9  11.9    54    76   118      0     0
2020  2.53   9.5   7.1  21.7  13.1   8.4   0.2 0.24  0.53  41.6   0.65   3.4   6.0  12.1    57    79   121      0     0
2025  2.57   9.7   6.9  21.2  12.7   8.3   0.2 0.24  0.53  41.1   0.71   3.5   6.1  12.4    61    83   125      0     0
2030  2.57   9.8   6.8  20.7  12.2   8.2   0.3 0.24  0.53  40.7   0.70   3.7   6.1  12.6    64    87   128      0     0
2035  2.60  10.0   6.7  20.3  11.8   8.1   0.4 0.24  0.53  40.3   0.75   4.1   6.3  12.9    67    91   131      0     0
2040  2.63  10.1   6.6  20.0  11.4   8.1   0.5 0.24  0.53  40.1   0.72   4.3   6.3  13.2    70    95   135      0     0
2045  2.62  10.2   6.5  19.8  11.1   8.2   0.6 0.24  0.53  40.0   0.75   4.6   6.2  13.5    73    98   138      0     0
2050  2.61  10.4   6.4  19.8  10.8   8.3   0.7 0.24  0.52  39.8   0.81   5.0   6.2  13.7    76   101   141      0     0
2055  2.66  10.5   6.2  19.8  10.5   8.4   0.9 0.24  0.52  39.9   0.85   5.4   6.5  14.0    79   105   145      0     0
2060  2.71  10.6   6.1  19.9  10.2   8.7   1.0 0.23  0.51  40.1   0.76   5.4   6.5  14.2    81   108   148      0     0
2065  0.00   2.4   1.0   4.6   0.5   3.3   0.8 0.23  0.51   8.7  13.77  89.7   0.0   0.0     0   104   112     40     0
2070  0.00   2.5  10.7  34.2   8.1  21.6   4.5 0.40  1.00  48.8   3.08  55.1   0.0   0.0     0    58   107      0     0
2075  0.02   2.7   7.9  45.5  10.1  27.5   8.0 0.40  1.00  57.5   1.54  39.3   0.0   0.0     0    41    98      0     0
2080  0.07   2.8   5.9  51.4  10.7  29.6  11.1 0.40  1.00  61.6   0.00  29.4   0.2   0.2     0    30    91      0     0
2085  0.17   2.9   3.5  56.5  10.9  31.5  14.1 0.39  0.97  64.5   0.01  19.9   0.4   0.6     0    21    85      0     0
2090  0.31   3.0   2.1  60.7  10.5  33.3  16.8 0.35  0.76  67.2   0.03  11.1   0.7   1.5     0    14    81      0     0
2095  0.49   3.1   1.4  60.9   9.8  32.7  18.4 0.30  0.55  66.7   0.04   6.0   1.1   2.3     2    11    78      0     0
```

This report provides a look at the dynamics of live and dead, standing and surface biomass. Before simulating management, a user might run a no-management simulation to assess model performance (see if predicted fuel loads are reasonable) and possibly calibrate the model by adjusting snag or fuel keywords. Then, a number of management alternatives can be simulated and results compared in terms of predicted fuel loads over time. If management objectives are expressed in terms of an acceptable range of surface fuel loadings, prescriptions can be developed by repeatedly changing treatment prescriptions and examining this report to see whether objectives are met.

The fuels report is produced after all management is simulated, but before any of the other processes such as snag fall and decay are simulated. The last two columns showing the removals can give some indication of the level of impact expected from harvest or fire. The fuel consumption report can also aid in interpretation of the table because it shows, for each surface fuel class, how those pools are affected by fire.

The change in stand biomass from one cycle to another can be calculated as:

$$TotBio_t = TotBio_{t-1} - TotalConsumption - Removals - Decay + Growth$$

The growth and decay terms are not explicitly included in the table, so their net contribution must be inferred.

Some changes in pool size can be tracked between different parts of the table. Standing live may become standing dead. Standing dead will become surface fuel, and some portion of the surface fuels will become duff.

Using the keywords **DWDCVOUT** and **DWDVLOUT**, the user can request the down woody debris cover and volume reports. These tables describe down wood in percent (%) cover and cuft/acre by size class and decay class (hard/soft) (Table 2.4.12 and Table 2.4.13). All down wood is included in this table, with the exception that the cover report does not include wood less than 3 inches. The following is a short description of the columns in the output tables.

Year	The simulation year of the report
Down Dead Wood Volume	Reported in cuft/acre. The down woody debris is separated by diameter class and decay status (hard or soft). The total columns estimate the total down wood volume for hard and soft wood separately.
Down Dead Wood Cover	Reported in percent cover (%). The down woody debris is separated by diameter class and decay status (hard or soft). Down wood cover is not estimated for wood less than 3". The total columns estimate the total down wood cover (3" and larger) for hard and soft wood separately.

Table 2.4.12 - Example down woody debris volume report. Notice that a thinning in 2025 in which crowns are left as slash causes the down wood volume to increase, especially in the 0-3" size class. Also notice that a prescribed burn in 2030 consumed down wood and caused the down wood volume estimate to decrease.

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                                          ******  FIRE MODEL VERSION 1.0 ******
                                              DOWN DEAD WOOD VOLUME REPORT
STAND ID: 060305403015                  MGMT ID: NONE
---------------------------------------------------------------------------------------------------------------------------------------
                              ESTIMATED DOWN WOOD VOLUME (CUFT/ACRE) BY SIZE CLASS (INCHES)
                                 HARD                                                              SOFT
      -------------------------------------------------------------   -------------------------------------------------------------
YEAR    0-3   3-6  6-12     12-20  20-35    35-50     >=50      TOT       0-3    3-6   6-12    12-20  20-35    35-50     >=50      TOT
---------------------------------------------------------------------------------------------------------------------------------------
2010    619  1145  1528      1145     76       38       38     4589         1      0      0        0      0        0        0        1
2015    648  1098  1474      1098     73       36       36     4464         1      3      7        1      0        0        0       12
2020    733  1078  1454      1065     69       35       35     4469         1      4     11        4      0        0        0       21
2025   1315  1096  1514      1053     66       33       33     5110         3     11     21       10      0        0        0       45
2030    468   602  1168       912     54       27       27     3257         1      8     29       16      0        0        0       54
2035    516   616  1228       965     54       25       25     3430         3     16     50       26      0        0        0       96
2040    499   635  1293       994     55       24       24     3525         4     21     59       34      1        0        0      118
2045    508   627  1317      1040     59       23       23     3597         4     22     63       42      2        0        0      133
2050    524   634  1336      1080     67       22       22     3685         4     25     70       52      3        0        0      154
2055    544   653  1402      1127     80       21       21     3847         3     27     75       61      5        0        0      171
```

Table 2.4.13 - Example down woody debris cover report. The increase in down wood due to the thinning in 2025 is not as noticeable given that the down wood cover report does not include material less than 3". However, the prescribed burn in 2030 does lead to a noticeable decrease in down wood cover.

```
---------------------------------------------------------------------------------------------------------------------------
                                          ******  FIRE MODEL VERSION 1.0 ******
                                              DOWN DEAD WOOD COVER REPORT
STAND ID: 060305403015                  MGMT ID: NONE
---------------------------------------------------------------------------------------------------------------------------
                              ESTIMATED DOWN WOOD PERCENT COVER (%) BY SIZE CLASS (INCHES)
                              HARD                                                         SOFT
      -----------------------------------------------------  -----------------------------------------------------
YEAR   3-6    6-12   12-20   20-35   35-50    >=50     TOT       3-6    6-12   12-20   20-35   35-50    >=50     TOT
---------------------------------------------------------------------------------------------------------------------------
2010   7.7     5.8     2.9     0.2     0.1     0.6    17.3       0.0     0.0     0.0     0.0     0.0     0.0     0.0
2015   7.4     5.6     2.8     0.2     0.1     0.6    16.8       0.0     0.1     0.0     0.0     0.0     0.0     0.1
2020   7.3     5.6     2.8     0.2     0.1     0.6    16.5       0.1     0.1     0.0     0.0     0.0     0.0     0.2
2025   7.4     5.8     2.7     0.2     0.1     0.5    16.7       0.1     0.1     0.0     0.0     0.0     0.0     0.3
2030   4.4     4.6     2.4     0.2     0.1     0.5    12.1       0.1     0.2     0.1     0.0     0.0     0.0     0.4
2035   4.5     4.8     2.5     0.2     0.1     0.5    12.5       0.2     0.3     0.1     0.0     0.0     0.0     0.6
2040   4.6     5.0     2.6     0.2     0.1     0.5    12.9       0.2     0.3     0.1     0.0     0.0     0.0     0.7
2045   4.5     5.1     2.7     0.2     0.0     0.5    13.0       0.2     0.4     0.2     0.0     0.0     0.0     0.8
2050   4.6     5.2     2.8     0.2     0.0     0.4    13.3       0.3     0.4     0.2     0.0     0.0     0.0     0.9
2055   4.7     5.4     2.9     0.2     0.0     0.4    13.7       0.3     0.4     0.2     0.0     0.0     0.0     1.0
```

Like all the FFE reports, these reports are produced after all management is simulated, but before any of the other processes such as snag fall and decay are simulated

The down wood volume and cover estimates in these reports are linked directly to the down wood biomass as tracked in the detailed All Fuels Report. First, the values in the All Fuels Report (dry tons/acre) are converted to volume (cuft/acre), assuming a conversion factor of 24.96 lbs/cuft. (This value is based on a specific gravity value of 0.4, suggested for down wood in Brown (1974).)

Second the down wood volume (cuft/acre) is converted to percent cover (%) using the formulas in Table 2.4.14.

Table 2.4.14 – Relationships used to estimate down wood percent cover (%) from down wood volume (cuft/acre) by size class. These equations were developed using CVS down wood data collected via the line intercept method (Kim Mellen-McLean, personal communication).

size class	**formula**
3-6"	% cover = 0.0166 * $\text{volume}^{0.8715}$
6-12"	% cover = 0.0092 * $\text{volume}^{0.8795}$
12-20"	% cover = 0.0063 * $\text{volume}^{0.8728}$
20-35"	% cover = 0.0069 * $\text{volume}^{0.8134}$
35-50"	% cover = 0.0033 * $\text{volume}^{0.8617}$
>50"	% cover = 0.0949 * $\text{volume}^{0.5}$

2.5 Fire Submodel

2.5.1 Overview

FFE-FVS uses the fire submodel two different ways. First, model users can simulate the effect of a prescribed fire or wildfire at any point in time. Repeated fires can be simulated, and fires can be set at random times or when certain conditions are met. If a fire is simulated in this way, it modifies stand and fuel conditions by killing trees and consuming fuel, and alters future stand and fuel dynamics. The second method uses exactly the same calculations to examine *potential* fire behavior and effects without actually changing any of the stand conditions. In this case, managers can assess the changing fuel conditions by examining predicted changes in fire characteristics and impacts. Typically one might look at potential fire behavior and effects over the course of the simulation period, possibly also scheduling one or more fires along the way.

The fire model receives input from other model components. Users provide simulation instructions such as the year to simulate fire or calculate potential fire effects, and the conditions at the time of the burn. FVS provides detailed information about all the trees in the stand. The fuel component of FFE provides information on surface fuel loadings and canopy fuel characteristics. The fire model can then calculate the predicted effects of the fire on fuel, live trees, and snags, as well as fire characteristics such as flame length and fire type. This section describes the fire model in more detail. First, burn conditions are discussed. Methods for calculating fire behavior are then presented. We then discuss fire effects including tree mortality, fuel consumption and smoke production. Use of potential fire calculations follows, and finally, fire related output tables are summarized.

2.5.2 Burn Conditions

In nature, the conditions under which a fire burns have a large impact on its behavior and effects. Users can specify fuel moisture content, wind speed, and ambient air temperature using various keywords, or they can choose from a set of predefined conditions using the **SIMFIRE** keyword. The model does not simulate changes in any of these environmental variables over time, so the values must be entered for each simulated fire. Other conditions, such as slope and fuel loading, cannot be altered by the user at the time of a fire. Slope is a constant that is established at the beginning of the simulation, and fuel loading is simulated by FFE once the initial inventory fuel loadings are set (see section 2.4).

If a fire is scheduled with the **SIMFIRE** keyword, it will be simulated and result in tree mortality and fuel consumption even if burn conditions are marginal. In FFE, all fires are assumed to be head fires, which spread with the wind. Lower intensity backing fires can be simulated by adjusting the environmental conditions or the adjusting the flame length directly with the **FLAMEADJ** keyword.

Fuel Moisture: The fuel moisture content (weight of water/dry weight of fuel expressed as a percentage) is used to calculate fire intensity and fuel consumption. Each fuel size class must have an assigned moisture value. Users can choose one of four predefined fuel moisture combinations in the model (Table 2.5.1), or specify the moisture conditions for each of the classes using the **MOISTURE** keyword.

While all moisture levels affect fuel consumption, only the values for the live and the small (<3") fuel are used to calculate fire intensity. In general, wetter fuel produces shorter flames (Figure 2.5.1) and results in less fuel consumption, as is described further in section 2.5.5.

Wind Speed: Fire intensity increases with increasing wind speed. The default wind speed is 20 miles/hour. Users can set the wind speed using the **SIMFIRE** keyword.

Both the default wind speed and the value entered by the user describe the wind speed at 20 feet above the vegetation. This value is then converted to an expected mid-flame wind speed by multiplying it by a correction factor based on the canopy cover in the stand (Figure 2.5.2) (Albini and Baughman 1979).

Table 2.5.1 - Default percent fuel moisture for the four predefined moisture conditions for each fuel size class.

	Moisture Level			
	Very Dry	**Dry**	**Moist**	**Wet**
0-0.25" (1 hour)	4	8	12	16
0.25-1" (10 hour)	4	8	12	16
1-3" (100 hour)	5	10	14	18
>3"	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

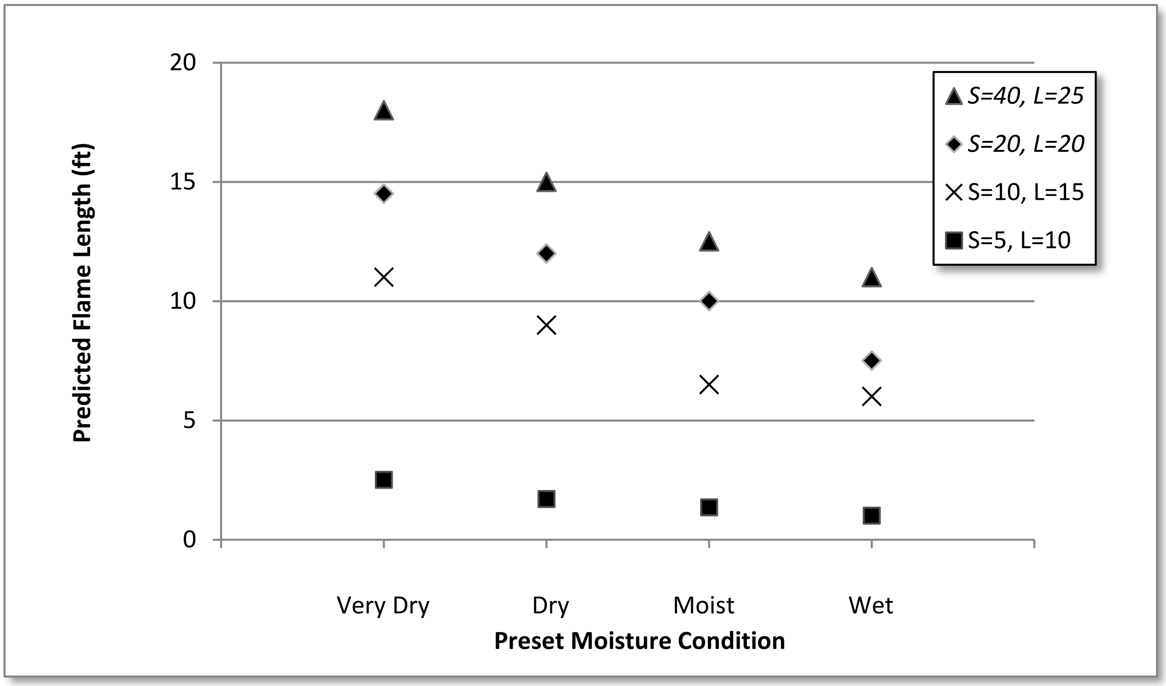


Figure 2.5.1 - Example flame lengths for each of the predefined moisture conditions for four different combinations of small (S<3") and large (L>3") fuel amounts (in tons/acre). Other factors being equal, the flame lengths decrease as moisture levels increase.

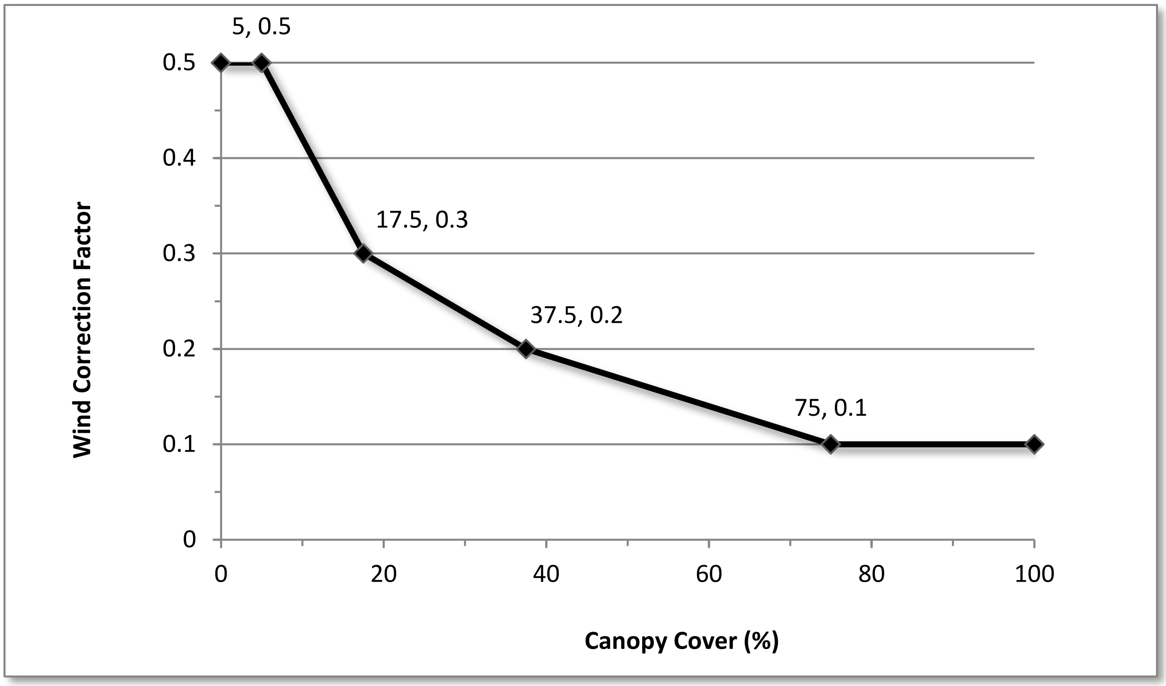


Figure 2.5.2 - The correction factors used to calculate mid-flame wind speed from wind at 20 feet above the vegetation

Air Temperature: The ambient air temperature (°F) at the time of a fire affects scorch height, and thus tree mortality. Scorch height increases exponentially with temperature (Figure 5.3, Van Wagner 1973). This is the only use of temperature in this model. The indirect effects of air temperature on fire behavior as fine fuel dries in response to heating are not simulated; fuel moisture content is a required user input.

2.5.3 Controlling fire extent

Continuous Burns: In FFE, by default, fires impact the entire area of the stand (i.e., no unburned patches remain). Continuous fires (either prescribed- or wild-fires) are scheduled using the **SIMFIRE** keyword. If a prescribed burn or wildfire is highly variable and includes some unburned patches, this can be adjusted accordingly on the **SIMFIRE** keyword using field 6 (percentage of stand area burned).

Pile Burns: Pile burns do not impact the entire area within the stand, but burn concentrations of fuel. This kind of fuel treatment is requested with the **PILEBURN** keyword. By default, in pile burning, 80% of the fuel from 70% of the stand is concentrated into piles that cover 10% of the stand area (Figure 2.5.4, left). These piles are assumed to be far enough from trees not to cause any mortality.

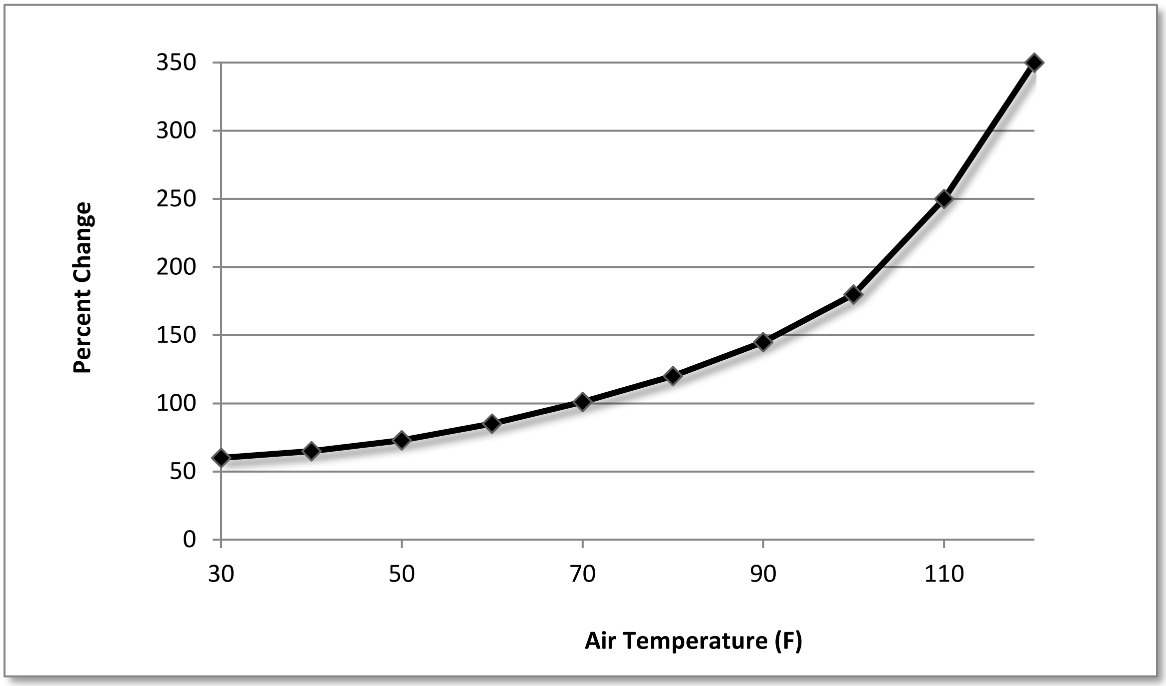


Figure 2.5.3 - The change in scorch height as temperature changes. In this figure, the scorch heights are relative to the scorch height at an air temperature of 70° (the default value). Thus, at 105° the scorch height would be about two times (200 percent) higher than at 70°.

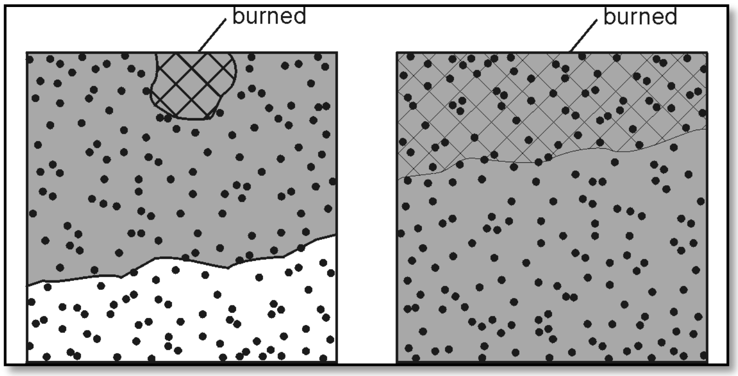


Figure 2.5.4 - Schematic diagram of the difference between pile burning (left) and jackpot burning (right). Each diagram represents a stand. The shaded areas are the areas from which fuel is concentrated. The hatched area represents the area that is then burned.

Jackpot burns are a special kind of pile burns. They are more widespread, burning by default 30% of the stand (Figure 2.5.4, right). The model assumes that the majority of the fuel is in the burned part of the stand (by default, 60% of the stand's fuel). These piles are assumed to be far enough from trees not to cause mortality.

In both cases, 100% of the litter and duff in the burned area are consumed, and all of the burned area will have the mineral soil exposed. In addition, 100% of piled fuel less than 1" and 90% of the piled fuel greater than that are burned. Smoke production is calculated assuming that the burned fuel contains the preset "moist" moisture values.

Afterwards, any unburned, piled fuel is assumed to again have the characteristics of unpiled fuels. Decay rates are unchanged by piling, and the burned and unburned areas are not tracked separately in the remainder of the simulation.

All parameters defining the area of the stand, the amount of fuels that are treated, and the associated tree mortality can be changed using the **PILEBURN** keyword.

2.5.4 Fire Behavior

Overview: FFE computes two indicators of fire behavior: flame length and fire type: surface, passive crown fire, conditional crown fire, or active crown fire. In addition, two indices of crown fire hazard are reported: the torching and crowning index.

Fire behavior in FFE-FVS is computed using methods developed by Rothermel (1972), Albini (1976a), Scott (2001), and Scott and Reinhardt (2001). Stand conditions and surface fuels are assessed to determine which fire behavior fuel models best represent current conditions. The selected fuel models, along with slope, user-specified fuel moistures, temperature, and 20-foot wind speed, and canopy cover, are used to compute the intensity of a surface fire. This computed intensity and the canopy base height determine the occurrence of torching. Active crowning is modeled if: 1. conditions support torching, and 2. canopy bulk density is great enough to support active crowning at the specified wind speed and fuel moisture conditions. (Conditional crown fire is modeled if the conditions support active crowning but do not support torching.) If torching or crowning occur, intensity is recalculated to take into account the contribution of canopy fuels and accelerated fire behavior. Flame length is then computed from intensity.

Fire behavior is an important output of FFE. It also impacts subsequent model behavior by causing tree mortality and thus impacting future stand and fuel dynamics, and influencing fuel consumption, further impacting future fuel dynamics.

Surface Fire Behavior: Surface fire intensity is calculated using Rothermel's 1972 fire behavior prediction model, as implemented in FIREMOD (Albini 1976a). Fire intensity depends on static variables such as slope, variables that depend on stand conditions such as fuel quantities (represented by fire behavior fuel models) and mid-flame wind speed, and environmental variables specified by the user, such as fuel moisture levels. Surface fire intensity is used to calculate flame length and scorch height, which affect tree mortality and growth. It is also used to determine the amount of crowning in the stand.

Intensity of continuous fires is computed by FFE. If users wish to control predictions of fire intensity more closely, they can use the **FLAMEADJ** keyword to specify either the flame length or a flame scaling factor.

Crown Fire: Crown fires are typically faster moving than surface fires, more difficult to suppress, and result in more tree mortality and smoke production. FFE-FVS uses information about surface fuel and stand structure to predict whether a fire is likely to crown.

Two crown fire hazard indices are calculated in the model: torching index and crowning index. Torching index is the 20-foot wind speed (in miles per hour) at which a surface fire is expected to ignite the crown layer, while crowning index is the 20-foot wind speed (in miles per hour) needed to support an active or running crown fire. Torching index depends on surface fuels, surface fuel moisture, canopy base height, slope steepness and wind reduction by the canopy. As surface fire intensity increases (with increasing fuel loads, drier fuels, or steeper slopes), or canopy base height decreases, it takes less wind to cause a surface fire to become a crown fire. Crowning index depends on canopy bulk density, slope steepness, and surface fuel moisture content. As a stand becomes more dense, active crowning occurs at lower wind speeds, and the stand is more vulnerable to crown fire. For both indices, lower index numbers indicate that crown fire can be expected to occur at lower wind speeds, so crown fire hazard is greater at lower index values. The complete algorithms for determining torching and crowning index are described in Scott and Reinhardt (2001).

Both torching and crowning index depend in part on surface fuel moisture; therefore these conditions must be specified. Drier conditions produce lower indices, indicating a more severe risk of crown fire. Temperature and wind speed do not affect the indices.

Torching and crowning indices, together with the specified wind speed (set using keywords **SIMFIRE** or **POTFWIND**), determine the amount of crowning. Four outcomes are possible (Table 2.5.2):

1) Surface fires -- crowns do not burn (if the specified wind speed is less than the torching index and the crowning index);
2) Active crown fires -- the fire moves through the tree crowns, burning all crowns in the stand (thus killing all trees); (specified wind speed is greater than the torching and crowning index) and
3) Passive crown fires -- some crowns will burn as individual trees or groups of trees torch (specified wind speed is greater than the torching index but less than the crowning index).

4) Conditional crown fires -- if the fire begins as a surface fire then it is expected to remain so. If it begins as an active crown fire in an adjacent stands, then it may continue to spread as an active crown fire (specified wind speed is greater than the crowning index but less than the torching index). FFE models this fire type as an active crown fire, in terms of the flame lengths, mortality, and other fire effects.

Users can override this prediction by entering their own value for the percent of the canopy that experiences crowning in a particular fire (using the **FLAMEADJ** keyword).

If active, passive, or conditional crown fire is predicted, intensity and flame length are recalculated using methods in Scott and Reinhardt (2001) and Scott (2001). Specifically, the fire intensity is re-computed based on the percentage of crowning (crown fraction burned), available canopy fuel load, and final spread rate; flame length is re-computed from this new intensity estimate.

Table 2.5.2 - Rules for determining the occurrence of crowning. Wind speed is the 20-ft wind speed (in miles per hour) at the time of the fire.

	Torching Index < Wind Speed	**Torching Index > Wind Speed**
Crowning Index > Wind Speed	PASSIVE	SURFACE
Crowning Index < Wind Speed	ACTIVE	CONDITIONAL

2.5.5 Fire Effects

When a fire is simulated, FFE calculates several different effects from the fire: crown scorch, tree mortality, fuel consumption, mineral soil exposure, and smoke production.

Effects on Trees: Fires can kill trees and can have a short-term effect on tree growth for some of the surviving stems. Probability of tree mortality, P_{mort}, is calculated based on scorch height, crown length, diameter, and species (Ryan and Reinhardt 1988).The tree mortality equation presented below is for surface fires. When crown fires are simulated, additional mortality is predicted based on the percent crowning predicted.

$$P_{mort} = \frac{1}{1 + e^{\left(-1.941 + 6.316\left(1 - e^{-b}\right) - 0.000535c^2\right)}}$$

$$b = v_{sp}\, d$$

$$c = 100s\left(\frac{2l - s}{l^2}\right)$$

where:

b = bark thickness (inches); not necessarily the same bark thickness equation as the one used by the base FVS model
v_{sp} = species bark thickness parameters (Table 2.5.3)
d = diameter (in inches) of the tree
c = percent of the crown volume that is scorched
s = length of the crown (feet) that is scorched
l = total length of the crown (feet)

When users set the percentage of the stand area to be burned to less than 100% (see the **SimFire** and **PotFPAB** keywords), a random number is used to determine whether a tree record is in the burned or unburned portion of the stand. Mortality and fire effects on tree crowns are then applied only to the tree records in the burned portion of the stand.

The resulting mortality is shown in Figure 2.5.5. This equation predicts some mortality of thin-barked trees even if none of the crown is scorched (c=0). The amount of mortality in this case is dependent just on species and diameter. In some variants (NI, IE, EM, KT), in all fires, at least 80% of the spruce of any size is killed.

When the scorch height is greater than the base of a tree's crown, but the tree is not killed, the crown is assumed partially killed. In these cases, the crown ratio of the tree is reduced and the growth of that tree may be slowed for the subsequent cycle. In the following cycle, FVS will recalculate the crown ratio assuming the tree is healthy but taking into account that the fire reduced the crown length. In some cases, this may result in the bottom of the crown being lower than it was after the fire.

Table 2.5.3 - Parameter values v_{sp}, used in the calculation of bark thickness.

	WP	WL	DF	GF	WH	RC	LP	ES	AF	PP	Oth
v	0.026	0.0745	0.0665	0.035	0.022	0.025	0.025	0.020	0.015	0.0710	0.0330

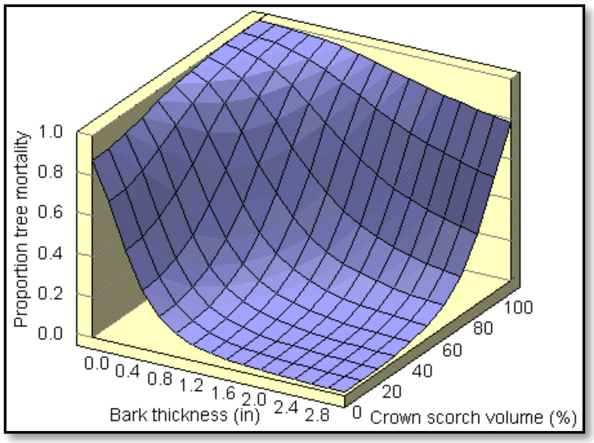


Figure 2.5.5 - Predicted tree mortality is based on bark thickness and the percent of the volume of the crown scorched.

Scorched foliage and branches are assumed to be killed and will fall to the ground at the rates specified for the crowns of snags (section 2.4.4).

The portion of a crown that is within the flames of either a surface or crown fire is killed. FFE assumes that 100% of the foliage and 50% of the small branch wood (<0.25 inches) in the flames are consumed. The remainder of the burned portion of a crown is assumed to be dead and falls at the same rate as scorched canopy material.

More complicated effects of fire on trees may include increased susceptibility to insects and disease, decreased growth due to fine root mortality, or increased growth due to enhanced nutrient availability. These effects are not represented by FFE-FVS. Fire may also indirectly result in increased tree growth of residual trees due to decreased stand density, and this effect is simulated by FVS.

Fuel Consumption: Fuel consumption algorithms in FFE are simplified from those in FOFEM (Reinhardt and others 1997). The three main factors affecting fuel consumption are: size, moisture content, and type (natural, activity, or piled) (Brown and others 1985; Ottmar and others 1993). The intensity of the fire does not directly affect surface fuel consumption in FFE.

The consumption of both activity and natural fuels greater than 3" depends on moisture and the size class of the fuels. Dry large woody fuel is more fully consumed than wet (Figure 2.5.6). The model assumes that at high moistures, natural fuel is more fully consumed than activity fuel because, in general, it is on the ground and partially rotted, while the activity fuel tends to be sound, green, and not as close to the ground.

The consumption of small fuel <1" diameter is dependent on the consumption of fuel that is 1-3". The rationale is that if over 90% of the larger fuel is consumed, conditions must be right to burn all of the smaller fuel. Otherwise only 90% of the smaller fuel is burned. The consumption of 1-3" fuel depends on the moisture content of the smaller fuel rather than its own moisture content (Figure 2.5.7). Naturally occurring fuel in these size classes is consumed independently of moisture levels (65% for the 1-3" fuel and 90% for fuel <1").

Litter and live fuel consumption in FFE is independent of their moisture content. The model assumes that 100% of litter and herbs and 60% of shrubs are consumed.

Mineral soil exposure is calculated by the model as a function of the burning of the duff layers (Figure 2.5.8; Brown and others 1985), which in turn is a function of the duff moisture content. If less than 10% of the duff layer is burned, then there will be no mineral soil exposure. Mineral soil exposure can have an impact on any automatic regeneration that is triggered in the following FVS cycle (in variants with the full establishment model only).

Fuel that has been piled burns differently (in general more completely) than unpiled fuel (section 2.5.3).

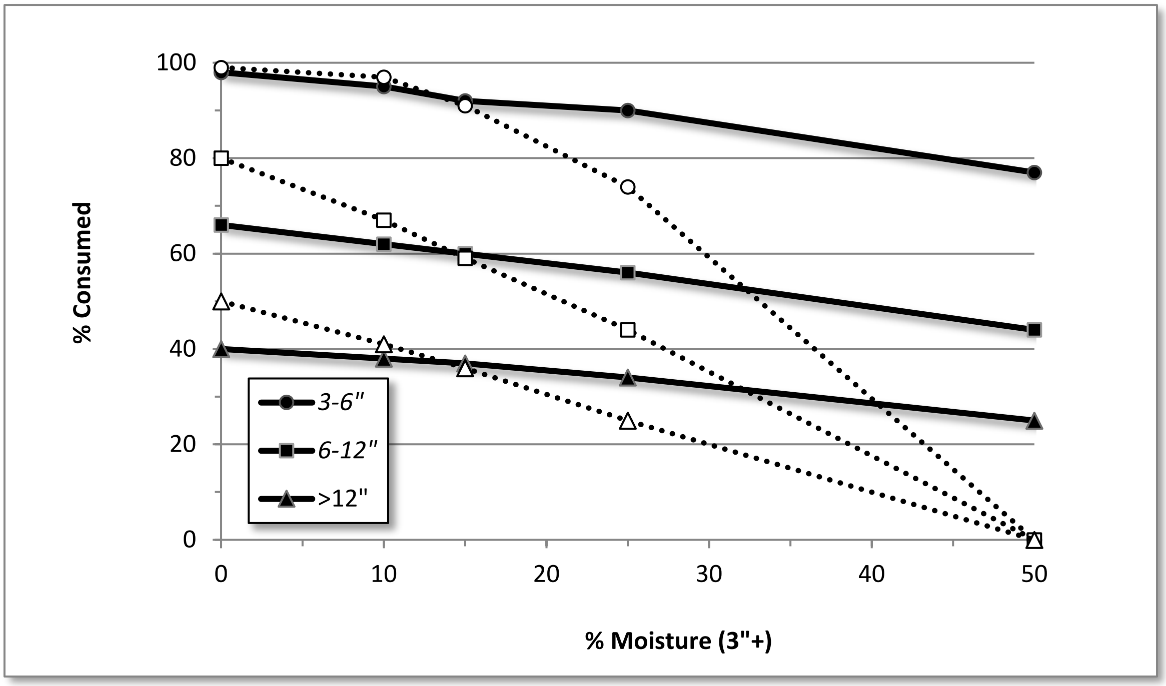


Figure 2.5.6 - Predicted fuel consumption for large woody fuel (>3") for different size classes and moisture contents. The points on the graph indicate the four default fuel moisture conditions. The solid lines and symbols are for the naturally occurring fuel, while the dotted lines and open symbols are for fuel resulting from management activities.

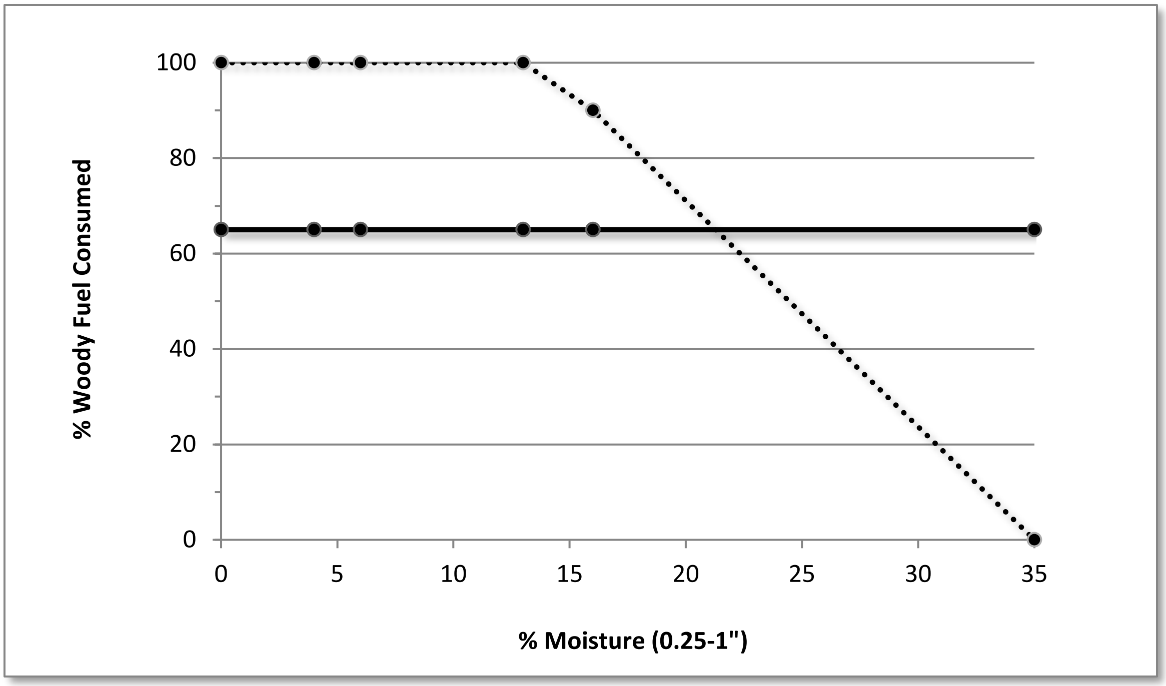


Figure 2.5.7 - Predicted fuel consumption for 1 to 3 inches woody fuel for different moisture levels. The points on the graph indicate the values at the four default fuel moisture conditions. The solid line is for the naturally occurring fuel, while the dotted line is for fuel resulting from management activities. Notice that the consumption of larger fuel depends on the moisture values of the smaller fuel.

Smoke Production: Two categories of particulate matter emissions are calculated: less than 2.5 microns in diameter and less than 10 microns in diameter. (The first category is a subset of the second.) Smoke production is calculated using a series of multipliers (emission factors) applied to the amount of fuel consumed in each size class (Table 2.17; Reinhardt and others 1997). For duff and large woody fuel, these multipliers vary with moisture content.

2.5.6 Potential Fires

In addition to simulating a fire and its effects at a specified point in time, FFE can also compute indicators of potential fire behavior and effects as they change over the simulation period. These provide an important method for assessing fuel and the associated fire hazard, as fuel and stand conditions change over time and with management actions.

For given wind and moisture conditions, fire intensity changes with the amount of fuel in the stand and with the likelihood of a full or partial crown fire. FFE calculates the potential surface fire flame length, degree of crown fire activity (surface, passive crown fire, conditional crown fire, or active crown fire), tree mortality (percent stand basal area, and percent volume), and smoke production. Each of these is calculated for two sets of conditions. By default, the first set represents severe conditions that might represent wildfires (dry, windy) and the second represents moderate conditions that are more typical of prescribed fires. Conditions can be modified by the user.

Crown fires play an important role in the spread and impact of fires. Information about canopy fuel and the wind speed necessary to induce crowning under various scenarios is useful to fire and fuel managers. The model therefore reports the canopy base height, the canopy bulk density, the torching index, and the crowning index. The predicted values change over time and can be affected by management activities (Figure 2.5.9).

All information about potential fires is calculated using the same methods that are used for calculating the simulated fires. Thus, if a fire with the same wind, temperature, and moisture conditions is scheduled in the same year that the potential fire information was calculated (in a separate, no-fire simulation), the simulated flame length and basal area mortality would be the same.

Users can control the frequency with which this information is calculated (**POTFIRE** keyword) and the wind, temperature, and moisture conditions that are used for the potential severe and moderate calculations (**POTFWIND**, **POTFTEMP** and **POTFMOIS** keywords). The percentage of the stand area burned can also be controlled (**POTFPAB** keyword.)

Table 2.5.4 - Emissions factors (lb emission per ton of fuel consumed) used to calculate smoke emissions. Emission factors for some fuels may vary with moisture content, others are constant.

		Particulate Matter < 2.5 microns			**Particulate Matter < 10 microns**		
		wet	**moist**	**dry**	**wet**	**Moist**	**Dry**
Surface woody fuels	Litter	7.9			9.3		
	0-0.25"	7.9			9.3		
	0.25-1"	7.9			9.3		
	1-3"	11.9			14.0		
	3+"	22.5	18.3	16.2	26.6	21.6	19.1
	Duff	23.9	25.8	25.8	28.2	30.4	30.4
Live	Herbs & shrubs	21.3			25.1		
	Canopy fuels	21.3			25.1		
	Piled fuels	17.0			20.0		

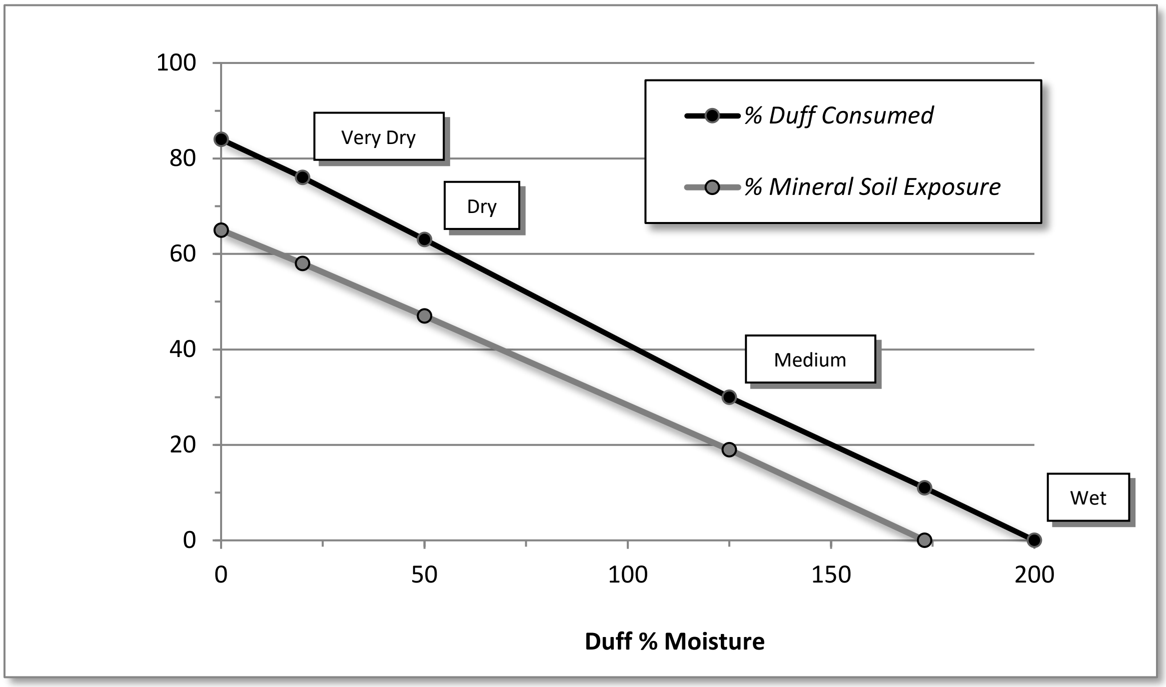
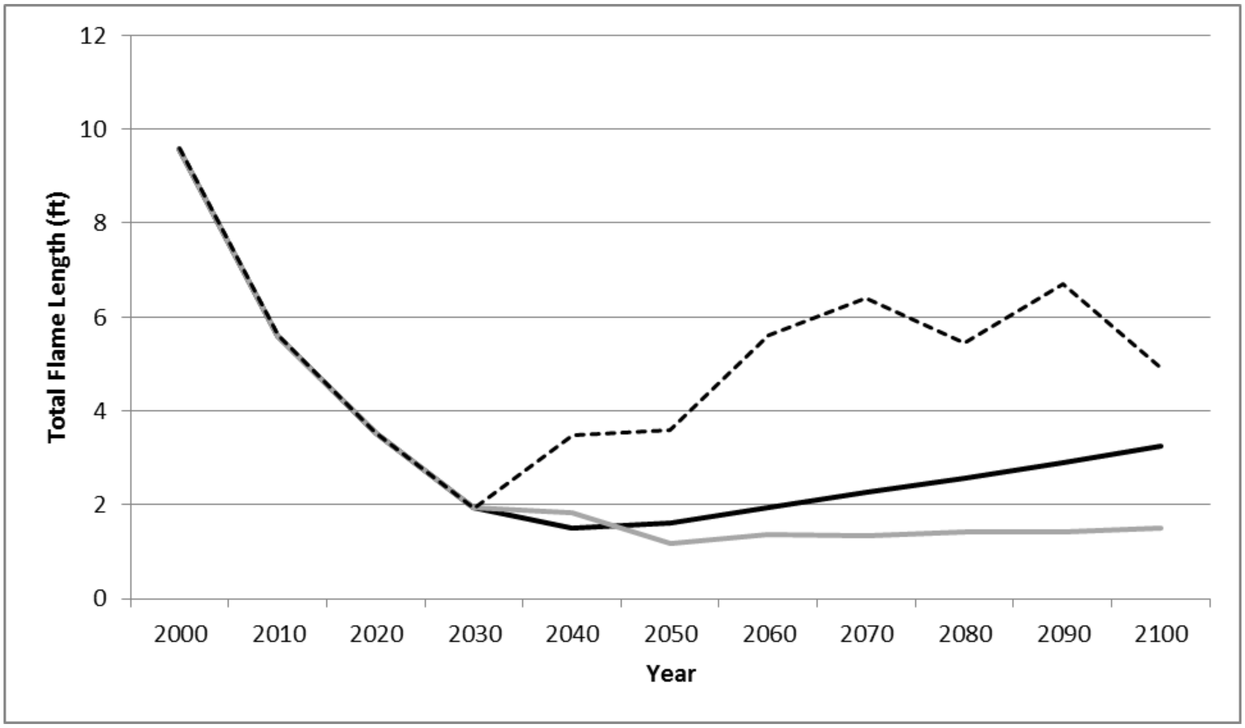


Figure 2.5.8 - Relationship between duff consumption, mineral soil exposure, and duff moisture levels. The points on the graph indicate the four default fuel moisture conditions. Duff consumption depends on duff moisture and mineral soil exposure is a function of duff consumption.



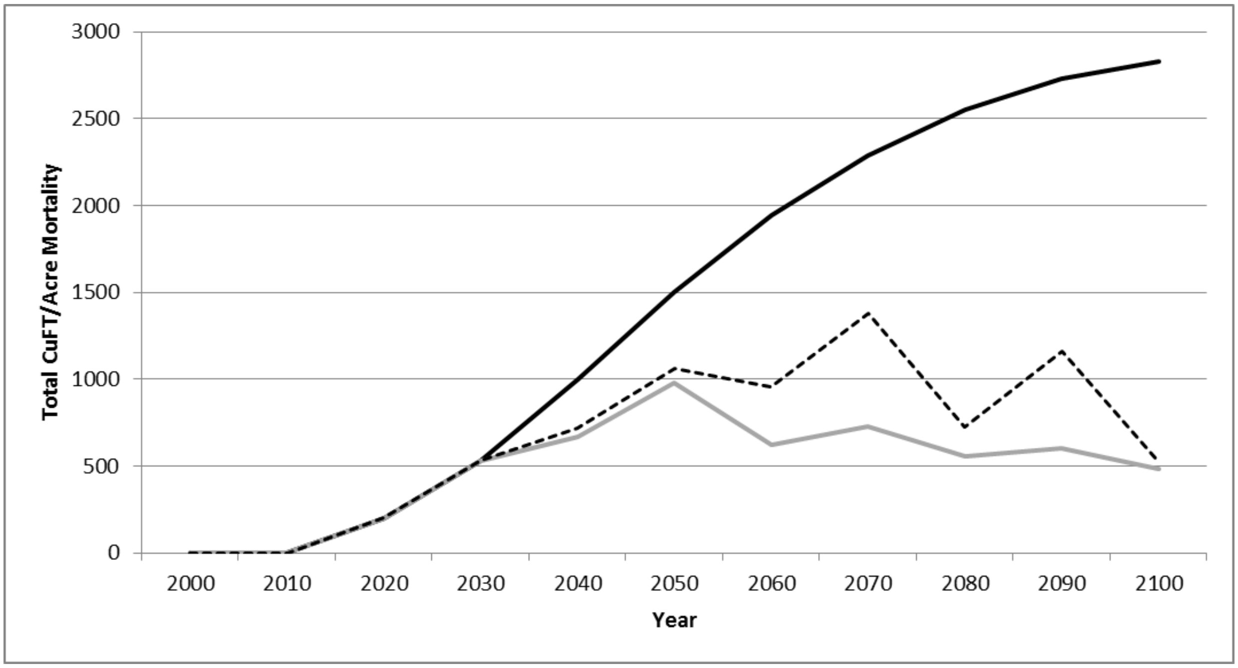


Figure 2.5.9 - Potential total flame length and cuft/acre mortality in a stand under three management scenarios. The stand is established at the beginning of the run. In one scenario no treatment was applied (dark line). In two scenarios the stand was thinned from below (in 2040, 2060, 2080, and 2100). In one scenario, the harvested material was left on the ground (dashed line) and in the other scenario it was all removed (light line). Leaving the harvested material as slash causes an increase in potential flame length and mortality compared to when no slash is left. Even when activity fuels are removed, flame length may increase after thinning because reductions in canopy cover cause an increase in mid-flame wind speed.

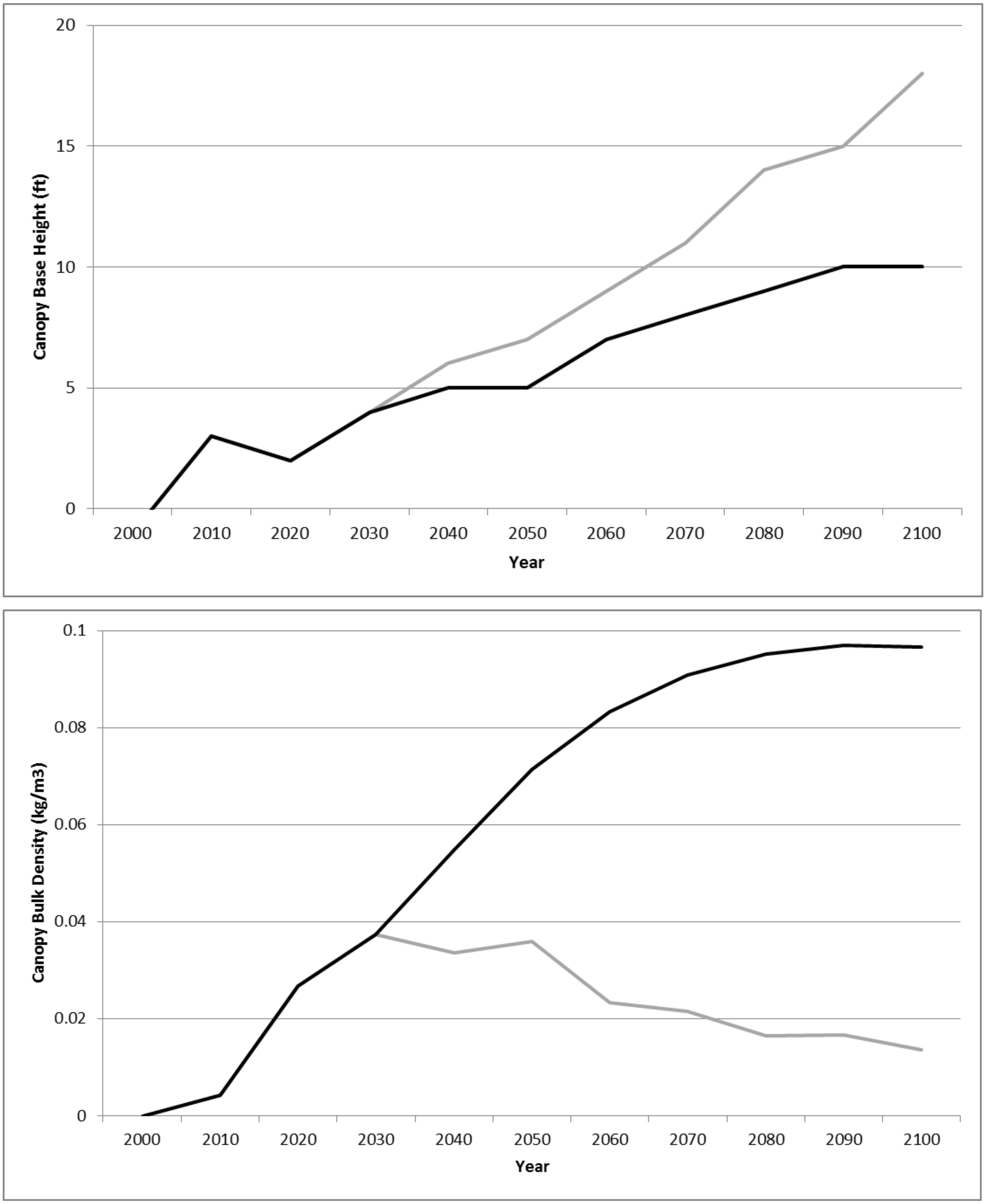


Figure 2.5.10 - Canopy base height and bulk density under different management scenarios. A mixed-conifer stand is established at the beginning of the simulation (dark line). In one scenario this stand is repeatedly thinned from below (light line). The canopy fuel is independent of whether the harvested material is removed or left in the stand.

2.5.7 Output

At the time of a fire, several output tables can be printed that give more information about the parameters that were set for the fire, predicted fire behavior, and the effect of the fire on trees, fuel, and soil. Each of these tables is optional and must be requested using a keyword. An additional output file that reports the potential intensity and effect of fires under two sets of conditions can also be produced.

Burn Conditions Report: At the time of a fire, the moisture conditions and wind speed play a role in the intensity and effects of the fire. The burn conditions report allows users to check the moisture conditions and slope (both originally set by the user) and to see the mid-flame wind speed, flame length and scorch heights that were calculated by the model (Table 2.5.5). The columns of the report are:

Year	The year of the burn.
% Moisture	The percent fuel moisture separated into the categories below. 1 hr – 0 to 0.25 inch fuel 10 hr – 0.25 to 1 inch fuel 100 hr – 1 to 3 inches fuel 3+ – fuel greater than 3 inches Duff – duff Live – live fuel
Mid-Flame Wind	The mid-flame wind speed (mph) calculated based on the user-defined 20-foot wind speed and the canopy cover of the stand.
Slope	The percent slope of the stand. This is part of the basic stand information. It is included in this report because it is one of the factors that determines flame length.
Flame Length	The flame length (ft) that will be used for calculating tree mortality.
Scorch Height	The scorch height (ft), based on the flame length.
Fire Type	Surface, passive, or active crown fire.
Fuel Model	Fire behavior fuel models and their weights.

This output file can be requested using the keyword **BURNREPT**. Use this output to make sure you are simulating the fire as you intended, and to document simulated fire treatments.

Table 2.5.5 - Example burn conditions report. This report shows that in the year 2065 the fuels were most like a fuel model 10, with some characteristics of a fuel model 12. The simulated fire was an active crown fire.

```
------------------------------------------------------------------------------------------------------------------
                                    ******  FIRE MODEL VERSION 1.0 ******
                         BURN CONDITIONS REPORT -- CONDITIONS AT THE TIME OF THE FIRE
------------------------------------------------------------------------------------------------------------------
                                          MIDFLAME       FLAME  SCORCH                     FUEL MODELS
      ------------ % MOISTURE ------------- WIND  SLOPE  LENGTH HEIGHT            --------------------------------
YEAR  1HR 10HR 100HR  3+ DUFF LIVE W LIVE H (MPH)  (%)    (FT)  (FT)  FIRE TYPE   MOD %WT MOD %WT MOD %WT MOD %WT
------------------------------------------------------------------------------------------------------------------
2065   4.   4.   5.  10.  15.   70.    70.   3.3    20   70.6  315.8  ACTIVE       10  88  12  12
```

Fuel Consumption Report: When fires occur, this report includes the amount of fuel consumed in each size class, the mineral soil exposure, and the amount of smoke produced (Table 2.5.6). The columns of the report are:

Year	The year of the fire.
Percent Mineral Soil Exposure	Percent of mineral soil exposure.
Fuel Consumed	In tons per acre, separated into the categories below. Litr – Litter Duff – Duff 0 to 3 inches – small woody fuel less than 3 inches diameter 3 inches+ – large fuel; the sum of the following three columns 3 to 6 inches – large fuel between 3 and 6 inches

	6 to 12 inches – large fuel between 6 and 12 inches 12 inches+ – large fuel greater than 12 inches diameter Herbs and Shrubs – Herbs and shrubs Crown – The amount of crowns consumed through crown scorching or crown fires. Total – The total amount of fuel consumed. The column is the sum of the litter, duff, small, and large fuel as well as the herbs, shrubs, and crowns. It corresponds to the column labeled “TOTAL CONS” in the all fuels report.
Percent Consume	Percent of available fuel that was consumed. Divided into duff and fuels greater than 3 inches.
Percent Trees with Crowning	The same as crown fraction burned except expressed as a percentage. A measure of the amount of crown fire activity. Surface fires have 0% crowning and active crown fires have 100%. Passive crown fires have values between 0 and 100.
Smoke Production	The amount (tons/acre) of smoke produced divided into two categories: smoke particles less than 2.5 microns, and smoke particles less than 10 microns (this value includes smoke less than 2.5 microns). Tiny particles (less than 2.5 microns) are considered respirable, and thus have implications to human health.

This report can be requested using the **FUELREPT** keyword.

Fuel consumption is an important indicator of fire severity. This report can be used to document simulated fire effects.

Table 2.5.6 - Example fuel consumption report. The total consumption reported here is the same as on the detailed fuel report.

```
--------------------------------------------------------------------------------------------------------
                             ******  FIRE MODEL VERSION 1.0 ******
                           FUEL CONSUMPTION & PHYSICAL EFFECTS REPORT
--------------------------------------------------------------------------------------------------------
     PERCENT           FUEL CONSUMED (TONS/ACRE)                                       %       SMOKE
     MINERAL-------------------------------------------------------------            TREES   PRODUCTION
      SOIL                                              HERB&       TOTAL  %CONSUME  WITH    (TONS/ACRE)
YEAR EXPOSR  LITR  DUFF   0-3"    3"+  3-6" 6-12"  12"+ SHRUB CRWNS CONS.  DUFF 3"+  CRWNG   <2.5   < 10
--------------------------------------------------------------------------------------------------------
2065   60     1.3   8.3    4.4   15.5    9.5   5.6   0.5   0.5   9.6   39.6    77  77   100    0.41   0.48
```

Mortality Report: A complete report on the percent of trees by species and size class that were killed by fires in a given year can be produced using the **MORTREPT** keyword (Table 2.5.7). This report is created only in years a fire occurs. The report contains the following fields.

Year	The year of the fire.
SP	The two-letter species code. Only species in the current stand are listed.
Number Killed / Number Before	In each column, the value to the left of the “/” are the number of trees that were killed (trees per acre) and the value to the right of the “/” are the number of trees in that size class and species that were present before the fire. This information can be used to easily tell what sizes and species of trees were killed as well as the relative susceptibility of different categories.
Basal Area	Total basal area killed (feet squared per acre).
Total Cu Ft	Total volume killed (feet cubed per acre).

This report allows users to examine in detail the impact of a simulated fire on a stand. It can be used to iteratively develop a burn prescription that achieves desired levels of tree mortality. It can also be used to gain insight into the expected effects of fire on a particular stand.

Table 2.5.7 - Example repot for fire-based mortality. In this simulation all trees were killed.

```
---------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------------
                                ******  FIRE MODEL VERSION 1.0 ******
                                          MORTALITY REPORT
---------------------------------------------------------------------------------------------------------------------
                    NUMBER KILLED / NUMBER BEFORE (BY DIAMETER CLASS IN INCHES)                        BASAL    TOTAL
YEAR  SP     0.0- 5.0     5.0-10.0    10.0-20.0    20.0-30.0    30.0-40.0    40.0-50.0      >=50.0      AREA    CU FT
---------------------------------------------------------------------------------------------------------------------
2065  WP       0/    0                                                                                  0.00        0
      WL       4/    4                                                                                  0.14        2
      DF     138/  138     72/   72     131/  131      6/    6      0/    0      0/    0               177.26     5714
      GF      29/   29                                                                                  0.02        0
      LP      12/   12     14/   14       1/    1                                                       7.25      323
      ES      21/   21                                                                                  0.03        0
      AF     121/  121                                                                                  0.10        0
      ALL    327/  327     87/   87     133/  133      6/    6      0/    0      0/    0               184.81     6041
```

Soil Heating Report: A complete soil heating report for fires in a given year can be produced using the **SOILHEAT** keyword (Table 2.5.8). This report is created only in years a fire occurs. The report contains the following fields.

Year	The year of the fire.
Temperature Below the Surface	The temperature in degrees celcius at various depths (in cm) below the surface
Depth where temperature exceeds 60˚	Depth (in cm) where temperature exceeds 60˚ (often considered the lethal temperature for living organisms)
Depth where temperature exceeds 275 ˚	Depth (in cm) where temperature exceeds 275˚

This report allows users to examine in detail the impact of a simulated fire on soil heating a stand. It can be used to develop a burn prescription that avoids undesirable levels of soil heating.

Table 2.5.8 - Example report for soil heating.

```
---------------------------------------------------------------------------
             FOFEM SOIL HEATING ESTIMATES FOR SIMULATED FIRES
                                                               DEPTH WHERE
      --TEMP IN CELCIUS AT THESE DEPTHS BELOW SURFACE (CM)---  TEMP EXCEEDS
YEAR    0   1   2   3   4   5   6   7   8   9  10  11  12  13    60  275 C
---------------------------------------------------------------------------
2065  328 274 227 188 154 127 104  86  71  64  56  46  34  21     9    0
```

Potential Fire Report: The potential fire report gives information about the potential impact of fires under two sets of conditions. By default, these conditions represent extreme and moderate fire conditions, but users can select any sets of conditions they choose (section 2.5.6). The report is produced by using the POTFIRE keyword (Table 2.5.9). The columns of the report are:

Year	The year of the fire.
Surface Flame Length	The potential surface fire flame length (ft) under both severe and moderate conditions. This flame length does not take any crown fire activity into account.
Total Flame Length	The potential total flame length (ft) under both severe and moderate conditions. This flame length takes any crown fire activity into account.
Type of Fire	Surface (S), passive (P), active crown (A), or conditional (C) crown fire under both severe and moderate conditions.
Probability of Torching	The potential probability of torching under both severe and moderate conditions. See Appendix A for more details.
Torching Index	The 20-ft wind speed (miles/hour) required to cause torching of some trees under severe conditions.
Crown Index	The 20-ft wind speed (miles/hour) required to cause an active crown fire under severe conditions.
Canopy Base Height	The height (ft) of the base of the canopy.

Canopy Bulk Density	The bulk density of the canopy (kg/m^3)
Potential Mortality	The potential tree mortality as measured by two different indicators for both fire conditions. The first indicator is the percent of basal area killed under either fire condition, and the second is the total volume (cubic feet) killed under either fire condition.
Potent Smoke	The potential amount of smoke emissions (tons per acre) less than 2.5 microns under either fire condition.
Fuel Models	The fire behavior fuel models that are used in the weighting scheme. Up to four such fuel models may be shown, but normally only one or two are present. If the static option is in effect, only one fuel model will be shown.
Mod	A fuel model
Percent Wt	The percent weighting for that model. These should sum up to 100, but may not due to rounding.

Values of –1 are printed for canopy base height, torching index and crowning index if canopy fuels are so sparse that the canopy base height is undefined (section 2.4.7).

This report provides a way to assess stand and fuel conditions, as well as proposed management, in terms of expected fire behavior and effects. Examining the potential mortality columns, for example, gives insight into the changing vulnerability of a stand to stand-replacement fire over time. Comparing this report from a no-management simulation and simulations with a variety of treatment alternatives provides a way of assessing treatments in terms of their impact on fire hazard. For example, a goal of management might be to reduce the likelihood of crown fire. Crown fire potential depends on both surface and canopy fuels. A number of treatments might be simulated to compare the effectiveness of prescribed fire, surface fuel management, and thinning in reducing the likelihood of crowning.

The potential fire report is produced after all management is simulated, but before any of the other processes such as snag fall and decay are simulated.

Table 2.5.9 - Example potential fire report. Changes in fuels are reflected in the flame length (which also affects mortality) and type of fire. Changes in stand structure are reflected in the canopy base height and canopy bulk density.

```
------------------------------------------------------------------------------------------------------------------------------------
                                ******  FIRE MODEL VERSION 1.0 ******
                                        POTENTIAL FIRE REPORT
------------------------------------------------------------------------------------------------------------------------------------
FIRE        WIND   TEMP ------------- FUEL MOISTURE CONDITIONS (PERCENT) ---------------
CONDITION   (MPH)   (F) 0-0.25"  0.25-1"   1-3"     3"+   DUFF    LIVE WOODY   LIVE HERB
SEVERE      20.0    70     4.        4.      5.     10.     15.         70.         70.
MODERATE     6.0    70    12.       12.     14.     25.    125.        150.        150.
------------------------------------------------------------------------------------------------------------------------------------
      FLAME LENGTH (FT)  FIRE PROB OF   TORCH  CROWN CNPY CANPY    POTENTIAL MORTALITY  POTEN. SMOKE
       SURFACE    TOTAL  TYPE TORCHING  INDEX  INDEX BASE BULK   ---------------------- ------------           FUEL MODELS
      ---------- ------- ---- --------- SEVERE SEVERE HT  DENSTY SEV. MOD. SEV.  MOD.   SEV.  MOD.   -------------------------------
YEAR  SEV   MOD  SEV MOD S  M SEV   MOD MI/HR  MI/HR  FT  KG/M3   %BA  %BA (TOT CU VOL)  (T/A <2.5)  MOD %WT MOD %WT MOD %WT MOD %WT
------------------------------------------------------------------------------------------------------------------------------------
1993   1.9   0.8  53   1 C  S 0.00 0.00  364.8   15.2  18  0.168  100   35  2929    990 0.23  0.10     8  92  10   8
1995   2.8   1.1  55   1 C  S 0.00 0.00  209.2   15.2  18  0.168  100   35  2929    990 0.25  0.12     8  77  10  23
2000   3.9   1.6  57   2 C  S 0.00 0.00  110.7   15.5  19  0.164  100   33  3218   1026 0.32  0.16    10  52   8  48
2005   5.7   2.4  65   2 C  S 0.19 0.00   55.2   14.7  21  0.175  100   32  3445   1059 0.38  0.20    10  86  12  14
2010   6.2   2.8  67   3 C  S 0.20 0.00   54.2   14.7  22  0.176  100   31  3671   1085 0.42  0.23    10  72  12  28
2015   6.1   2.7  70   3 C  S 0.13 0.00   58.7   13.8  23  0.190  100   29  3893   1107 0.42  0.23    10  76  12  24
2020   6.0   2.6  71   3 C  S 0.07 0.00   65.4   13.2  25  0.201  100   28  4135   1133 0.42  0.22    10  77  12  23
2025   5.9   2.6  70   3 C  S 0.04 0.00   69.4   13.1  26  0.202  100   27  4374   1150 0.41  0.22    10  80  12  20
2030   5.9   2.5  70   3 C  S 0.02 0.00   76.1   12.9  28  0.207  100   26  4594   1161 0.41  0.22    10  82  12  18
2035   5.8   2.5  70   2 C  S 0.01 0.00   86.1   12.7  31  0.211  100   24  4814   1165 0.41  0.21    10  84  12  16
2040   5.8   2.4  70   2 C  S 0.00 0.00   89.9   12.7  32  0.211  100   23  5044   1171 0.41  0.21    10  85  12  15
2045   5.7   2.4  69   2 C  S 0.00 0.00   96.7   12.4  34  0.217  100   22  5251   1171 0.40  0.21    10  86  12  14
2050   5.7   2.4  69   2 C  S 0.00 0.00  103.5   12.2  36  0.221  100   21  5440   1165 0.40  0.21    10  88  12  12
2055   5.6   2.4  71   2 C  S 0.00 0.00  107.3   12.2  37  0.222  100   20  5634   1155 0.41  0.21    10  88  12  12
2060   5.6   2.4  71   2 A  S 0.00 0.00    0.0   12.2   3  0.220  100   20  5835   1152 0.41  0.21    10  88  12  12
2065   5.6   2.4  71   2 A  S 0.00 0.00    0.0   12.2   3  0.222  100   19  6041   1145 0.41  0.21    10  88  12  12
2070  12.4   5.1  12   5 S  S 0.00 0.00   -1.0   -1.0  -1  0.000  100  100     0      0 0.32  0.24    12  71  10  29
2075  13.4   5.7  13   6 S  S 0.43 0.43   -1.0   -1.0  -1  0.000  100  100     0      0 0.40  0.30    12  98  13   2
2080  13.7   5.8  19   6 P  P 1.00 1.00    0.0   85.9   1  0.016   99   99     0      0 0.43  0.32    12  93  13   7
2085  12.3   5.3  23   6 P  P 1.00 1.00    0.0   49.7   1  0.034   99   99    14     14 0.45  0.33    12  90  13  10
2090  10.5   4.8  26   5 P  P 1.00 1.00    0.0   41.6   1  0.044   99   99    77     77 0.47  0.35    12  86  13  14
2095   9.4   4.4  28   5 P  P 1.00 1.00    0.0   37.0   1  0.052   99   99   214    214 0.47  0.34    12  89  13  11
```

2.6 Carbon Submodel

2.6.1 Overview

Natural resource managers may be interested in the amount of carbon being sequestered by their forest. In addition, they may want to know how various management activities affect the amount of carbon sequestered. The accounting and detailed fuel modeling approach used by FFE lends itself naturally to an accounting of stand carbon stocks and carbon in harvested products. With the exception of the litter and duff pools, carbon found in the living and dead biomass is converted to units of carbon by multiplying by 0.5 (Penman and others, 2003); litter and duff biomass are converted using a multiplier of 0.37 (Smith and Heath, 2002). By default, the reports use the default units of FVS and FFE: tons C per acre, where a ton is a short ton (2000 lbs). Users may optionally request output using metric or combined units: metric tons C per hectare or metric tons C per acre. The requested units are used in the main output and in any optional output that may be written to an external database.

Stand C stocks are calculated and reported for the following categories:

- Total aboveground live: live trees, including stems, branches, and foliage, but not including roots.
- Merchantable aboveground live: only the merchantable portion of live trees
- Belowground live: the roots of live trees
- Belowground dead: the roots of dead and cut trees
- Standing dead: dead trees, including stems and any branches and foliage still present, but not including roots
- Forest down dead wood: all woody surface fuel, regardless of size
- Forest floor: litter and duff
- Herbs and shrubs
- Total stand carbon: the sum of the above categories
- Total removed carbon: carbon removed thru the cutting of live trees, dead trees, and the hauling away of woody debris.
- Carbon released from fire: carbon in fuel consumed by simulated wildfires, prescribed burns, and pile-burns

Aboveground dead biomass is always computed using the existing FFE algorithms; however, aboveground live tree components can be calculated either with the existing FFE biomass algorithms, or alternatively with a set of allometric equations described by Jenkins and others (2003). The Jenkins equations, based on 10 species groups (see Appendix A of Jenkins and others (2003)), are also used to estimate belowground components. Belowground dead biomass is formed when trees die or are cut; the root decay rate is 0.0425 by default (Kim Ludovici (personal communication) and Ludovici and others 2002) and can be adjusted by the model user with the **CARBCALC** keyword.

As Table 2.6.1 shows, the assumptions and internal pool sources used by the two reporting methods are similar, but differ in the estimation of live tree biomass. FFE live tree merchantable biomass estimates are based on FVS volume equations which vary by geographic variant, and do not include C from bark biomass. Calculation of FFE live tree total biomass includes the merchantable biomass, as well as crown biomass and biomass from any unmerchantable portion of the tree. The Jenkins biomass estimates are based on allometric relationships for aboveground and merchantable biomass, including C from bark, but are not fitted for trees less than 1 inch (2.5 cm) DBH. In this implementation, trees smaller than 1 inch DBH are assigned aboveground and belowground biomass based on a linear interpolation of their diameter relative to the 1 inch minimum. For example, a tree of 0.5 inches DBH will have one half the aboveground biomass of a tree of 1 inch DBH.

Biomass included in the input inventory data (live trees, dead trees, and surface fuel) are included in the stand C pools. Stand and fuel management activities simulated through existing FVS base model keywords and through the **SIMFIRE**, **PILEBURN**, **SALVAGE** and **FUELMOVE** FFE keywords are all accounted for in the stand C pools. When thinning or harvesting, users can optionally control what is removed and what is left in the stand as slash through the **YARDLOSS** keyword, and these choices are also mirrored in the stand C pools. Lastly, when fires are simulated with the **SIMFIRE** or **PILEBURN** keywords, the carbon released from fire is reported based upon the predicted amount of fuel consumed during that fire.

Table 2.6.1 - Stand carbon accounting is based on a combination of FFE and Jenkins methods. Users can request FFE-based C estimates, in which case FFE volume and crown biomass estimates are used for total and merchantable live tree biomass. Merchantablitiy limits may vary depending on variant and settings chosen by the user. Alternatively, Jenkins estimates can be requested, in which case Jenkins equations are used for aboveground total biomass and aboveground merchantable biomass. Regardless of the requested reporting method, FFE-biomass is the basis for herb, shrub, standing dead, litter, duff and woody debris pools, while Jenkins-biomass is the basis for live and dead root biomass. The calculation method column shows corresponding categories from the FFE All Fuels report.

Stand Carbon Report Label [1]	**Requested Reporting Method [2]**		**Calculation Method**	
	FFE	**Jenkins**	**FFE All Fuels Report [3]**	**Jenkins**
Aboveground Live, Total	✓	✓	Live, Fol Live, 0-3in [4] Live >3”	f(sp,dbh)
Aboveground Live, Merchantable	✓	✓	Portions of Live >3”	f(sp,dbh)
Stand Dead	✓	FFE method always used	Standing Dead, 0-3in Standing Dead, >3”	
Forest, Shb/Hrb	✓		Herb Shrub	
Forest, Floor	✓		Litter Duff	
Forest, DDW	✓		Dead Surface Fuel 0-3in Dead Surface Fuel >3in	
Belowground, Live	Jenkins method always used	✓		f(sp,dbh)
Belowground, Dead		✓		f(sp,dbh)
Notes:				

[1] – Column headings from FFE Stand Carbon Report
[2] – Report method requested through field 1 of CARBCALC keyword
[3] – Column headings from the FFE All Fuels Report
[4] –This depends on the merchantability limits being used.

Stand entries that remove live trees or snags from the stand can be reported in a harvested products report, which reports the fate of C in merchantable biomass as it decays over time. Depending on the user selection, live merchantable biomass can use either FFE or Jenkins estimates; dead merchantable biomass from snags always uses FFE estimates. Stems smaller than a threshold diameter (by default, 9 inches DBH for softwood; 11 inches for hardwood) are assumed to be harvested for pulpwood; those greater than or equal to the threshold diameter are assumed to be harvested for timber (sawlog) use. The fate of C in each of these 4 categories (hardwood/softwood and pulpwood/sawlog) is recorded as being either in use, in a landfill, emitted with energy capture, or emitted without energy capture. These categories are further described in Table 2.6.2. Transfer of C among these end-use categories is based on regional estimates from Smith and others (2006) (see Figure 1 of Smith and others (2006)), and differs among the FVS-FFE geographic variants. The year of removal and the subsequent ageing of harvested products is assumed to take place in the first year of an FVS cycle.

Table 2.6.2 – Categories for disposition of carbon in harvest wood (Smith and others 2006)

Category	Label in Harvested Products Report	Description
Products in use	Products	End-use products that have not been discarded or otherwise destroyed, examples include residential and non-residential construction, wooden containers, and paper products.
Landfills	Lndfill	Discarded wood and paper placed in landfills where most carbon is stored long-term and only a small portion of the material is assumed to degrade, at a slow rate.
Emitted with energy capture	Energy	Combustion of wood products with concomitant energy capture as carbon is emitted to the atmosphere.
Emitted without energy capture	Emissions	Carbon in harvested wood emitted to the atmosphere through combustion or decay without concomitant energy recapture.

2.6.2 Output

Information about the carbon content of the stand components can be useful for quantifying sources and sinks as stands are managed for timber or other ecosystem values. Two reports – one for stand carbon and one for carbon in harvested products – can be produced by the model.

Stand Carbon Report: Using the **CARBREPT** keyword, carbon content in a variety of live and dead pools can be summarized to the main output. The content of the Stand Carbon Report is described in section 2.6.1 of this document. The content of this report mirrors the content of the All Fuels Report (see section 2.4.10 and Table 2.4.11) and in some configurations will give identical results, after allowing for unit conversions.

By default, FFE biomass estimates are used to calculate C, and results are expressed as tons C per acre. However, the **CARBCALC** and **CARBREPT** keywords can be used in concert to request different carbon accounting algorithms and different measurement units. An alternative methodology can be requested which uses species-based biomass relationships published by Jenkins and others (2003). Similarly, if metric or combined units are requested, output reporting units are expressed as metric tons C per hectare or metric tons C per acre, respectively.

In the example shown in Table 2.6.3 (which includes parallel extracts from the Stand Carbon Report and the All Fuels Report), a harvest in 2010 removes 76 t/ac biomass and adds crown material to the dead surface fuel pools. From a carbon perspective the entry removes 38.1 tC/ac from the stand and reduces the aboveground live C; crowns left in the stand increase the carbon stored in the Forest DDW and Floor pools. A simulated fire in 2025 then reduces litter and duff biomass from 25.9 t/ac to 6.0 t/ac (equivalent to a residual 2.22 tC/ac, using a biomass-to-carbon conversion factor of 0.37). Biomass of live and dead surface fuels, excluding litter and duff, are reduced from 34.9 t/ac to 13.1 t/ac (residual 6.5 tC/ac; using a conversion factor of 0.50).

Table 2.6.3 - Example Stand Carbon Report using the default FFE-calculated biomass and units. Note that changes to the various pools also include contributions from stand growth and mortality, as well as from stand management actions and fire disturbance. Two disturbances are shown in bold and highlighted with asterisks at the end of the report line. First, a harvest in 2010 reduces C in the aboveground live and merchantable categories. This harvest transfers some live belowground C in roots to dead root C, representing the roots of harvested trees. Second, further changes occur with a simulated fire in 2025, which consumes much of the C in surface fuel but has neglible effect upon the C held in standing wood. A corresponding extract from the All Fuels Report is shown below, for comparison.

```
--------------------------------------------------------------------------------------------------------------
                              ******  CARBON REPORT VERSION 1.0 ******
                                         STAND CARBON REPORT
                              ALL VARIABLES ARE REPORTED IN TONS/ACRE

STAND ID: 9999114                       MGMT ID: NONE
--------------------------------------------------------------------------------------------------------------
      Aboveground Live    Belowground                        Forest             Total    Total     Carbon
     ----------------- -----------------    Stand  -------------------------    Stand  Removed   Released
YEAR    Total    Merch     Live     Dead     Dead      DDW    Floor  Shb/Hrb   Carbon   Carbon  from Fire
--------------------------------------------------------------------------------------------------------------
2005     74.1     53.5     18.8      0.6     11.9     10.5     10.3      0.1    126.3      0.0        0.0
2010     29.9     22.4      8.2     12.2     11.6     18.5     11.1      0.9     92.4     38.1        0.0  **
2015     31.3     23.6      8.6      2.3      9.2     17.2      9.6      0.9     79.1      0.0        0.0
2020     33.5     25.4      9.2      0.4      6.7     16.6      9.6      0.8     76.8      0.0        0.0
2025     33.0     25.4      8.9      0.9      7.2      5.7      2.2      0.8     58.9      0.0       18.7  **
2030     35.2     27.1      9.5      0.2      5.1      7.2      2.4      0.9     60.4      0.0        0.0
2035     37.4     28.9     10.1      0.1      4.1      7.7      2.4      0.8     62.6      0.0        0.0
--------------------------------------------------------------------------------------------------------------------------
                                                    ESTIMATED FUEL LOADINGS
                     SURFACE FUEL (TONS/ACRE)                           STANDING WOOD (TONS/ACRE)
     -----------------------------------------------------------  -----------------------------------
                    DEAD FUEL                      LIVE               DEAD            LIVE
     -----------------------------------------  ---------- SURF   -----------   ---------------        TOTAL TOTAL BIOMASS
YEAR LITT.  DUFF  0-3"   >3"  3-6" 6-12"  >12"  HERB SHRUB TOTAL   0-3"   >3"   FOL  0-3"   >3" TOTAL BIOMASS CONS REMOVED
--------------------------------------------------------------------------------------------------------------------------
2005  2.97  24.9   4.1  16.9   7.1   8.0   1.7  0.15  0.10  49.1   1.34  22.4   8.6  21.3   118   172   221     0      0
2010  5.15  25.0  17.3  19.8   7.4   9.1   3.3  0.26  1.50  68.9   1.73  21.5   2.4   8.4    49    83   152     0     76
2015  0.98  25.0  11.4  23.0   7.7  10.3   5.0  0.26  1.45  62.2   0.86  17.6   2.5   8.7    51    81   143     0      0
2020  0.86  25.0   7.5  25.7   7.7  11.3   6.8  0.25  1.42  60.7   0.35  13.0   2.7   9.2    55    80   141     0      0
2025  0.40   5.6   1.4  10.1   0.4   4.4   5.3  0.25  1.39  19.2   1.34  13.1   2.4   8.7    55    81   100    43      0
2030  0.79   5.7   2.1  12.4   0.4   4.8   7.2  0.26  1.46  22.6   0.40   9.9   2.4   9.0    59    81   103     0      0
2035  0.83   5.7   2.0  13.4   0.4   4.8   8.2  0.26  1.43  23.7   0.28   8.0   2.6   9.6    63    83   107     0      0
-------------------------------------------------------------------------------------------------------------------------
```

Harvested Products Report: Using the **CARBCUT** keyword, the carbon content of the merchantable timber utilized from stand entries (including salvage harvests) can be followed over time and summarized to the main output. By default, FFE biomass estimates are used to calculate C in harvest products, and results are expressed as tons C per acre. However, the **CARBCALC** and **CARBCUT** keywords can be used in concert to request alternative carbon accounting algorithms and different measurement units. An alternative methodology can be requested which uses species group-based biomass relationships published by Jenkins and others (2003). Similarly, if metric or combined units are requested, output reporting units are expressed as metric tons C per hectare or metric tons C per acre, respectively.

The Merch Carbon removed as reported within the Harvested Products reports usually differs from the Total Removed Carbon reported by the Stand Carbon report, since the Stand Carbon report includes C removals based on both merchantable and unmerchantable biomass removed. Carbon reported as removed in the Harvested Products report includes the carbon in the merchantable biomass only, including merchantable biomass from snags harvested with the SALVAGE keyword. Also, the removals in the Stand Carbon Report are for a given year alone. In contrast, the removals in the Harvested Products report are cumulative and include removed carbon up to and including the year of the output.

Table 2.6.4 - Example Harvested Products Report using the default FFE-calculated biomass and units. The result of a harvest in 2010 is shown in bold and highlighted with asterisks at the end of the report line. (see Table 2.27 for the corresponding Stand Carbon report). Note that the 34.3 tC/ac of merchantable removed carbon is less than the total carbon removed from the stand (38.1 tC/ac). The Total Carbon Stored category is the sum of the Products and Landfill; Total Carbon Removed is the sum of all four categories.

```
-----------------------------------------------------------------------------------------
                             ******  CARBON REPORT VERSION 1.0 ******
                                     HARVESTED PRODUCTS REPORT
                             ALL VARIABLES ARE REPORTED IN TONS/ACRE

STAND ID: 9999114                       MGMT ID: NONE
-----------------------------------------------------------------------------------------
                                            Merch Carbon
                                          ---------------
YEAR  Prducts  Lndfill   Energy  Emissns   Stored  Removed
-----------------------------------------------------------------------------------------
2005      0.0      0.0      0.0      0.0      0.0      0.0
2010     24.2      0.0      7.2      3.0     24.2     34.3  **
2015     18.6      2.6      9.1      4.0     21.2     34.3
2020     15.0      4.2     10.3      4.8     19.3     34.3
2025     12.8      5.2     11.0      5.3     18.0     34.3
2030     11.3      5.9     11.4      5.7     17.2     34.3
2035     10.2      6.3     11.8      6.0     16.5     34.3
-----------------------------------------------------------------------------------------
```

The format of the Harvested Products report follows the decay-fate categories of Smith and others (2006), and these are described in Table 2.6.2. Over time, harvested merchantable C may continue to reside in a Products or Landfill category, or may be released as one of two kinds of Emissions: emitted with energy capture or emitted without energy capture. As decay occurs, more and more of the C resides in an Emitted category.

Some care must be taken when interpreting the Stand Carbon report and the Harvested Products report: there are differences in terminology among FVS variants and differences in the assumptions made by the FFE and Jenkins algorithms. In western FVS variants, both merchantable cubic foot volume and total cubic foot volume are predicted for trees. In these variants, the total carbon (either standing or removed) in live trees is based on the total volume and crown biomass equations that predict the biomass of branchwood and foliage. The merchantable carbon reported is based on the merchantable cubic foot volume and does not include unmerchantable trees or the unmerchantable parts of merchantable trees. In eastern variants, the total carbon (either standing or removed) in live trees is based on the merchantable cubic foot volume in pulpwood and crown biomass equations that predict unmerchantable biomass for a tree. The merchantable carbon reported is based on the merchantable cubic foot volume in pulpwood. Whatever volume definition is used, it is combined with the specific gravity of wood for each tree species to calculate biomass and C stock for that portion of the tree. The FFE biomass/carbon algorithms do not include stem bark in the estimate of total or merchantable biomass, therefore stem bark is also missing from the C accounting. In contrast, the Jenkins equations include bark in their estimate of total aboveground biomass. Also, when

Jenkins equations are used and merchantable biomass is reported, this includes the stem wood portion of trees and does not include the stem bark.

2.7 Discussion

2.7.1 Model Contributions

FFE-FVS is a tool for managers. It has a broad geographic scope encompassing most forest types of the United States. A broad range of management actions – silvicultural as well as prescribed fire and mechanical fuel treatment - can be simulated. FFE-FVS provides an extensive set of outputs that allow forest management decisions to be assessed in a temporal context: not only short term effects on fuels, stand dynamics, and potential fire behavior are modeled, but also the way in which these interacting ecosystem components may be expected to change over time.

Perhaps the most important contribution of this model is to explicitly link stand and fuel dynamics. A simulation tracks the biomass, growth and mortality of individual trees in a stand; litterfall from the living trees and falldown of the snags determine surface woody fuel loads. Fire, if simulated, impacts surface fuels directly by consuming them, indirectly, over time, as fire-killed trees fall to the ground, and, even more indirectly, by impacting future stand structure.

Recent research on potential for crown fire behavior is linked in this model with dynamically computed canopy fuel characteristics. With or without management, canopy fuels change over time. Since FVS already tracked crown characteristics of the individual trees making up the stand over time (including ingrowth), it provides a natural vehicle for assessing changing crown fire hazard.

Many of the components of FFE-FVS have long histories in both scientific and management communities. For example, Rothermel's surface fire model, included here, was first presented in 1972, and has been in widespread use ever since. Both modelers and users have gained a good understanding of its robustness as well as its limitations, and are comfortable interpreting its output. This is also true of the growth and yield algorithms that drive FVS.

2.7.2 Model Limitations

FFE-FVS has a number of weaknesses, including discontinuous behavior, poor live fuel estimates, and others discussed below.

Discontinuous behavior may be evident in indicators that depend in part on canopy base height – canopy base height itself, torching index, potential tree mortality, and fire type. In this case the underlying processes probably are discontinuous – regeneration often occurs in pulses, a stand suddenly passes a critical point after which vulnerability to torching sharply increases or decreases. These intended discontinuities are probably exaggerated by the fact that in the model, all regeneration occurs on cycle boundaries, as well as all natural tree mortality. Self-pruning and mortality of suppressed under-story trees may cause the stand's canopy base height to increase sharply at a cycle boundary, or in-growth may cause the canopy base height to fall abruptly.

Within each cycle, users cannot control the order of simulated management actions.

Live fuels (herbaceous plants and shrubs) are poorly represented in FFE-FVS. Their biomass and its contribution to fuel consumption and smoke is only nominally represented as a fixed amount that depends on percent cover and dominant tree species. Live fuels can contribute significantly to the behavior of a fire. Their contribution to fire behavior is represented in the selection of fire behavior fuel models. Canopy cover, over-story composition, habitat type and stand history influence selection of fire behavior fuel models. Live fuels are not dynamically tracked and simulated in FFE-FVS.

Decomposition rates in most variants are not sensitive to aspect, elevation or potential vegetation type. Decomposition rates can be controlled by the user, however, so it is possible for a knowledgeable user to “tune” the decomposition algorithms and thus, the fuel dynamics.

Fire conditions (fuel moisture, wind speed, and temperature) must be selected by the user. FFE contains no climatologic data and will not estimate site-specific moistures. If you want to look at differences in fire dynamics between north and south slopes for example, you must be able to give the model different fuel moistures for the different sites.

These limitations suggest opportunities for further research and model development. In the meantime, we designed FFE so that its commands allow users to apply any information they have to their specific situation. Users can overcome many of these limitations and customize the model by careful use of the keywords.

Chapter 3
User's Guide / Keyword Manual

Abstract: The Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) simulates fuel dynamics and potential fire behavior over time, in the context of stand development and management. This chapter presents the model's options and associated keywords.

Keywords: FVS, FFE, forest fire, stand dynamics, FOFEM, BEHAVE, snags, coarse woody debris.

3.1 Introduction

The Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) is introduced in Chapter 1—Purpose and Applications and Chapter 2—Model Description covers the model's content. FFE-FVS is controlled through the use of keywords, which are described in this chapter. Topics covered include how to change the initial values, set fires, adjust the snag and fuel parameters, specify management actions, and control the generation of outputs.

This document assumes that you already know how to use the FVS (Crookston and Dixon 2005) and that you have the software installed on your computer. Instructions for getting this program and accessing the background information you need are listed at the beginning of this volume.

3.2 FFE Keywords

Keyword Groups

Output Control

CANCALC	68	**CARBREPT**	69	**FUELREPT**	76	**SNAGCLAS**	81	**SVIMAGES**	85
CANFPROF	68	**DWDCVOUT**	70	**MORTCLAS**	77	**SNAGOUT**	84		
CARBCALC	69	**DWDVLOUT**	71	**MORTREPT**	77	**SNAGSUM**	85		
CARBCUT	69	**FUELOUT**	76	**POTFIRE**	78	**SOILHEAT**	85		

Management

FUELMOVE	75	**PILEBURN**	78	**SALVAGE**	79	**SALVSP**	80	**SIMFIRE**	80
FUELTRET	76								

Fire Behavior Adjustments

DEFULMOD	69	**FIRECALC**	71	**FMODLIST**	72	**FUELMODL**	74	**STATFUEL**	85
DROUGHT	70	**FLAMEADJ**	71	**FMORTMLT**	72				

Fire Weather Adjustments

MOISTURE	77	**POTFPAB**	79	**POTFSEAS**	79	**POTFTEMP**	79	**POTFWIND**	79
POTFMOIS	78								

Snag Initializations and Adjustments

SNAGBRK	81	**SNAGFALL**	82	**SNAGINIT**	84	**SNAGPBN**	84	**SNAGPSFT**	85
SNAGDCAY	82								

Surface and Canopy Fuels Initialization and Adjustments

CANCALC	68	**FUELDCAY**	72	**FUELINIT**	74	**FUELPOOL**	76	**FUELSOFT**	76
DUFFPROD	70	**FUELFOTO**	73	**FUELMULT**	75				

***FMIN signals the start of the FFE keywords and END signals the end.

FMIN Signals the start of the FFE keywords.

END Signals the end of the FFE keywords. Note: All other FFE keywords must appear between the FMIN-END pair. You may code several FMIN-END pairs and you may have one or many FFE keywords between each pair.

BURNREPT: Request the burn conditions report output.

CANCALC: Modify the calculation of canopy base height and canopy bulk density. Users can specify which trees are included in these calculations. They can also change the cutoff value used to determine canopy base height.

field 1: The method used. 0 = standard method. Currently this is the only method supported.

field 2: Minimum height (in feet) of trees used in the calculation. Default is 6.

field 3: The species included in the calculation; 0 = conifers only, 1 = all species; default value is 0.

field 4: Cutoff value used in determining canopy base height. Default is 30 lbs/acre/foot.

CANFPROF: Request that the canopy fuels profile information be sent to an output FVS database. Output includes the available canopy fuel (kg/m^3 or lbs/acre/ft) at various heights above the ground (feet or meters). This keyword creates the FVS_CanProfile table (See the Users Guide to the Database Extension of FVS (Crookston and others 2003) for more details on this table). There is no corresponding text output table. The database extension to FVS is required to obtain this output. Available canopy fuels include foliage and fine branchwood only - See section 2.4.7 for more information on canopy fuels.

CARBCALC: Set carbon accounting parameters.

field 1: Use FFE algorithm for aboveground biomass (field is 0 or blank), or use Jenkins and others (2003) algorithm for aboveground biomass (field is 1). Default value is 0.

field 2: Use US units (tons carbon per acre) for output (field is 0 or blank), or metric units (metric tons carbon per hectare) (field is 1), or combined units (metric tons carbon per acre) (field is 2). Default value is 0. (With US units, a ton = a short ton = 2000 lbs.)

field 3: Annual decay rate (proportion per year) for belowground-dead carbon pool (dead roots). Default is 0.0425. Valid range is > 0.0 – 1.0.

field 4: DBH breakpoint (inches) for softwood species. Stem biomass from trees smaller than this size assigned to a pulpwood class for calculations that produce the harvested products report. Those equal or larger are assigned to a sawlog class. Default is 9 inches DBH.

field 5: DBH breakpoint (inches) for hardwood species. Stem biomass from trees smaller than this size assigned to a pulpwood class for calculations that produce the harvested products report; those equal or larger are assigned to a sawlog class. Default is 11 inches DBH.

CARBCUT: Request the harvested carbon products report.

CARBREPT: Request the stand carbon report.

DEFULMOD: Modify the parameters of an existing fuel model or define the parameters of a new fuel model. Note that the defaults for fields 3-12 are those defined models listed in Appendix C. Fields 8-14 are coded on a second line; each value in fields that are for the fuel 10 columns wide starting in column 1. Even if these fields are not used, this additional line must be entered. Loadings should be entered in lbs/ft^2.

field 1: The FVS cycle number or the calendar year when the definition takes place; default is 1. Once in effect, the changes stay until they are changed again.

field 2: Fuel model index numbers shown in Appendix C. Values for the standard 13 fuel models of Anderson (1982) are 1-13. Values for the Scott and Burgan (2005) fuel models are 101-204. Numbers 14, 25, and 26 are custom fuel models. You can define new fuel models by giving them values between 15 and 30.

field 3: Surface to volume ratio (1/ft) for 0-0.25 inch fuel.

field 4: Surface to volume ratio (1/ft) for 0.25-1.00 inch fuel.

field 5: Surface to volume ratio (1/ft) for 1-3 inch fuel.

field 6: Surface to volume ratio (1/ft) for live woody fuel.

field 7:	Loading (lbs/ft^2) for 0-0.25 inch fuel.
field 8:	Loading (lbs/ft^2) for 0.25-1 inch fuel.
field 9:	Loading (lbs/ft^2) for 1-3 inch fuel.
field 10:	Loading (lbs/ft^2) for live woody fuel.
field 11:	Fuel depth (ft.)
field 12:	Moisture of extinction (0.0-1.0).
field 13:	Surface to volume ratio (1/ft) for live herbaceous fuel.
field 14:	Loading (lbs/ft^2) for live herbaceous fuel.

DROUGHT: Set drought years for the fuel model selection process. Drought conditions are used in the automatic fuel model selection in a few variants.

field 1:	The FVS cycle number or the calendar year when the drought starts; default is 1.
field 2:	The duration in years; default is 1.

Notes: DROUGHT has no impact on the moisture content of fuels or on the fire conditions. In some variants (such as CR, UT, and LS), it affects the choice of fire behavior fuel model, which will affect fire intensity and mortality.

DUFFPROD: Set the proportion of the decayed material that becomes duff, the remainder is lost.

field 1:	Decay class code, range 1-4. Code a 5 to set the rates for all 4 decay classes at once; no default value.
field 2:	Proportion of decayed litter; default is 0.02.
field 3:	Proportion for the 0-0.25 inch fuel; default is 0.02.
field 4:	Proportion for the 0.25-1 inch fuel; default is 0.02.
field 5:	Proportion for the 1-3 inch fuel; default is 0.02.
field 6:	Proportion for the ≥3 inch fuel; default is 0.02.
field 7:	Proportion for all fuel size classes. Values coded in this field automatically replace blanks in fields 2-6; default is 0.02.

Notes: As the biomass in each pool decays, some portion becomes duff, while the remainder is lost to the air. Since duff usually decays very slowly, the amount of decayed biomass that becomes duff plays an important role in the amount of duff present in the stand over the long term. The decay rate of the duff pool can be changed using the FUELDCAY keyword. You can change the proportion of the decayed biomass that goes into the duff pool using the DUFFPROD keyword. This keyword does not affect the decay rate of the original pools, just the amount that moves from the original pools to the duff pool. The portion that does not enter the duff pool is lost to the atmosphere and is not tracked by FFE.

DWDCVOUT: Request the down woody debris cover report.

DWDVLOUT: Request the down woody debris volume report.

FIRECALC: Modify the fire behavior calculations. Users can choose to use the original fuel model selection logic, the new fuel model selection logic (includes the 40 Scott and Burgan (2005) fuel models) or can choose to predict fire behavior from modelled fuel loads directly. The surface area to volume ratio and bulk density values entered are used only if the new fuel model selection logic or the modelled loads option is chosen. The heat content entered is used only if the modelled loads option is chosen. These variables should be entered as they pertain to your fuel bed and will be used to help select the most similar fuel model(s) (if using the new fuel model logic) or will be used directly in the fire behavior calculations (if using the modelled loads option). When using the modelled loads option, no standard fuel model is actually selected and used, but the use of this option is reported as fm 89. See Appendix B for more details on the new fuel model logic and the modelled loads option. If the fuel model is set with the FUELMODL keyword or set within the StandInit table of an input FVS database, that selection will override settings on the FIRECALC keyword.

field 1:	Year or cycle in which the fire behavior calculations will be changed. Default is 1. (Once in effect, this keyword stays in effect until replaced with another FireCalc keyword.)
field 2:	The fire behavior calculations should use: 0 = the original FFE fuel model selection logic (Default) 1 = the new fuel model selection logic (includes the 40 new fuel models) 2 = modelled loads directly in predicting fire behavior
field 3:	Fuel model set for use with the new fuel model logic: 0 = use the original 13 fuel models 1 = use the 40 new Scott and Burgan fuel models 2 = use all 53 fuel models (Default)
field 4:	Surface area to volume ratio (1/ft) for 1 hr (0-.25") fuels. Default = 2000.
field 5:	Surface area to volume ratio (1/ft) for live herb fuels. Default = 1800.
field 6:	Surface area to volume ratio (1/ft) for live woody fuels. Default = 1500.
field 7:	Bulk density (lbs/ft3) for live fuels. Default = 0.10
field 8:	Bulk density (lbs/ft3) for dead fuels. Default = 0.75
field 9:	Heat content (BTU/lb). Default = 8000 .

Notes: When using the new fuel model logic, the keyword FMODLIST can be used to select or de-select a particular fuel model from the potential pick list.

FLAMEADJ: Modify or set the flame length for a fire simulated using the SIMFIRE keyword scheduled for the same year.

If flame length is modified without specifying the percent crowning, the model will not alter how it calculates percent crowning. Likewise, flame length calculations will not be altered if only percent crowning is specified. To keep flame length and percent crowning calculations consistent, both should be entered. If flame length, percent crowning, and scorch height are all entered, the program skips fire behavior calculations and applies fire effects based on the values entered.

field 1: The FVS cycle number or calendar year; default is 1.

field 2: Flame length multiplier; default is 1.0 which is suggested for free-burning fires. A value of 0.3 is suggested to simulate a throttle-back fire and 2.0 to simulate a mass-ignition fire.

field 3: Flame length to be used in the place of a computed length. The default is for the model to compute the length and is signified by leaving the field blank or coding -1.

field 4: Percent of crowns that burn (crowning). If blank or -1. the model computes the percent crowning.

field 5: Scorch height (feet). If blank or -1, the model computes the scorch height based on the flame length and percent crowning of the fire.

FMODLIST: Adjust the fuel models available for selection in conjuction with the new fuel model logic (also see FireCalc keyword). Fuel models can either be turned "on" (they will be part of the potential fuel model pick list) or turned "off". See Appendix B for details on the new fuel model logic and see Table B.2.2 for what fuel models are part of the pick list by default. Once set, this keyword stays in effect unless reset.

field 1: Year or cycle in which the keyword will apply. Default is 1. (Once in effect, this keyword stays in effect unless reset. Multiple FMODLIST keywords can be used simultaneously.)

field 2: Fuel model (1 - 204). Default = 1

field 3: Fuel model status:

-1 = use default logic to determine if fuel model is part of the pick list (Default)

0 = fuel model IS part of the pick list

1 = fuel model IS NOT part of the pick list

FMORTMLT: Modify the FFE calculation of the probability that a tree will die due to fire. The multipliers coded using this keyword are only in effect for the cycle or year in which they are scheduled. Several FMORTMLT keywords can be specified for the same time period where each applies to a different species or portion of the tree DBH distribution. The values apply to fire effects computed for potential fires as well as simulated fires that are scheduled for the same year. A major purpose for using this keyword is to represent the effects drought in years prior to the fire have on tree mortality (van Mantgem and others 2013). The keyword can also be used to represent the effect on mortality of wet years prior to fire. Values greater than 1.0 increase mortality rates, values less than 1.0 decrease mortality rates.

field 1: Year/cycle to which the keyword applies.

field 2: The multiplier value, default is 1.0.

field 3: The species code to which the multiplier applies, default is 0 for all species.

field 4: Smallest DBH to which multiplier is applied (greater than/equal to).

field 5: Largest DBH to which multiplier is applied (less than):

Notes: This keyword can be specified using the PARMS feature of FVS where fields 2 through 5 can be expressions.

van Mantgem and others (2013) reported models that predict the probability of mortality given tree bark thickness, fire severity measures, and changes in climatic water deficit relative to long-term averages prior to fire. Using results from that work the following general guidelines can be used to choose multipliers on the FMORTMLT keyword. For low moisture deficit, code 1.2, for moderate, code 1.4, for high code 1.6, for very high code 1.8. Of course, any values may be used and you can use this keyword to represent other effects besides climatic water deficit.

Additional reference:
van Mantgem, Philip J.; Nesmith, Jonathan C.B.; Keifer, MaryBeth; Knapp, Eric E.; Flint, Alan; Flint, Lorriane. 2013. Climatic stress increases forest fire severity across the western United States. *Ecology Letters* doi: 10.1111/ele.12151.

FUELDCAY: Set the decay rates for each the fuel pools. The default values depend on the variant.

field 1: Decay class code, range 1-4. Code a 5 to set the rates for all 4 decay classes at once; an entry is required.

field 2: Decay rate for the litter fuel size class.

field 3: Decay rate for the duff fuel size class.

field 4: Decay rate for the 0-0.25 inch fuel size class.

field 5: Decay rate for the 0.25-1 inch fuel size class.

field 6: Decay rate for the 1-3 inch fuel size class.

field 7: Decay rate for the ≥3 inch fuel size class.

Notes: Fuels are tracked in several pools. You can change the decay rates associated with these pools using the FUELDCAY keyword. You can modify the decay rates for each class rather than setting them directly using the FUELMULT keyword to specify a multiplier of the model's default rates.

FUELFOTO: Initialize surface fuel loading by selecting a photos series photo.

field 1: The photo series reference number (1-32)

field 2: The photo reference code (integer)

Notes: When included with input FVS data, the photo series information should be specified in the StandInit table in columns labeled Photo_Ref and Photo_Code. Photo_Ref holds the photo series reference number (1 - 32) and Photo_Code holds the character string photo reference code. The photo series reference numbers and photo reference codes are listed in Appendix D.

FUELINIT: Set the amount of hard (sound) dead fuel in each fuel size class, as well as litter and duff. Values left blank are replaced with variant-dependent defaults shown in the documentation for the individual variants in Chapter 4 Variant Descriptions. Individual fuel loadings can also be set within the StandInit table of an input FVS database.

field 1:	Initial hard fuel load for the 0-1 inch class (tons/acre). This loading gets divided equally between the 0-0.25 inch class and the 0.25-1 inch class.
field 2:	Initial hard fuel load for the 1-3 inch class (tons/acre).
field 3:	Initial hard fuel load for the 3-6 inch class (tons/acre).
field 4:	Initial hard fuel load for the 6-12 inch class (tons/acre).
field 5:	Initial hard fuel load for the 12-20 inch class (tons/acre).
field 6:	Initial fuel load for litter (tons/acre).
field 7:	Initial fuel load for duff (tons/acre).
field 8:	Initial hard fuel load for the 0-0.25 inch class (tons/acre).
field 9:	Initial hard fuel load for the 0.25-1 inch class (tons/acre).
field 10:	Initial hard fuel load for the 20-35 inch class (tons/acre).
field 11:	Initial hard fuel load for the 35-50 inch class (tons/acre).
field 12:	Initial hard fuel load for the ≥ 50 inch class (tons/acre).

Notes: Initial soft (rotten) down wood can be set with the FUELSOFT keyword. In addition to entering initial fuel loadings (tons/acre) directly, users can initialize their surface fuel loads by specifying a representative fuels photo series photo. This can be done with the FFE keyword FUELFOTO or by including this information in the StandInit table of an input FVS database.

FUELMODL: Specify the fuel models and the weights used in place of the fuel model selection described in Chapter 2 and the variant-specific sections in Chapter 4. This keyword over-rides the normal fuel model selection during the years it is in effect. Code fields 8 and 9 on a second line, each value in fields that are 10 columns wide starting in column 1. If these fields are not used, there must be a blank line after the keyword. The weights are automatically scaled so that they sum to 1. The initial fuel model can also be set within the StandInit table of an input FVS database. Once this keyword is set, it stays in effect until a new fuel model is chosen or the automatic logic is re-invoked. Fuel models selected with this keyword override settings made with the FIRECALC keyword.

field 1:	The FVS cycle number or the calendar year the fuel models specified start being used; default is 1. (Once in effect, this keyword stays in effect until replaced with another FuelModl keyword.)
field 2:	Index to fuel model 1 (if left blank or zero, then the automatic logic is used from this year onward).
field 3:	Weight given fuel model 1; default is 1.
field 4:	Index to fuel model 2.

field 5: Weight given fuel model 2; default is 1 when field 4 contains an entry, zero otherwise.

field 6: Index to fuel model 3.

field 7: Weight given fuel model 3; default is 1 when field 6 contains an entry, zero otherwise.

field 8: Index to fuel model 4.

field 9: Weight given fuel model 4; default is 1 when field 8 contains an entry, zero otherwise.

FUELMOVE: Move fuel between size classes to simulate fuel treatments. This keyword can be used to simulate the chipping or chunking of large fuel that is made smaller in size. The amount of fuel to move can be specified in four different ways (see fields 4-7); if values are provided for more than one method, FFE will use the method that results in the largest transfer. Setting the source pool to 0=none implies that fuel is being imported from outside and setting the destination pool to 0=none implies that fuel is being removed. The order FUELMOVE keywords are entered into the keyword file is important, especially if proportions are used. FFE processes keywords in the scheduled order and removes the fuel from the source pool at that time. The fuel is not added to the destination pool until all keywords for the year have been processed.

field 1: The FVS cycle number or the calendar year; default is 1.

field 2: Source fuel pool (0=none, 1=<0.25 inch, 2=0.25-1 inch, 3=1-3 inch, 4=3-6 inch, 5=6-12 inch, 6=12-20 inch, 7=20-35 inch, 8=35-50 inch, 9=≥50 inch, 10=litter, 11=duff); default is 6.

field 3: Destination fuel pool; same codes used as field 2; default is 11.

field 4: Amount of fuel (tons/acre) to move from the source pool; default is 0.

field 5: Proportion of source fuel to move; default is 0.

field 6: Residual fuel (tons/acre) to leave in the source pool; default is 999.

field 7: Final amount (tons/acre) of fuel in the target; default is 0.

Notes: With FUELMOVE, users may specify an amount of fuel to move from one class to another. You may alternatively specify the proportion to move or the residual to leave. This keyword can be used multiple times in the same year to treat multiple size classes simultaneously. It can also be used in conjunction with the YARDLOSS keyword and any thinning keyword to simulate a mastication treatment where standing trees are chipped and left as surface fuel in the stand.

FUELMULT: Specify multipliers for each decay rate class that apply to the decay rates for all fuel size classes.

field 1: Multiplier for decay rate class 1=very slow; default is 1.

field 2: Multiplier for decay rate class 2=slow; default is 1.

field 3: Multiplier for decay rate class 3=fast; default is 1.

field 4: Multiplier for decay rate class 4=very fast; default is 1.

Notes: Fuels are tracked in several pools. You can change the decay rates associated with these pools using the FUELDCAY keyword. You can modify the decay rates for each class rather than setting them directly using the FUELMULT keyword to specify a multiplier of the model's default rates.

FUELOUT: Request the detailed fuels report.

FUELPOOL: Specify the assignment of each species to a specific decay rate class.

field 1: Valid species letter codes or number. Use a "0" or "ALL" to indicate all species; no default value.

field 2: Decay rate class number, 1 to 4; no default value.

Notes: The decay rate class of fuel is determined by the tree species from which it originated. You can change the assignment of a species to a different decay rate class (or pool) using the FUELPOOL keyword. If different decay rates are set for each decay class, then the assignment of the species to a class is important.

FUELREPT: Request the fuel consumption report.

FUELSOFT: Set the amount of soft (rotten) dead fuel in each fuel size class. Values left blank are replaced with the default value of 0. Individual fuel loadings can also be set within the StandInit table of an input FVS database.

field 1: Initial soft fuel load for the 0-0.25 inch class (tons/acre).

field 2: Initial soft fuel load for the 0.25-1 inch class (tons/acre).

field 3: Initial soft fuel load for the 1-3 inch class (tons/acre).

field 4: Initial soft fuel load for the 3-6 inch class (tons/acre).

field 5: Initial soft fuel load for the 6-12 inch class (tons/acre).

field 6: Initial soft fuel load for the 12-20 inch class (tons/acre).

field 7: Initial soft fuel load for the 20-35 inch class (tons/acre).

field 8: Initial soft fuel load for the 35-50 inch class (tons/acre).

field 9: Initial soft fuel load for the ≥ 50 inch class (tons/acre).

Notes: Initial hard (sound) down wood, as well as litter and duff, can be set with the FUELINIT keyword. In addition to entering initial fuel loadings (tons/acre) directly, users can initialize their surface fuel loads by specifying a representative fuels photo series photo. This can be done with the FFE keyword FUELFOTO or by including this information in the StandInit table of an input FVS database.

FUELTRET: Specify a fuel treatment or harvest method, or specify the multiplier used to modify the fuel depth. For each method FFE supplies a multiplier (Table 3.2.1) to the fuel depth that simulates the treatment. This effect on fuel depth lasts for 5 years.

field 1: The FVS cycle number or the calendar year; default is 1.

field 2: Fuel treatment type: 0=none, 1=lopping or flailing, 2=trampling, chopping, chipping, or crushing; default is 0.

field 3: Harvest type: 1=ground-based, cat skidding or line skidding, 2=high lead or skyline, 3=precommercial or helicopter; default is 1.

field 4: Multiplier used to increase or decrease fuel depth; default depends on the values in field 2 and 3 (Table 3.2.1) but if both are 0.0, the default for this field is 1.0.

Table 3.2.1 - Default fuel depth multipliers used to simulate various fuel treatments and harvest types. Users can also specify their own multiplier on field 4 of the FUELTRET keyword.

Harvest Method (field 3)	Fuel Treatment (field 2)		
	0=none	1=lopping or flailing	2=trampling, chopping, chipping, or crushing
1=ground-based, cat skidding or line skidding	1.0	0.83	0.75
2=high lead or skyline,	1.3	0.83	0.75
3=precommercial or helicopter	1.6	0.83	0.75

MOISTURE: Set the moisture content for each fuel size class. These moisture values apply to simulated fires scheduled for the same calendar year. If this keyword is used for any size class, it must be used for all size classes because there are no default moisture conditions.

field 1: The FVS cycle number or the calendar year; default is 1.

field 2: Moisture value for 1 hour fuel (0-0.25 inch).

field 3: Percent moisture for 10 hour fuel (0.25 – 1 inch).

field 4: Percent moisture for 100 hour fuel (1-3 inch).

field 5: Percent moisture for 3+ inch fuel.

field 6: Percent moisture for duff.

field 7: Percent moisture for live woody fuel.

field 8: Percent moisture for live herbaceous fuel.

MORTCLAS: Specify the class boundaries used in the detailed mortality report. The classes must be specified in increasing order.

field 1: Minimum dbh of size class 1; default is 0 inches.

field 2: Minimum dbh of size class 2; default is 5 inches.

field 3: Minimum dbh of size class 3; default is 10 inches.

field 4: Minimum dbh of size class 4; default is 20 inches.

field 5: Minimum dbh of size class 5; default is 30 inches.

field 6: Minimum dbh of size class 6; default is 40 inches.

field 7: Minimum dbh of size class 7; default is 50 inches.

MORTREPT: Request the detailed mortality report. Note: The diameter classes used in this output report can be modified with the MortClas keyword.

PILEBURN: Signal that a pile or other concentration of fuel is to be burned.

field 1: The FVS cycle number or the calendar year; default is 1.

field 2: The index to the type of fuel burn where 1=pile burn and 2=jackpot burn; the default is 1. These values control the defaults for fields 3-5 on this keyword and otherwise have no special significance.

field 3: Percent of the stand's area affected by the treatment; the default is 70 when field 2 is 1=pile burn, and 100 for 2=jackpot burn.

field 4: Percent of the affected area into which the fuel is concentrated (area which will be treated, i.e. footprint of piles); the default is 10 when field 2 is 1=pile burn, and 30 when it is 2=jackpot burn.

field 5: Percent of the fuel from the affected area that is concentrated in the treated area; the default is 80 when field 2 is 1=pile burn, and 60 when it is 2=jackpot burn.

field 6: Percent mortality of trees in the stand caused by this fuel treatment; default is 0.

Notes: The PILEBURN keyword is used to simulate burning piled fuel in the stand. When used, it reduces fuels, estimates smoke production, and kills the proportion of trees you specify. No other fire effects are simulated. Default conditions for pile burns and jackpot burns can be used simply by indicating either of these types of fuel burns on the keyword in field 2. In place of selecting one of the default types of burns, you can specify exact values for the parameters of the burn, or do both.

The default conditions imply a pile burn and can be interpreted as: 80% of the fuels from 70% of the stand are concentrated into piles that cover 10% of the stand's area. When these piles burn, no trees die. Since FFE-FVS is a non-spatial model, the fuel is assumed to be evenly distributed across the stand both before and after the treatment. Thus, these percentages are simply used to determine how much of the fuel actually burns, and how much mineral soil will be exposed after the burn. For example, if there were 100 tons/acre of fuels in the stand excluding litter and duff, the result of applying the default treatment would be to burn 0.8*0.7*100 = 56 tons/acre. Ten percent of the litter and duff would burn and 10% of the mineral soil would be exposed. Because of differential consumption rates, if the fuels include some that are larger than 1 inch, less than 56 tons/acre of fuel will actually be consumed by fire.

POTFIRE: Request the potential fire report.

Notes: The model estimates two sets of values within the potential fire report. One set assumes conditions that are consistent with severe fire conditions often associated with wild fires, and the other set corresponds to moderate conditions often associated with prescribed fire situations where the suppression policy or required level of action would be considered moderate or light. You can specify the wind speed, temperature, fuel moisture, and other conditions for each of the two categories, severe and moderate, with the PotFMois, PotFTemp, PotFWind, PotFPAB, and PotFSeas keywords.

POTFMOIS: Set the fuel moisture conditions for the two categories of potential fire severity. The defaults for severe conditions correspond to the values for very dry moistures (extremely dry in the SN variant) as described in Chapter 4 for each variant and the defaults for moderate conditions correspond to the moist values (dry values in the SN variant).

field 1: An index value that signals which of the two categories of fire the values in fields 2-8 apply where 1=severe and 2=moderate; 1 is the default.

field 2: Percent moisture for 1-hour fuels (0-0.25 inch)

field 3: Percent moisture for 10 hour fuel (0.25 – 1 inch).

field 4: Percent moisture for 100 hour fuel (1-3 inch).

field 5: Percent moisture for 3+ inch fuel.

field 6: Percent moisture for duff.

field 7: Percent moisture for live woody fuels.

field 8: Percent moisture for live herbaceous fuels.

POTFPAB: controls the percentage of the stand area burned for potential fire calculations.

field 1: Percentage of the stand area burned for potential severe fires; default is 100%.

field 2: Percentage of the stand area burned for potential moderate fires; default is 100%.

POTFSEAS: Controls the season of the burn for potential fire calculations.

field 1: Season of the burn for potential severe fires; 1 =early spring (compact leaves), 2 =before greenup, 3 =after greenup (before fall), 4 = fall; default value is 1.

field 2: Season of the burn for potential moderate fires; 1 =early spring (compact leaves), 2 =before greenup, 3 =after greenup (before fall), 4 = fall; default value is 1.

Notes: The season of burn is used in the soil heating estimates. In some variants, such as NE and LS, the season of the burn is used to determine the fuel model and within the fire-related mortality predictions. Check the variant descriptions in Chapter 4 for more information.

POTFTEMP: Set the temperature for the two categories of potential fire severity.

field 1: The temperature for the severe category; default is 70°F.

field 2: The temperature for the moderate category; default is 70°F.

POTFWIND: Set the wind speeds (20 feet above the vegetation) for the two categories of potential fire severity.

field 1: The 20-foot wind speed for the severe category; default is 20 miles per hour.

field 2: The 20-foot wind speed for the moderate category; default is 6 miles per hour.

SALVAGE: Schedule a snag removal operation.

field 1: The FVS cycle number or the calendar year; default is 1.

field 2: Minimum dbh (inches) to be removed; default is 0.

field 3: Maximum dbh (inches) to be removed; default is 999.

field 4: Maximum number of years the removed snags have been dead; default is 5.

field 5: Decay state to remove where: 0=both hard and soft, 1=hard, and 2=soft; default is 1.

field 6: Proportion of eligible snags to remove; default is 0.9.

field 7: Proportion of affected snags to leave in the stand; default is 0.0.

Notes: Use the SALVAGE keyword to simulate the removal of snags, since the standard thinning keywords only apply to live trees. You can specify a size range, age, and decay status of snags to be removed.

SALVSP: Allows users to select a species to either be cut or left when using the SALVAGE keyword. Once in effect, this keyword stays in effect until reset.

field 1: The FVS cycle number or the calendar year.

field 2: Species or species group. Default value is all.

field 3: Whether the species listed in the field 2 is to be cut or left in subsequent salvage operations; 0 = cut this species, 1 = leave this species; default value is 0.

SIMFIRE: Signal that a fire and its effects should be simulated and specify some of the environmental conditions for the fire. Use one SIMFIRE keyword for each fire you wish to simulate. The percentage of stand area burned affects many of the fire effects calculations, such as mortality, fuel consumption, smoke production, and mineral soil exposure.

field 1: The FVS cycle number of the calendar year; default is 1.

field 2: Wind speed in miles per hour 20 feet above the vegetation; default is 20.

field 3: 1, 2, 3, or 4 to represent the categorical moisture levels as shown in Table 3.2.2 for the IE variant. If the MOISTURE keyword is used, the value in this field is ignored; default is 1=very dry.

field 4: Temperature (°F); default is 70.

field 5: Mortality Code. 0 = Turn off FFE mortality predictions, 1= FFE estimates mortality; default is 1.

field 6: Percentage of stand area burned; default is 100.

field 7: Season of the burn. 1= early spring (compact leaves); 2 = before greenup; 3 = after greenup (before fall); 4 = fall; default is 1.

Notes: FLAMEADJ can be used to modify the fire behavior predicted by the model for simulated fires, in turn affecting the predicted fire effects. Specific fuel moistures can be set for the fire using the MOISTURE keyword.

Table 3.2.2 - Percent fuel moisture for the four nominal levels defined for field 3 of the SIMFIRE keyword. These values are for the IE variant. See Chapter 4 for the values used in other variants.

	Name of	Fuel size class					
Field 3 Value	moisture level	0-2.5 inch (1 hour)	0.25-1 inch (10 hour)	1-3 inch (100 hour)	≥3 inch	Duff	Live
1	Very dry	4	4	5	10	15	70
2	Dry	8	8	10	15	50	110
3	Moist	12	12	14	25	125	150
4	Wet	16	16	18	50	200	150

SNAGBRK: Control the snag height loss rates. The default values depend on the species of the snag. See the individual variant description for details.

field 1: The tree species letter code or number for the FVS variant you are using. Code a zero ("0") or "All" for all species; the default is 0.

field 2: The number of years from when a hard snag is created until 50% of the original height is lost.

field 3: The number of years from when a soft snag is created until 50% of the original height is lost.

field 4: The number of years from when a hard snag is created until the next 30% of the original height is lost. The height loss rate implied by this number is used until the snag falls down.

field 5: The number of years from when a soft snag is created until the next 30% of the original height is lost. The height loss rate implied by this number is used until the snag falls down.

Notes: Height loss occurs in two stages. The first stage lasts until 50% of the original height is lost. The second stage lasts for the remainder of the life of the snag. Use the SNAGBRK to change the number of years it takes for hard and soft snags of various species to lose 50 percent of the height they had at the time the tree died and to set the number of additional years it takes for the next 30 percent of the snag's height to be lost. FFE converts these values into snag breakage rates and uses them in the snag breakage equations described in section 2.3. The snag breakage rates for initially soft snags are generally faster than initially hard snags.

SNAGCLAS: Set the snag class boundaries used to assign snags to class in the snag summary report and for the detailed snag report. Values must be specified in increasing order.

field 1: Lower boundary of size class 1; default is 0 inches.

field 2: Lower boundary of size class 2; default is 12 inches.

field 3: Lower boundary of size class 3; default is 18 inches.

field 4: Lower boundary of size class 4; default is 24 inches.

field 5: Lower boundary of size class 5; default is 30 inches.

field 6: Lower boundary of size class 6; default is 36 inches.

Note: The maximum value for the snag class boundaries is 36 inches due to how FFE tracks snags in dbh classes, with the largest class being 36 inches and larger.

SNAGDCAY: Set a rate multiplier that modifies how fast hard snags become soft.

field 1: The tree species letter code or number for the FVS variant you are using. Code a zero ("0") or "All" for all species; the default is 0.

field 2: The rate of decay adjustment multiplier; must be positive; Higher values increase the amount of time it takes for a hard snag to become soft; default is 1.0. How this multiplier affects the snag decay rate depends on whether it is higher or lower than the default multiplier used for that species; these default snag decay multipliers are described in the variant-specific snag section in Chapter 4.

Notes: For most variants, the formula used to compute the base snag decay rate is covered in section 2.3.5. A few variants (AK, PN, WC, EC, BM, the Oregon portion of SO, and LS) do not use the normal decay time formula – see Chapter 4 for details on these variants. For variants that do use the Marcot snag decay model described in section 2.3.5 (all except AK, PN, WC, EC, BM, the Oregon portion of SO, and LS), the following section applies:

Table 3.2.3 shows a set of multipliers that imply different numbers of years that snags of different sizes will take to make the transition from being hard to being soft. For example, a multiplier of 1 means that a 10 inch tree will take 27 years to become soft, while a 20-inch tree will take 39 years to become soft. You can use the multipliers shown in the body of the table to pick adjustment multipliers that meet your needs. Note that a single multiplier is used for all sizes of a given species.

Table 3.2.3 - Multipliers useful in the SNAGDCAY keyword that result in different numbers of years that must pass for a hard snag to become soft.

Years to Soft	Snag dbh (inches)				
	10	15	20	25	30
10	0.38	0.31	0.26	0.22	0.20
20	0.76	0.62	0.52	0.45	0.39
30	1.14	0.93	0.78	0.67	0.59
40	1.53	1.23	1.04	0.89	0.78
50	1.91	1.54	1.29	1.12	0.98
60	2.29	1.85	1.55	1.34	1.18
70	2.67	2.16	1.81	1.56	1.37
80	3.05	2.47	2.07	1.78	1.57
90	3.43	2.78	2.33	2.01	1.76
100	3.81	3.08	2.59	2.23	1.96

SNAGFALL: Set a rate multiplier that modifies how soon snags fall and set the length of time that some of the large snags stand.

field 1: The tree species letter code or number for the FVS variant you are using. Code a zero ("0") or "All" for all species; the default is 0.

field 2: The rate of fall adjustment multiplier; must be greater than or equal to 0.001; default 1.0. This affects all snags less than the variant-specific dbh cutoff (usually18 inches dbh) and the first 95% of snags greater than cutoff. How this multiplier affects the snag fall rate depends on whether it is higher or lower than the default multiplier used for that species; these default snag fall multipliers are described in the variant-specific snag section in Chapter 4.

field 3: The snag age (number of years the tree is dead) by which the last 5% of snags have fallen. This only affects snags larger than the dbh cutoff (usually 18 inches). This field is not used in the following variants: AK, PN, WC, EC, BM, and Oregon portion of SO.

FFE computes that rate at which snags fall depending on whether the snag was present at the time of a fire in addition to the snag's size and species. Furthermore, there is a built in assumption that some of the large snags (a few of those over a cutoff dbh - usually18 inches dbh) will stand for a long time. See section 2.3 and the variant specific snag sections in Chapter 4 for details.

For variants that use the Marcot snag fall model described in section 2.3 (all except AK, PN, WC, EC, BM, the Oregon portion of SO, LS, and NE), the following section applies:

A multiplier of 1 means that 95% of 10-inch snags will fall in 20 years, and they will all be gone in 22 years. For a 20-inch snag, 95% will fall in 31 years. Table 3.2.4 shows a set of multipliers that imply different numbers of years that snags of different sizes will take to fall. For example, to have 95% of 15-inch snags fall in 40 years, a multiplier of 0.61 would be entered in field 2 of the SNAGFALL keyword. Multipliers for snags of other sizes or persistence times can be estimated through interpolation. Note that the multiplier in field 2 of the keyword is used for all sizes of snags. For example, if a multiplier of 0.5 were to be used, 95% of 10-inch snags would fall in 40 years, while 30-inch snags would take 139 years for 95% of them to fall.

Table 3.2.4 - Multipliers useful in the SNAGFALL keyword that result in different numbers of years that must pass before 95% of the snags fall.

Years to 95% Fall	**Snag dbh (inches)**				
	10	**15**	**20**	**25**	**30**
10	2.00	2.43	3.09	4.25	6.81
20	1.00	1.21	1.55	2.13	3.41
30	0.67	0.81	1.03	1.42	2.27
40	0.50	0.61	0.77	1.06	1.70
50	0.40	0.49	0.62	0.85	1.36
60	0.33	0.40	0.52	0.71	1.14
70	0.29	0.35	0.44	0.61	0.97
80	0.25	0.30	0.39	0.53	0.85
90	0.22	0.27	0.34	0.47	0.76
100	0.20	0.24	0.31	0.43	0.68
110	0.18	0.22	0.28	0.39	0.62

Years to 95% Fall	Snag dbh (inches)				
	10	15	20	25	30
120	0.17	0.20	0.26	0.35	0.57
130	0.15	0.19	0.24	0.33	0.52
140	0.14	0.17	0.22	0.30	0.49
150	0.13	0.16	0.21	0.28	0.45

SNAGINIT: Add a snag to the snag list. Use as many of these keywords as you need to enter the data that represent your stand.

field 1: Species number or letter code; entry is required.

field 2: DBH at the time of death (inches); entry is required.

field 3: Height at the time of death (feet); entry is required

field 4: Current height (feet); entry is required.

field 5: Number of years the tree has been dead.

field 6: Number of snags per acre with these characteristics; entry is required.

Notes: A better way to initialize your snag estimates is through your input dataset since trees that are recorded as mortality in the FVS tree data file are made into snags in FFE.

SNAGOUT: Request the detailed snag report.

field 1: The FVS cycle number or the calendar year when the output starts; default is 1.

field 2: Number of years to output; default is 200.

field 3: No longer used.

field 4: Fortran data set reference number to which the output file is written; default is 13, which writes to the *.chp file.

field 5: Enter a 0 if headings output for the table is wanted, and enter 1 to suppress headings; default is 0.

Notes: The diameter classes used in this output report can be modified with the SNAGCLAS keyword. Because of its potential size, the detailed snag output table is printed to a separate file, by default the *.chp file.

SNAGPBN: Control the fall rates for snags that are present during a fire.

field 1: Proportion of soft snags which will fall faster after a fire; range is 0-1; default is 1.0.

field 2: Proportion of small snags which will fall faster after a fire; range is 0-1; default is 0.9.

field 3: Number of years it will take for these snags to all fall; default is 7.

field 4: Dbh (inches) which divides small snags from large snags for this calculation; default is 12. Snags less than this dbh value are considered small.

field 5: Scorch height (feet) that must be exceeded for the increases fall rates implied by this option to be used by FFE; default is 0.

Notes: The SNAGPBN (SNAG Post BurN) keyword is used to set the snag fall down rates for snags that exist when a fire burns. The basic assumption is that soft snags and small snags fall faster than usual if they are present when a fire burns. Using the defaults for this keyword implies that all soft snags and 90% of snags less than 12 inches will fall in seven years after any fire. Note that the parameters are not species specific and that the rates implied by the SNAGFALL keyword will take precedence if they are faster than the post fire rates.

SNAGPSFT: Set the proportion of snags listed soft when trees die. This proportion applies to snags created from all sources, which include those specified using the SNAGINIT keyword, the input sample tree data file, mortality caused by fires and all other causes, and by stand management. The snags that are initially soft can lose height at a different rate than those snags that are initially hard.

field 1: The tree species letter code or number for the FVS variant you are using. Code a zero (“0”) or “All” for all species; the default is 0.

field 2: The proportion of snags that are soft when they are created; range is 0 to 1; default is zero.

SNAGSUM: Request the snag summary report.

Notes: The diameter classes used in this output report can be modified with the MORTCLAS keyword.

SOILHEAT: Request the soil heating report when a fire is simulated.

field 1: No longer used.

field 2: No longer used.

field 3: Soil type – 1 (Loamy Skeletal), 2 (Fine Silt), 3 (Fine), 4 (Coarse Silt), or 5 (Coarse Loam).

STATFUEL: Signal that the dynamic interpolation logic not be used throughout the simulation. No fields are associated with this keyword.

Notes: By default, FFE picks multiple fuel models and the resulting fire intensity is an average from those fuel models. This interpolation between multiple fuel models provides fire behavior that changes more gradually as stand conditions change than those that are computed without the interpolation logic. We call this dynamic fuel model selection. However, you can tell the model to use only the one fuel model it considers the best choice, rather then using the interpolation approach, with the STATFUEL keyword. This is called static fuel model selection.

SVIMAGES: Set the number of frames, or images, showing the fire progression when the base model SVS keyword is used. This keyword is related to the use of the Stand Visualization System.

field 1: The number of frames or images; default is 3.

3.3 FFE Event Monitor Variables and Functions

The event monitor is a part of FVS that tracks specific internal variables, allowing users to compute custom output variables and conditionally schedule activites. For an in-depth discussion of the event monitor, see the Essential FVS Guide (Dixon 2002). The following describes the FFE event monitor variables and functions, with the variables listed first.

CRBASEHT is the canopy base height reported in the potential fire report.

CRBULKDN is the canopy bulk density reported in the potential fire report.

CROWNIDX is the crowning index reported in the potential fire report.

FIRE has the value 1 (yes) if a fire was simulated in the preceding FVS cycle and has the value 0 (no) if not.

FIREYEAR is the year that the last fire is simulated; the value will be zero if a fire has not been simulated during the run.

MINSOIL is the percent of mineral soil exposure from the most recent fire.

TORCHIDX is the torching index reported in the potential fire report.

CARBSTAT(a) This function returns the amount of carbon stored in various carbon pools, in whatever units are designated with the CARBCALC keyword. These carbon pools correspond to those reported in the carbon reports which are generated by the Fire and Fuels Extension. This function has one argument; a value for the argument is required since there is no default value.

Argument 1: Code indicating the carbon pool, as follows:
1 = Total above ground live tree carbon
2 = Merchantable above ground live tree carbon
3 = Below ground live carbon (roots)
4 = Below ground dead carbon (roots of dead or cut trees)
5 = Standing dead carbon
6 = Down dead wood carbon
7 = Forest floor carbon
8 = Shrub and herb carbon
9 = Total stand carbon
10 = Total removed carbon
11 = Carbon released from fire
12 = Merchantable removed carbon in wood products
13 = Merchantable removed carbon in landfills
14 = Merchantable removed carbon emitted with energy capture
15 = Merchantable removed carbon emitted without energy capture
16 = Merchantable removed stored carbon (products + landfills)
17 = Merchantable removed carbon (all categories)

DWDVAL(a,b,c,d) This function, only available when using the Fire and Fuels Extension, returns the cubic foot volume per acre and percent cover of down woody debris, for a range of size classes and by decay class. The values correspond to those reported in the FFE down wood reports.

Argument 1: Code indicating which measurement is desired, as follows:
1 = down wood volume in cubic feet per acre
2 = down wood cover percent

Argument 2: Code indicating decay status. Only snags with the specified status will be included, as follows:
0 = all
1 = hard
2 = soft

Argument 3: Code indicating the smallest size class to be included, as follows:
1 = Greater than or equal to zero, less than 3 inches
2 = Greater than or equal to 3 inches, less than 6 inches
3 = Greater than or equal to 6 inches, less than 12 inches
4 = Greater than or equal to 12 inches, less than 20 inches
5 = Greater than or equal to 20 inches, less than 35 inches
6 = Greater than or equal to 35 inches, less than 50 inches
7 = Greater than or equal to 50 inches

Argument 4: Code indicating the largest size class to be included. Codes are the same as those described for Argument 3 above. The value used for Argument 4 must be greater than or equal to the value used for Argument 3. If these values are equal, the output will represent a single size class.

FUELLOAD(a,b) This function, only available when using the Fire and Fuels Extension, returns the course woody debris in tons per acre. Only a portion of the total debris is included as indicated by the lower (argument 1) and upper (argument 2) bounds. That is, the function includes all the kinds of woody debris within the range of lower to upper bounds. This function has two arguments; values for the arguments are required since there are no default values.

Argument 1: Code indicating the smallest woody debris size class to be included, as follows:
1 = Greater than or equal to zero, less than 0.25 inch
2 = Greater than or equal to 0.25 inch, less than 1 inch
3 = Greater than or equal to 1 inch, less than 3 inches
4 = Greater than or equal to 3 inches, less than 6 inches
5 = Greater than or equal to 6 inches, less than 12 inches
6 = Greater than or equal to 12 inches, less than 20 inches
7 = Greater than or equal to 20 inches, less than 35 inches
8 = Greater than or equal to 35 inch, less than 50 inches
9 = Greater than or equal to 50 inches
10 = Litter
11 = Duff = decayed material from the other classes

Argument 2: Code indicating the largest woody debris size class to be included. Codes are the same as those described for Argument 1 above. The value used for Argument 2 must be greater than or equal to the value used for Argument 1. If these values are equal, the output will represent a single size class.

FUELMODS(a,b) This function, only available when using the Fire and Fuels Extension, returns the model number or associated weight of a fuel model being used. This function has two arguments; values for the arguments are required since there are no default values.

Argument 1: Code indicating which of the four fuel models to use, as follows:
1 = first fuel model selected
2 = second fuel model selected
3 = third fuel model selected
4 = fourth fuel model selected

Argument 2: Code for which value to return, as follows:
1 = actual fuel model number
2 = fuel model weight as a percent

HERBSHRB(a) This function, only available when using the Fire and Fuels Extension, returns values for live surface fuels in tons per acre. The function will return a value for herbs, shrubs, or the total of herbs and shrubs. This function has one argument; a value for the argument is required since there is no default value.

Argument 1: Code indicating which value to return, as follows:
1 = live surface fuels of herbs in tons/acre
2 = live surface fuels of shrubs in tons/acre
3 = live surface fuels of herbs and shrubs in tons/acre

POTFLEN(a) This function, only available when using the Fire and Fuels Extension, returns the potential flame length that can be expected given nominal burning conditions. The terms “moderate” and “severe” are as defined in the potential fire report. This function has one argument; a value for the argument is required since there is no default value.

Argument 1: Code indicating the fire severity and flame type, as follows:
1 = severe fire total flame length in feet
2 = moderate fire total flame length in feet
3 = severe fire surface flame length in feet
4 = moderate fire surface flame length in feet

POTFMORT(a) This function, only available when using the Fire and Fuels Extension, returns the potential fire mortality. This function has one argument; a value for the argument is required since there is no default value.

Argument 1: Code indicating the units of mortality and the fire severity, as follows:
1 = potential severe fire mortality in percent of total basal area
2 = potential moderate fire mortality in percent of total basal area
3 = potential severe fire mortality in cubic foot volume per acre
4 = potential moderate fire mortality in cubic foot volume per acre

POTFTYPE(a) This function, only available when using the Fire and Fuels Extension, returns the fire type code (1 = surface fire, 2 = passive crown fire, 3 = active crown fire, 4 = conditional crown fire) for severe or moderate potential fires, as defined in the potential fire report. This function has one argument; a value for the argument is required since there is no default value.

Argument 1: Code indicating fire severity, as follows:
1 = potential severe fire
2 = potential moderate fire

POTREINT(a) This function, only available when using the Fire and Fuels Extension, returns the reaction intensity in BTU/ft^2/min for severe or moderate potential fires, as defined in the potential fire report. This function has one argument; a value for the argument is required since there is no default value.

Argument 1: Code indicating fire severity, as follows:
1 = potential severe fire
2 = potential moderate fire

POTSRATE(a) This function, only available when using the Fire and Fuels Extension, returns the spread rate in feet/min for severe or moderate potential fires, as defined in the potential fire report. This function has one argument; a value for the argument is required since there is no default value.

Argument 1: Code indicating spread rate type and fire severity, as follows:
1 = surface fire spread rate for a potential severe fire
2 = surface fire spread rate for a potential moderate fire
3 = final spread rate for a potential severe fire, taking any crown fire activity into account
4 = final spread rate for a potential moderate fire, taking any crown fire activity into account

SALVVOL(a,b,c) This function, only available when using the Fire and Fuels Extension, returns the salvage volume removed in total cubic feet per acre (western variants) or merchantable cubic feet per acre (eastern variants). It returns the cumulative volume of all salvage operations scheduled within a cycle. This function has three arguments; values for the arguments are required since there are no default values.

Argument 1: Species code (alpha code, species sequence number, species group name or species group sequence number). Only trees of the specified species or species group will be included. Code a zero (or All) for all species. Numeric species codes are variant specific.

Argument 2: Smallest DBH in inches to be included. Trees with a DBH greater than or equal to this value will be included.

Argument 3: Largest DBH in inches to be included. Trees with a DBH less than this value will be included.

SNAGS(a,b,c,d,e,f,g) This function, available only when using the Fire and Fuels Extension, returns the volume, basal area, or number of snags per acre for a specified subset of the snag list. The function has 7 arguments; values for the first three arguments are required; default values are present for the last four arguments. The general form of the function is as follows:

SNAGS(measurement, species, snag type, lower DBH, upper DBH, lower height, upper height)

Argument 1: Code indicating which measurement is desired, as follows:
1 = number of snags per acre
2 = basal area per acre in snags
3 = total cubic volume per acre in snags

Argument 2: Species code (species alpha code, species sequence number, species group name, or species group sequence number). Only snags of the specified species or species group will be included. Code a zero (or All) for all species. Numeric species codes are variant specific.

Argument 3: Code indicating decay status. Only snags with the specified status will be included, as follows:
0 = both hard and soft snags
1 = hard snags only
2 = soft snags only

Argument 4: Smallest DBH in inches to be included. Trees with a DBH greater than or equal to this value will be included. The default value is 0.0

Argument 5: Largest DBH in inches to be included. Trees with a DBH less than this value will be included. The default value is 999.0

Argument 6: Shortest snag in feet to be included. Trees with a height greater than or equal to this value will be included. The default value is 0.0.

Argument 7: Tallest snag in feet to be included. Trees with a height less than this value will be included. The default value is 999.0.

TREEBIO(a,b,c,d,e,f,g,h) This function, available only when using the Fire and Fuels Extension, supplements information provided in the Fire and Fuels Extension All Fuels Report. It returns estimates of the biomass (dry weight tons per acre) of the specified trees. The specified trees can be live or dead, standing or removed, of a particular species or species group, and of a particular size range (dbh and height). The biomass returned can be the biomass of the stem, the crown (includes foliage), total tree biomass (i.e. stem plus crown), or, in some cases, only the live foliage.

This function has eight arguments; values for the first three arguments are required since there are no default values.

Argument 1: Code indicating standing or removed trees, as follows:
-1 = standing trees
0 = removed trees
1 = both standing and removed trees

Argument 2: Code indicating live or dead trees, as follows:
-1 = dead trees
0 = live trees
1 = both dead and live trees

Argument 3: Code indicating stem or crown biomass, as follows:
-1 = stem biomass
0 = crown biomass (includes foliage)
1 = both stem and crown biomass (includes foliage)
2 = live foliage. Warning: "live foliage" is calculated only for standing, live trees. Requesting "live foliage" with other selections will result in an undefined function.

Argument 4: Species code (alpha code, species sequence number, species group name, or species group sequence number). Only trees of the specified species or species group will be included. Code a zero (or All) for all species. Numeric species codes are variant specific.

Argument 5: Smallest DBH in inches to be included. Trees with a DBH greater than or equal to this value will be included. The default value is 0.0.

Argument 6: Largest DBH in inches to be included. Trees with a DBH less than this value will be included. The default value is 999.0.

Argument 7: Shortest tree in feet to be included. Trees with a height greater than or equal to this value will be included. The default value is 0.0.

Argument 8: Tallest tree in feet to be included. Trees with a height less than this value will be included. The default value is 999.0.

Chapter 4
Variant Descriptions

Abstract: The Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) simulates fuel dynamics and potential fire behavior over time, in the context of stand development and management. This chapter documents differences between geographic variants of FFE. It is a companion document to the FFE "Model Description" and "User's Guide". People who use FFE variants can use this document to learn about the unique features of each geographic variant.

Keywords: FVS, FFE, forest fire, stand dynamics, snags, down woody debris.

4.1 Introduction

The Fire and Fuels Extension (FFE) has been developed for all of the Forest Vegetation Simulator (FVS) variants. Northern Idaho was the first variant developed and is considered the "base variant" as described in the FFE Model Description and User's Guide. The Model Description document provides an in-depth look into the logic and parameters of that variant. As new variants have been developed, logic and parameter modifications were made to the NI variant in order to model fire effects in the regions covered by the new variants. The modifications were based on workshops and consultations with scientists and other fire experts familiar with each variant's region. Many revisions were based on "expert knowledge" and unpublished information. References are included for modifications based on published information.

The user can modify many of the model processes, for instance snag dynamics. Some of the keywords are identified in this section; however, all of the user keywords are described in Chapter 3 User's Guide / Keyword Manual.

The purpose of this document is to describe the parameterization differences and, where applicable, logical modifications made to the NI variant in order to make the FFE model fire effects appropriately in other variants of the Fire and Fuels Extension to FVS.

4.2 Alaska (AK)

4.2.1 Tree Species

The Alaska variant models the 21 tree species shown in Table 4.2.1. Two additional categories, ‘other hardwood’and ‘other softwood’, are modeled using black cottonwood and white spruce, respectively.

Table 4.2.1 - Tree species simulated by the Alaska variant.

Common Name	Scientific Name	Mapped to in FFE
Pacific silver fir	*Abies amabilis*	
subalpine fir	*Abies lasiocarpa*	
Alaska cedar	*Callitropsis nootkatensis*	
tamarack	*Larix laricina*	*= subalpine larch*
white spruce	*Picea glauca*	
hybrid spruce	*Picea lutzii*	*= white spruce*
black spruce	*Picea mariana*	*= white spruce*
Sitka spruce	*Picea sitchensis*	
lodgepole pine	*Pinus contorta*	
western redcedar	*Thuja plicata*	
western hemlock	*Tsuga heterophylla*	
mountain hemlock	*Tsuga mertensiana*	
other softwood		*= white spruce*
alder	*Alnus*	*= red alder*
red alder	*Alnus rubra*	
paper birch	*Betula papyrifera*	
resin birch	*Betula neoalaskana*	*= paper birch*
balsam poplar	*Populus balsamifera*	*= black cottonwood*
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus balsamifera ssp. trichocarpa*	
willow	*Salix*	
Scouler’s willow	*Salix scouleriana*	*= willow species*
other hardwood		*= black cottonwood*

4.2.2 Snags

The snag height loss rates were set to 2% a year for all species other than western redcedar and Alaska cedar. Snag height loss is not modeled (i.e. is set to zero) for these two species. These values are based on Hennon and Loopstra (1991) and Hennon and others (2002). Soft snags lose height twice as fast as hard snags.

The snag fall and snag decay predictions are those used in the PN-FFE, which are based on work by Kim Mellen-McLean, regional wildlife ecologist. (These relationships are described in the following document: http://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/R6snags.pdf) In PN-FFE, these rates are based on the plant association code, which is used to estimate a moisture class, temperature class, and other information about slope position and soil depth. The AK variant does not use a habitat type or plant association code, so a cold, wet plant association is assumed, as well as non-shallow soils and a non-ridgetop position.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.2.2 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

4.2.3 Fuels

A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and dead surface fuel. Live herb and shrub fuel load and the initial dead surface fuel load are assigned based on the species with greatest basal area.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using wood density calculated from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999).

Table 4.2.2 - Wood density (ovendry lbs/green ft3) used in the AK-FFE variant.

Species	Density (lbs/ft^3)
Pacific silver fir	24.9
subalpine fir	19.3
Alaska cedar	26.2
tamarack	29.9
white spruce	23.1
hybrid spruce	23.1
black spruce	23.1
Sitka spruce	20.6
lodgepole pine	23.7
western redcedar	19.3
western hemlock	26.2
mountain hemlock	26.2
other softwood	23.1
alder	23.1
red alder	23.1
paper birch	29.9
resin birch	29.9
balsam poplar	19.3
quaking aspen	21.8
black cottonwood	19.3
willow	22.5
Scouler’s willow	22.5
other hardwood	19.3

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for many species in the AK-FFE (Table 4.2.3).

Table 4.2.3 - The crown biomass equations used in the AK-FFE. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
Pacific silver fir	grand fir; Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
Alaska cedar	western redcedar; Brown and Johnston (1976)
tamarack	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
white spruce	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
hybrid spruce	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
black spruce	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Sitka spruce	Engelmann spruce; Brown and Johnston (1976)
lodgepole pine	Brown and Johnston (1976)
western redcedar	Brown and Johnston (1976)
western hemlock	Brown and Johnston (1976)
mountain hemlock	Brown and Johnston (1976)
other softwood	white spruce; Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
alder	Snell and Little (1983)
red alder	Snell and Little (1983)
paper birch	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
resin birch	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
balsam poplar	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
black cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
willow	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Scouler’s willow	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other hardwood	black cottonwood; Jenkins et. al. (2003); Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.2.4. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Values for AK-FFE were predominantly taken from PN-FFE. Values for western redcedar, Alaska cedar, western hemlock, mountain hemlock, and 3”+ material were adjusted based on Hennon and others (2002).

Table 4.2.4 - Life span of live and dead foliage (yr) and dead branches for species modeled in the AK-FFE variant.

	Live	Dead				
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**1 – 3”**	**3”+**
Pacific silver fir	7	2	5	5	15	50
subalpine fir	7	2	5	5	15	50
Alaska cedar	5	5	15	15	30	55
tamarack	1	1	5	5	15	50
white spruce	6	2	5	5	10	50
hybrid spruce	6	2	5	5	10	50
black spruce	6	2	5	5	10	50
Sitka spruce	5	2	5	5	15	50
lodgepole pine	3	2	5	5	15	50
western redcedar	5	5	15	15	30	55
western hemlock	4	1	5	5	15	50
mountain hemlock	5	1	5	5	15	50
other softwood	6	2	5	5	10	50
alder	1	1	10	15	15	50
red alder	1	1	10	15	15	50
paper birch	1	1	10	15	15	50
resin birch	1	1	10	15	15	50
balsam poplar	1	1	10	15	15	50
quaking aspen	1	1	10	15	15	50
black cottonwood	1	1	10	15	15	50
willow	1	1	10	15	15	50
Scouler’s willow	1	1	10	15	15	50
other hardwood	1	1	10	15	15	50

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.2.5). When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.2.5). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on PN-FFE defaults.

Table 4.2.5 - Values (dry weight, tons/acre) for live fuels used in the AK-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
Pacific silver fir	E	0.15	0.1	
	I	0.3	2	
subalpine fir	E	0.15	0.1	
	I	0.3	2	
Alaska cedar	E	0.2	0.2	
	I	0.4	2	
tamarack	E	0.3	0.2	Use Engelmann spruce
	I	0.3	2	
white spruce	E	0.3	0.2	Use Engelmann spruce
	I	0.3	2	
hybrid spruce	E	0.3	0.2	Use Engelmann spruce
	I	0.3	2	
black spruce	E	0.3	0.2	Use Engelmann spruce
	I	0.3	2	
Sitka spruce	E	0.3	0.2	
	I	0.3	2	

Species		Herbs	Shrubs	Notes
lodgepole pine	E	0.2	0.1	
	I	0.4	1	
western redcedar	E	0.2	0.2	
	I	0.4	2	
western hemlock	E	0.2	0.2	
	I	0.4	2	
mountain hemlock	E	0.15	0.2	
	I	0.3	2	
other softwood	E	0.3	0.2	Use Engelmann spruce
	I	0.3	2	
alder	E	0.2	0.2	Use red alder
	I	0.4	2	
red alder	E	0.2	0.2	
	I	0.4	2	
paper birch	E	0.2	0.2	Use red alder
	I	0.4	2	
resin birch	E	0.2	0.2	Use red alder
	I	0.4	2	
balsam poplar	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
quaking aspen	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
black cottonwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
willow	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
Scouler's willow	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other hardwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on the FIA forest type. Default fuel loadings are based on Alaska FIA plot data. (see Table 4.2.6). All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.2.6 – FIA forest type is used to assign default down woody debris (tons/acre) by size class. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

FIA Forest Type	Size Class (in)							
	< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	12-20	Litter	Duff
White spruce (122)	0.06	0.47	0.82	0.60	2.66	2.72	3.75	49.75
black spruce (125)	0.10	0.19	0.88	0.02	0.17	0.00	4.75	49.75
mountain hemlock (270)	0.05	0.16	0.5	0.18	0.40	1.01	1.62	55.33
Alaska yellow cedar (271)	0.03	0.08	0.4	0.26	1.25	3.89	1.45	76.93
lodgepole pine (281)	0.02	0.07	0.14	0.32	0.82	0.28	1.76	55.33
western hemlock (301)	0.09	0.36	1.21	0.63	1.98	9.26	2.00	59.80

FIA Forest Type	Size Class (in)							
	< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	12-20	Litter	Duff
western redcedar (304)	0.05	0.25	0.41	0.31	1.32	1.26	2.43	79.86
sitka spruce (305)	0.07	0.28	1.07	0.83	1.67	8.00	2.42	49.61
cottonwood (703)	0.02	0.17	0.42	0.09	0.83	0.00	8.08	47.03
cottonwood-willow (709)	0.04	0.49	2.11	0.08	0.54	0.00	3.54	52.49
aspen (901)	0.04	0.04	0.44	0.05	0.39	0.00	16.58	67.23
paper birch (902)	0.09	0.43	1.64	0.17	1.76	0.19	13.82	61.51
red alder (911)	0.15	1.50	2.68	0.15	5.62	5.39	2.78	59.80
nonstocked (999)	0.02	0.12	0.82	0.56	1.74	0.81	7.28	46.41
others	0.22	0.47	1.62	0.62	2.88	7.99	5.35	46.41

4.2.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires. The bark thickness multipliers in Table 4.2.7 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.2.7 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species	Multiplier (V_{sp})
Pacific silver fir	0.047	other softwood	0.025
subalpine fir	0.041	alder	0.026
Alaska cedar	0.022	red alder	0.026
tamarack	0.031	paper birch	0.027
white spruce	0.025	resin birch	0.027
hybrid spruce	0.025	balsam poplar	0.040
black spruce	0.032	quaking aspen	0.044
sitka spruce	0.027	black cottonwood	0.044
lodgepole pine	0.028	willow	0.041
western redcedar	0.035	Scouler's willow	0.041
western hemlock	0.040	other hardwood	0.044
mountain hemlock	0.040		

4.2.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5. Default decay rates (Table 4.2.8) are based on values provided by Kim Mellen-McLean, Pacific Northwest Regional wildlife ecologist, for the Pacific Northwest area. A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster. Decay rates vary based on the decay rate class of a species (see Table 4.2.9).

Table 4.2.8 - Default annual loss rates are applied based on size class and decay rate class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate				Proportion of Loss Becoming Duff
	decay class 1	decay class 2	decay class 3	decay class 4	
< 0.25	0.052	0.061	0.073	0.098	0.02
0.25 – 1					
1 – 3					
3 – 6	0.012	0.025	0.041	0.077	
6 – 12					
> 12	0.009	0.018	0.031	0.058	
Litter	0.35	0.40	0.45	0.50	
Duff	0.002	0.002	0.003	0.003	0.0

The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.2.9 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.2.9 - Default wood decay classes used in the AK-FFE variant. Classes are based on the advice of an expert panel at the Dead Wood Decay Calibration workshop organized by Kim Mellen-McLean in July 2003.

Species	Decay Rate Class	Species	Decay Rate Class
Pacific silver fir	3	other softwood	4
subalpine fir	3	alder	4
Alaska cedar	1	red alder	4
tamarack	1	paper birch	4
white spruce	2	resin birch	4
hybrid spruce	2	balsam poplar	4
black spruce	2	quaking aspen	4
sitka spruce	2	black cottonwood	4
lodgepole pine	2	willow	4
western redcedar	1	Scouler's willow	4
western hemlock	2	other hardwood	4
mountain hemlock	2		

4.2.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.2.10) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.2.10 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	4	8	12	16
0.25 – 1.0 in. (10-hr)	4	8	12	16
1.0 – 3.0 in. (100-hr)	5	10	14	18
> 3.0 in. (1000+ -hr)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.2.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. Stand management actions such as thinning and harvesting can abruptly increase fuel loads, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the AK-FFE to follow the third of these four options.

NOTE: Currently AK-FFE does not have a detailed fuel model selection logic. As a result, fuel models are selected based on fuel loading only (Figure 4.2.1). When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.2.1, fuel model 8 becomes a candidate model. When fuel loads are higher, other fuel models (fm 10 – 13) may also become candidates.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by the logic described above. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

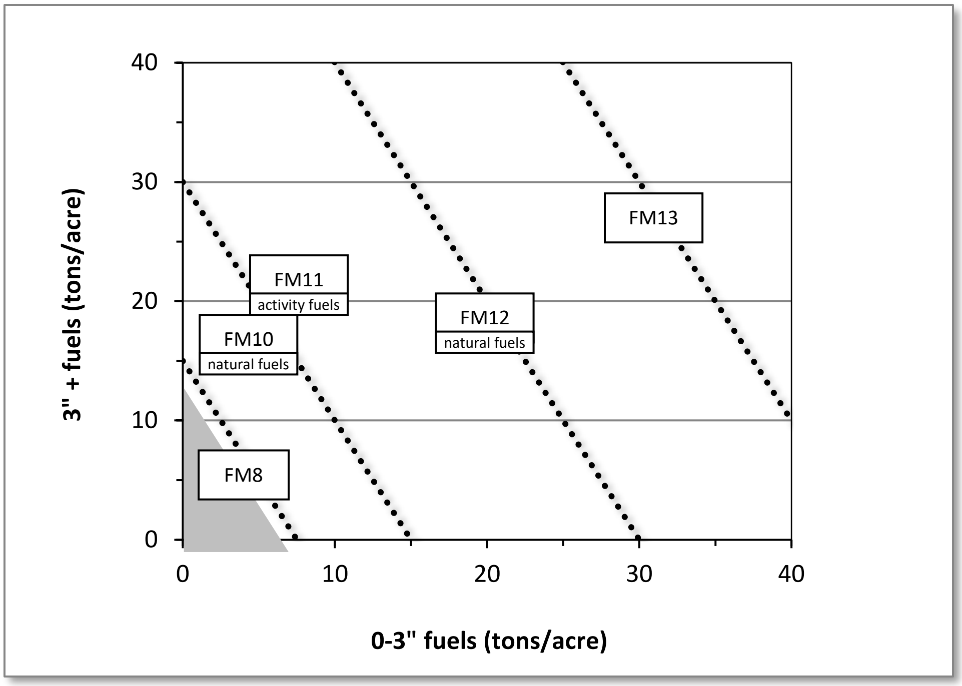


Figure 4.2.1 - At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. At low fuel loads, fuel model 8 is selected.

4.3 Blue Mountains (BM)

4.3.1 Tree Species

The Blue Mountains variant models the 16 tree species shown in Table 4.3.1. Two additional categories, 'other softwood' and 'other hardwood', are modeled using BM ponderosa pine and West Cascades 'other hardwoods' respectively.

Table 4.3.1 - Tree species simulated by the Blue Mountains variant.

Common Name	Scientific Name	Notes
western white pine	*Pinus monticola*	
western larch	*Larix occidentalis*	
Douglas-fir	*Pseudotsuga menziesii*	
grand fir	*Abies grandis*	
mountain hemlock	*Tsuga mertensiana*	
western juniper	*Juniperus occidentalis*	= SO & UT western juniper
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
subalpine fir	*Abies lasiocarpa*	
ponderosa pine	*Pinus ponderosa*	
whitebark pine	*Pinus albicaulis*	= SO & TT whitebark pine
limber pine	*Pinus flexilis*	= UT limber pine
Pacific yew	*Taxus brevifolia*	= SO & WC Pacific yew
Alaska cedar	*Callitropsis nootkatensis*	= WC Alaska cedar
quaking aspen	*Populus tremuloides*	= SO & UT quaking aspen
black cottonwood	*Populus balsamifera ssp. trichocarpa*	= SO & WC black cottonwood
other softwood		= ponderosa pine
other hardwood		= SO & WC other hardwoods

4.3.2 Snags

In the BM variant, the snag dynamics were modified based on the work of Kim Mellen-McLean, region 6 wildlife ecologist. These relationships are described in the following document: http://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/R6snags.pdf

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.3.2 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

4.3.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a 'bare ground' stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a Douglas-fir cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density values calculated from the green specific gravity values from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.3.2 for Douglas-fir is based on 'Douglas-fir west'.

Table 4.3.2 - Wood density (ovendry lb/ft3) used in the BM-FFE variant.

Species	Density (lb/ft^3)
western white pine	22.5
western larch	29.9
Douglas-fir	28.7
grand fir	21.8
mountain hemlock	26.2
western juniper	34.9
lodgepole pine	23.7
Engelmann spruce	20.6
subalpine fir	19.3
ponderosa pine	23.7
whitebark pine	22.5
limber pine	22.5
Pacific yew	26.2
Alaska cedar	26.2
quaking aspen	21.8
black cottonwood	19.3
other softwood	23.7
other hardwood	21.8

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the BM-FFE (Table 4.3.3). Mountain hemlock biomass is based on Gholz and others (1979), using western hemlock equations from Brown and Johnston to partition the biomass and also to provide estimates for trees less than one inch diameter. Western juniper equations are based on a single-stem form.

Table 4.3.3 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
western white pine	Brown and Johnston (1976)
western larch	Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
grand fir	Brown and Johnston (1976)
mountain hemlock	Gholz and others (1979); Brown and Johnston (1976)
western juniper	oneseed juniper; Grier and others (1992)
lodgepole pine	Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
whitebark pine	Brown (1978)
limber pine	use lodgepole pine; Brown and Johnston (1976)
Pacific yew	western redcedar; Brown and Johnston (1976)
Alaska cedar	western larch; Brown and Johnston (1976)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
black cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other softwood	Use ponderosa pine

Species	Species Mapping and Equation Source
other hardwood	aspen; Jenkins et. al. (2003); Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.3.4. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are from Keane and others (1989). Lifespans of western white pine and mountain hemlock are mapped using ponderosa pine, and western hemlock and western redcedar are based on Douglas-fir.

Table 4.3.4 - Life span of live and dead foliage (yr) and dead branches for species modeled in the BM-FFE variant.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
western white pine	4	3	10	15	15
western larch	1	1	10	15	15
Douglas-fir	5	3	10	15	15
grand fir	7	3	10	15	15
mountain hemlock	5	3	10	15	15
western juniper	4	3	5	5	15
lodgepole pine	3	3	10	15	15
Engelmann spruce	6	3	10	10	10
subalpine fir	7	3	10	15	15
ponderosa pine	4	3	10	10	10
whitebark pine	3	3	5	5	15
limber pine	3	3	5	5	15
Pacific yew	7	3	5	5	20
Alaska cedar	5	3	5	5	20
quaking aspen	1	1	5	5	15
black cottonwood	1	1	5	5	15
other softwood	4	3	10	10	10
other hardwood	1	1	5	5	15

Live Herbs and Shrub: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.3.5). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.3.5). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Some species use alternative data sources and are noted below.

Table 4.3.5 - Values (dry weight, tons/acre) for live fuels used in the BM-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
western white pine	E	0.15	0.10	
	I	0.30	2.00	
western larch	E	0.20	0.20	
	I	0.40	2.00	
Douglas-fir	E	0.20	0.20	
	I	0.40	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
mountain hemlock	E	0.20	0.20	Use Douglas-fir

Species		Herbs	Shrubs	Notes
	I	0.40	2.00	
western juniper	E	0.14	0.35	Ottmar and others (1998)
	I	0.10	2.06	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Engelmann spruce	E	0.15	0.20	
	I	0.30	2.00	
subalpine fir	E	0.15	0.20	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	
	I	0.25	0.10	
whitebark pine	E	0.20	0.10	Use BM lodgepole pine
	I	0.40	1.00	
limber pine	E	0.20	0.10	Use BM lodgepole pine
	I	0.40	1.00	
Pacific yew	E	0.20	0.20	Use BM Douglas-fir
	I	0.40	2.00	
Alaska cedar	E	0.20	0.20	Use WC redcedar
	I	0.40	2.00	
quaking aspen	E	0.25	0.25	Use UT quaking aspen; Ottmar and others 2000b
	I	0.18	1.32	
black cottonwood	E	0.25	0.25	Use UT quaking aspen; Ottmar and others 2000b
	I	0.18	1.32	
other softwood	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
other hardwood	E	0.25	0.25	Use UT quaking aspen; Ottmar and others 2000b
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.3.6). As with the live herb and shrub estimates above, some species such as western juniper, quaking aspen, black cottonwood, and other hardwoods use other data sources (Ottmar and others (1998) and Ottmar and others 2000b). If tree canopy cover is <10 percent, the DWD pools are assigned an "initiating" value and if cover is >60 percent they are assign the "established" value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.3.6 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

		Size Class (in)							
Species		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
western larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
mountain hemlock	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
whitebark pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
limber pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Pacific yew	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Alaska cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.1	1.1	3.6	6.0	8.0	6.0	0.5	12.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other softwood	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
other hardwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.3.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.3.7 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.3.7 - Species-specific constants for detemining single bark thickness.

Species	Multiplier (V_{sp})
western white pine	0.035
western larch	0.063
Douglas-fir	0.063
grand fir	0.046
mountain hemlock	0.040
western juniper	0.025
lodgepole pine	0.028
Engelmann spruce	0.036
subalpine fir	0.041
ponderosa pine	0.063
whitebark pine	0.030
limber pine	0.030
Pacific yew	0.025
Alaska cedar	0.022
quaking aspen	0.044
black cottonwood	0.044
other softwood	0.063
other hardwood	0.044

4.3.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5. Default decay rates (Table 4.3.8). are based on values provided by Kim Mellen-McLean, Pacific Northwest Regional wildlife ecologist, for the Pacific Northwest area. They are from published literature with adjustment factors based on temperature and moisture as determined by an expert panel at the Dead Wood Decay Calibration workshop in July 2003. The habitat code set by the **STDINFO** keyword or read in from an input database determines the temperature and moisture class for a stand, as shown in Table 4.3.9.

A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster. The decay rates for individual species vary based on the decay rate class of that species (Table 4.3.10). The decay rates may be modified for each decay class using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.3.8 - Default annual loss rates are applied based on size class, temperature and moisture class, and decay rate class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

	Size Class (inches)	**Annual Loss Rate**				**Proportion of Loss Becoming Duff**
		decay class 1	**decay class 2**	**decay class 3**	**decay class 4**	
hot, mesic	< 0.25	0.113	0.121	0.134	0.168	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.036	0.048	0.063	0.111	
	6 – 12					
	> 12	0.028	0.037	0.049	0.086	
hot, dry	< 0.25	0.057	0.061	0.068	0.085	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.021	0.028	0.049	
	6 – 12					
	> 12	0.014	0.019	0.025	0.044	
moderate, wet	< 0.25	0.103	0.109	0.122	0.153	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.035	0.046	0.061	0.107	
	6 – 12					
	> 12	0.026	0.034	0.045	0.078	
moderate, mesic	< 0.25	0.076	0.081	0.090	0.113	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.032	0.043	0.056	0.099	
	6 – 12					
	> 12	0.019	0.025	0.033	0.058	
moderate, dry	< 0.25	0.067	0.071	0.079	0.099	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.023	0.030	0.040	0.070	
	6 – 12					
	> 12	0.017	0.022	0.029	0.051	
cold, wet	< 0.25	0.092	0.098	0.109	0.137	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.034	0.045	0.059	0.104	
	6 – 12					
	> 12	0.023	0.030	0.040	0.070	
cold, mesic	< 0.25	0.087	0.092	0.103	0.129	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.033	0.044	0.058	0.102	
	6 – 12					
	> 12	0.022	0.029	0.038	0.066	
cold, dry	< 0.25	0.057	0.061	0.068	0.085	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.021	0.028	0.049	
	6 – 12					
	> 12	0.014	0.019	0.025	0.044	
All	Litter	0.65	0.65	0.65	0.65	0.02
	Duff	0.002	0.002	0.002	0.002	0.0

Table 4.3.9 - Habitat type - moisture and temperature regime relationships for the BM-FFE variant. The moisture and temperature classes affect the default decay rates.

Habitat Code	Temperature	Moisture	Habitat Code	Temperature	Moisture	Habitat Code	Temperature	Moisture
CAG111	cold	dry	CLG211	cold	dry	CPS511	hot	dry
CAG4	cold	dry	CLM112	cold	dry	CPS522	moderate	dry
CDG111	moderate	dry	CLM113	moderate	wet	CPS523	moderate	dry
CDG112	moderate	dry	CLM114	cold	wet	CPS524	moderate	dry
CDG121	moderate	dry	CLM312	moderate	wet	CPS525	moderate	dry
CDS611	moderate	mesic	CLM313	moderate	mesic	CWC811	moderate	wet
CDS622	moderate	dry	CLM314	moderate	wet	CWC812	moderate	wet
CDS623	moderate	dry	CLM911	cold	mesic	CWF311	moderate	mesic
CDS624	moderate	dry	CLS411	cold	dry	CWF312	moderate	mesic
CDS634	moderate	dry	CLS415	cold	dry	CWF421	moderate	mesic
CDS711	moderate	dry	CLS416	moderate	dry	CWF431	moderate	mesic
CDS722	moderate	mesic	CLS5	moderate	mesic	CWF512	moderate	wet
CDS821	moderate	dry	CLS511	moderate	mesic	CWF611	moderate	wet
CEF221	cold	mesic	CLS515	moderate	mesic	CWF612	moderate	wet
CEF311	cold	wet	CLS6	moderate	mesic	CWG111	moderate	dry
CEF331	cold	mesic	CMS131	cold	dry	CWG112	moderate	dry
CEF411	cold	dry	CMS231	cold	dry	CWG113	moderate	dry
CEM111	cold	wet	CPG111	hot	dry	CWG211	moderate	mesic
CEM221	cold	wet	CPG112	hot	dry	CWS211	moderate	mesic
CEM222	cold	mesic	CPG131	hot	dry	CWS212	moderate	mesic
CEM311	cold	wet	CPG132	hot	dry	CWS321	moderate	dry
CEM312	cold	wet	CPG221	moderate	dry	CWS322	moderate	dry
CES131	cold	mesic	CPG222	moderate	dry	CWS412	moderate	mesic
CES221	cold	mesic	CPM111	moderate	dry	CWS541	moderate	wet
CES311	cold	mesic	CPS131	hot	dry	CWS811	cold	dry
CES314	cold	mesic	CPS221	moderate	dry	CWS812	moderate	mesic
CES315	cold	mesic	CPS222	moderate	dry	CWS912	moderate	wet
CES411	cold	dry	CPS226	hot	dry	HQM121	moderate	mesic
CES414	cold	mesic	CPS232	moderate	dry	HQM411	moderate	mesic
CES415	cold	dry	CPS233	hot	dry	HQS221	hot	mesic
CLF211	moderate	mesic	CPS234	hot	dry			

Table 4.3.10 - Default wood decay classes used in the BM-FFE variant. Classes are based on the advice of an expert panel at the Dead Wood Decay Calibration workshop organized by Kim Mellen-McLean in July 2003.

Species	Decay Class
western white pine	1
western larch	1
Douglas-fir	1
grand fir	3
mountain hemlock	2
western juniper	1
lodgepole pine	2
Engelmann spruce	2
subalpine fir	3
ponderosa pine	3
whitebark pine	1
limber pine	1
Pacific yew	1
Alaska cedar	1
quaking aspen	4
black cottonwood	4
other softwoods	3
other hardwoods	4

4.3.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.3.11) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.3.11 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	4	8	12	16
0.25 – 1.0 in. (10-hr)	4	8	12	16
1.0 – 3.0 in. (100-hr)	5	10	14	18
> 3.0 in. (1000+ -hr)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.3.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger ‘Activity Fuels’ conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the BM-FFE to follow the third of these four options. The fuel model logic for the BM variant is based on stand classification tables provided by Les Holsapple (USFS, Pendleton, OR (pers. comm., 2001)).

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.3.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The stand classificationsystem shown in Table 4.3.12 and the flow diagrams in Figure 4.3.2 define which low fuel model(s) will become candidates.

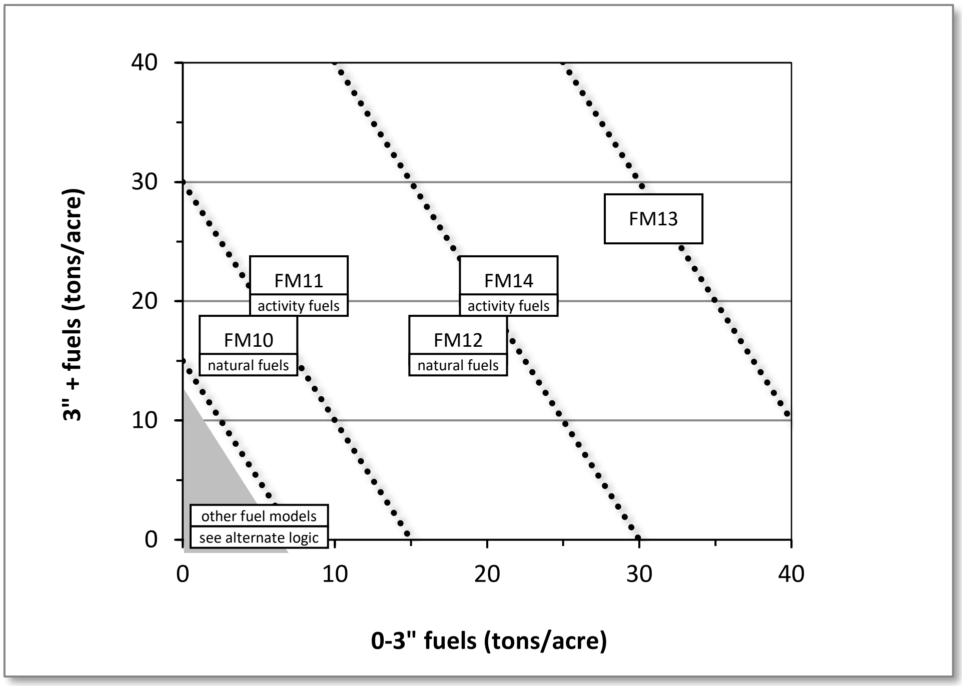


Figure 4.3.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.3.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

Figure 4.3.2 uses size class, canopy cover of the dominant canopy layer and canopy cover in the canopy layers, to assign stands to a single fuel model. To implement the logic of Table 4.3.12 and Figure 4.3.2, two additional processing steps are made. The first step uses a simplified and hardwired version of the FVS stand structure logic (Crookston and Stage 1999) to provide estimates of canopy cover in up to two vertical layers of the stand. The second step begins by classifying the stand into one of the 13 size class codes shown in Table 4.3.12.

Table 4.3.12 - Size classes used in the BM-FFE fuel model selection logic.

Code	Notes
1	Seedlings; trees less than 1 inch DBH
2	Seedlings and saplings mixed
3	Saplings; trees 1 – 4.9” DBH
4	Saplings and poles mixed
5	Poles; trees 5 – 8.9” mixed
6	Poles and small trees mixed
6.5	Small trees 9 – 14.9” DBH
7	Small trees 9 – 20.9” DBH
7.5	Small trees 15 – 20.9” DBH
8	Small and medium trees mixed
9	Medium trees 21 – 31.9” DBH
10	Medium and large trees mixed
11	Large trees 32 – 47.9” DBH

As stand structure changes with time or management, the classification of the dominant size class may also change. This can lead to abrupt changes in the fuel model selection. To smooth out these discontinuities, the sample treelist is further processed by repeatedly classifying the stand based on adding a uniform random deviate with a range equal to +/–20% of the diameter of each tree. This is repeated 50 times, potentially generating more than one size classification.

When the classification weights are taken into the fuel model selection, the fuel model selection varies more smoothly as class boundaries are approached.

Introducing gradual transitions at all the logical breakpoints of the fuel model selection diagram also supports smoother transitions between fuel models. These transitions begin 5% below the nominal breakpoint for dominant overstory, percent total canopy cover (CC), percent lower canopy (CCA) and percent upper canopy (CCB).

In the accompanying diagram showing the BM fuel model logic, PP and DF refer to the percentage of stand basal area in ponderosa pine and Douglas-fir respectively. The size categories referred to in Table 4.3.12 are abbreviated as 'SZ'.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.3.1 or Figure 4.3.2. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

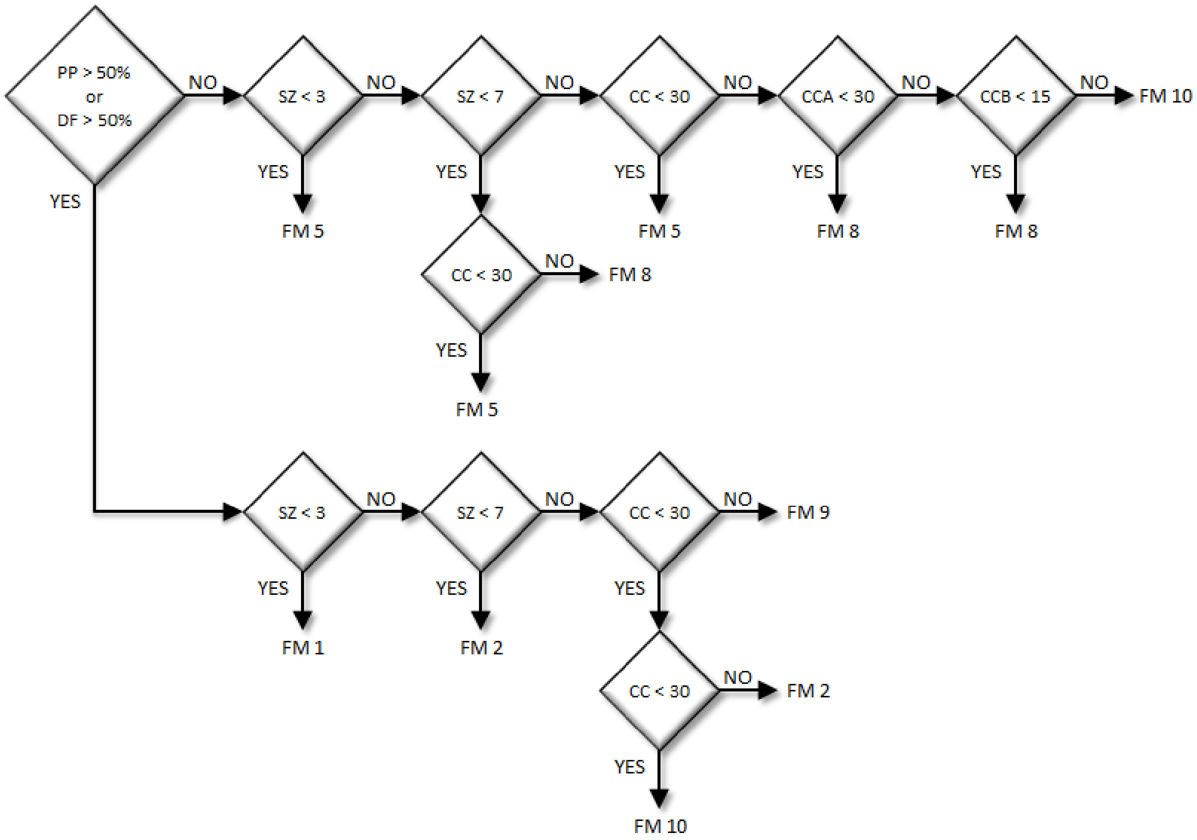


Figure 4.3.2 - Logic for modeling fire at "low" fuel loads in the BM-FFE variant.

4.4 Inland California and Southern Cascades (CA)

4.4.1 Tree Species

The Inland California and Southern Cascades variant models the 48 tree species shown in Table 4.4.1. Two additional categories, ‘other hardwood’ and ‘other softwood’ are modeled using California black oak and ponderosa pine, respectively.

Table 4.4.1 - Tree species simulated by the Inland California and Southern Cascades variant.

Common Name	Scientific Name	Notes
Port Orford cedar	*Chamaecyparis lawsoniana*	
incense cedar	*Calocedrus decurrens*	
western redcedar	*Thuja plicata*	
white fir	*Abies concolor*	
California red fir	*Abies magnifica*	
Shasta red fir	*Abies shastensis*	
Douglas-fir	*Pseudotsuga menziesii*	
western hemlock	*Tsuga heterophylla*	
mountain hemlock	*Tsuga mertensiana*	
whitebark pine	*Pinus albicaulis*	
knobcone pine	*Pinus attenuata*	
lodgepole pine	*Pinus contorta*	
Coulter pine	*Pinus coulteri*	
limber pine	*Pinus flexilis*	
Jeffrey pine	*Pinus jeffreyi*	
sugar pine	*Pinus lambertiana*	
western white pine	*Pinus monticola*	
ponderosa pine	*Pinus ponderosa*	
Monterey pine	*Pinus radiata*	
California foothill pine	*Pinus sabiniana*	
western juniper	*Juniperus occidentalis*	
Brewer spruce	*Picea breweriana*	
giant sequoia	*Sequoiadendron giganteum*	
Pacific yew	*Taxus brevifolia*	
California live oak	*Quercus agrifolia*	
canyon live oak	*Quercus chrysolepsis*	
blue oak	*Quercus douglasii*	
Engelmann oak	*Quercus engelmanni*	
Oregon white oak	*Quercus garryana*	
California black oak	*Quercus kelloggii*	
valley oak	*Quercus lobata*	
interior live oak	*Quercus wislizenii*	
bigleaf maple	*Acer macrophyllum*	
California buckeye	*Aesculus californica*	
red alder	*Alnus rubra*	
Pacific madrone	*Arbutus menziesii*	
giant chinquapin	*Chrysolepis chrysophylla* var. *chrysophylla*	
Pacific dogwood	*Cornus nuttallii*	
Oregon ash	*Fraxinus latifolia*	
walnut	*Juglans*	
tanoak	*Lithocarpus densiflorus*	
California sycamore	*Platanus racemosa*	
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	
willow	*Salix*	
California nutmeg	*Torreya californica*	
California laurel		
redwood	*Sequioa sempervirens*	

Common Name	Scientific Name	Notes
other softwood		*= ponderosa pine*
other hardwood		*= California black oak*

4.4.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the California variants workshop. A complete description of the Snag Submodel is provided in section 2.3.

Three variables are used to modify the Snag Submodel for the different species in the NC-FFE variant:

- a multiplier to modify the species' fall rate;
- the maximum number of years that snags will remain standing; and
- a multiplier to modify the species' height loss rate.

These variables are summarized in Table 4.4.2 and Table 4.4.3.

Unlike the some other FFE variants, snags in the CA-FFE do not decay from a hard to soft state. Users can initialize soft snags using the **SNAGINIT** keyword if they wish, but these initialized soft snags will eventually disappear as they are removed by snag fall. In addition, snags lose height only until they are reduced to half the height of the original live tree. The maximum standing lifetime is set to 50 years for most hardwood snag species and to 100 years for most softwoods.

Table 4.4.2 - Default snag fall, snag height loss and soft-snag characteristics for 20" DBH snags in the CA-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.4.3.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - -	- Years -	- - - - - - - - - -	
Port Orford cedar	25	150	20	–
incense cedar	45	100	20	–
western redcedar	25	150	20	–
white fir	35	100	20	–
California red fir	35	100	20	–
Shasta red fir	35	100	20	–
Douglas-fir	35	100	20	–
western hemlock	25	100	20	–
mountain hemlock	25	100	20	–
whitebark pine	25	100	20	–
knobcone pine	25	100	20	–
lodgepole pine	25	100	20	–
Coulter pine	25	100	20	–
limber pine	25	100	20	–
Jeffrey pine	25	100	20	–
sugar pine	25	100	20	–
western white pine	25	100	20	–
ponderosa pine	25	100	20	–
Monterey pine	25	100	20	–
California foothill pine	25	100	20	–
western juniper	45	150	20	–
Brewer spruce	25	100	20	–
giant sequoia	45	150	20	–
Pacific yew	45	100	20	–
California live oak	20	50	20	–

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
canyon live oak	20	50	20	–
blue oak	20	50	20	–
Engelmann oak	20	50	20	–
Oregon white oak	20	50	20	–
California black oak	20	50	20	–
valley oak	20	50	20	–
interior live oak	20	50	20	–
bigleaf maple	20	50	20	–
California buckeye	20	50	20	–
red alder	20	50	20	–
Pacific madrone	20	50	20	–
giant chinquapin	20	50	20	–
Pacific dogwood	20	50	20	–
Oregon ash	20	50	20	–
walnut	20	50	20	–
tanoak	20	50	20	–
California sycamore	20	50	20	–
quaking aspen	20	50	20	–
black cottonwood	20	50	20	–
willow	20	50	20	–
California nutmeg	20	50	20	–
California laurel	20	50	20	–
redwood	45	150	30	–
other softwood	25	100	20	–
other hardwood	20	50	20	–

All species: soft snags do not normally occur; height loss stops at 50% of original height.

Table 4.4.3 - Default snag fall, snag height loss and soft-snag multipliers for the CA-FFE. These parameters result in the values shown in Table 4.4.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
Port Orford cedar	1.24	1.0	–
incense cedar	0.69	1.0	–
western redcedar	1.24	1.0	–
white fir	0.89	1.0	–
California red fir	0.89	1.0	–
Shasta red fir	0.89	1.0	–
Douglas-fir	0.89	1.0	–
western hemlock	1.24	1.0	–
mountain hemlock	1.24	1.0	–
whitebark pine	1.24	1.0	–
knobcone pine	1.24	1.0	–
lodgepole pine	1.24	1.0	–
Coulter pine	1.24	1.0	–
limber pine	1.24	1.0	–
Jeffrey pine	1.24	1.0	–
sugar pine	1.24	1.0	–
western white pine	1.24	1.0	–
ponderosa pine	1.24	1.0	–
Monterey pine	1.24	1.0	–
California foothill pine	1.24	1.0	–
western juniper	0.69	1.0	–
Brewer spruce	0.69	1.0	–
giant sequoia	0.69	1.0	–
Pacific yew	0.69	1.0	–
California live oak	1.55	1.0	–
canyon live oak	1.55	1.0	–
blue oak	1.55	1.0	–
Engelmann oak	1.55	1.0	–

Species	Snag Fall	Height loss	Hard-to-Soft
Oregon white oak	1.55	1.0	–
California black oak	1.55	1.0	–
valley oak	1.55	1.0	–
interior live oak	1.55	1.0	–
bigleaf maple	1.55	1.0	–
California buckeye	1.55	1.0	–
red alder	1.55	1.0	–
Pacific madrone	1.55	1.0	–
giant chinquapin	1.55	1.0	–
Pacific dogwood	1.55	1.0	–
Oregon ash	1.55	1.0	–
walnut	1.55	1.0	–
tanoak	1.55	1.0	–
California sycamore	1.55	1.0	–
quaking aspen	1.55	1.0	–
black cottonwood	1.55	1.0	–
willow	1.55	1.0	–
California nutmeg	1.55	1.0	–
California laurel	1.55	1.0	–
redwood	0.69	1.0	–
other softwood	1.24	1.0	–
other hardwood	1.55	1.0	–

All species: soft snags do not normally occur; height loss stops at 50% of original height.

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.4.4 are used to convert volume to biomass.

4.4.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density calculated from Table 4-3a and Equation 3-5 of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.4.4 for Douglas-fir is based on ‘Douglas-fir Interior west’; whitebark pine and limber pine are based on western white pine; knobcone pine, Coulter pine, Monterey pine, gray pine are based on lodgepole pine and ponderosa pine; Jeffrey pine is based on sugar pine; Brewer spruce is based on Engelmann spruce; Pacific yew is based on baldcypress; coast live oak, canyon live oak and interior live oak are based on live oak; blue oak, Engelmann oak, Oregon white oak, valley white oak and California buckeye are based on white oak; Pacific madrone, giant chinquapin and California laurel are based on tanoak; and Pacific dogwood is based on bigleaf maple.

Table 4.4.4 - Wood density (overndry lb/ft^3) used in the CA-FFE variant.

Species	Density (lb/ft^3)	Species	Density (lb/ft^3)
Port Orford cedar	24.3	canyon live oak	49.9
incense cedar	21.8	blue oak	37.4
western redcedar	19.3	Engelmann oak	37.4
white fir	23.1	Oregon white oak	37.4
California red fir	22.5	California black oak	34.9
Shasta red fir	22.5	valley white oak	37.4
Douglas-fir	28.7	interior live oak	49.9
western hemlock	26.2	bigleaf maple	27.4
mountain hemlock	26.2	California buckeye	37.4
whitebark pine	22.5	red alder	23.1
knobcone pine	23.7	Pacific madrone	36.2
lodgepole pine	23.7	giant chinquapin	36.2
Coulter pine	23.7	Pacific dogwood	27.4
limber pine	22.5	Oregon ash	31.2
Jeffrey pine	21.2	walnut	31.8
sugar pine	21.2	tanoak	36.2
western white pine	22.5	California sycamore	28.7
ponderosa pine	23.7	quaking aspen	21.8
Monterey pine	23.7	black cottonwood	19.3
California foothill pine	23.7	willow	22.5
western juniper	34.9	California nutmeg	34.9
Brewer spruce	20.6	California laurel	36.2
giant sequoia	21.2	redwood	21.2
Pacific yew	26.2	other softwoods	34.9
California live oak	49.9	other hardwoods	34.9

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the CA-FFE. Some species mappings are used, as shown below in Table 4.4.5.

Table 4.4.5 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
Port Orford cedar	western redcedar (Brown and Johnston 1976)
incense-cedar	based on western redcedar (Brown and Johnston 1976)
western redcedar	Brown and Johnston 1976
white fir	grand fir (Brown and Johnston 1976)
California red fir	grand fir (Brown and Johnston 1976)
Shasta red fir	grand fir (Brown and Johnston 1976)
Douglas-fir	Brown and Johnston 1976
western hemlock	Brown and Johnston 1976
mountain hemlock	western hemlock (Brown and Johnston 1976); Gholz and others (1979)
whitebark pine	Brown and Johnston 1976
knobcone pine	lodgepole pine (Brown and Johnston 1976)
lodgepole pine	Brown and Johnston 1976
Coulter pine	lodgepole pine (Brown and Johnston 1976)
limber pine	lodgepole pine (Brown and Johnston 1976)
Jeffrey pine	western white pine (Brown and Johnston 1976)
sugar pine	western white pine (Brown and Johnston 1976)
western white pine	(Brown and Johnston 1976)
ponderosa pine	(Brown and Johnston 1976)
Monterey pine	ponderosa pine (Brown and Johnston 1976)
gray pine	lodgepole pine (Brown and Johnston 1976)
western juniper	oneseed juniper; Grier and others (1992)
Brewer spruce	Engelmann spruce (Brown and Johnston 1976)
giant sequoia	western redcedar, western hemlock (Brown and Johnston 1976)
Pacific yew	western redcedar (Brown and Johnston 1976)
Coast live oak	tanoak (Snell and Little 1983, Snell 1979)

Species	Species Mapping and Equation Source
canyon live oak	tanoak (Snell and Little 1983, Snell 1979)
blue oak	California black oak (Snell and Little 1983; Snell 1979)
Engelmann oak	tanoak (Snell and Little 1983, Snell 1979)
Oregon white oak	California black oak (Snell and Little 1983; Snell 1979)
California black oak	Snell and Little 1983; Snell 1979
valley oak	California black oak (Snell and Little 1983; Snell 1979)
interior live oak	tanoak (Snell and Little 1983, Snell 1979)
bigleaf maple	Snell and Little 1983
California buckeye	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
red alder	Snell and Little 1983
Pacific madrone	Snell and Little 1983
giant chinquapin	tanoak (Snell and Little 1983, Snell 1979)
Pacific dogwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Oregon ash	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
walnut	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
tanoak	Snell and Little 1983, Snell 1979
California sycamore	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
black cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
willow	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
California nutmeg	tanoak (Snell and Little 1983, Snell 1979)
California laurel	tanoak (Snell and Little 1983, Snell 1979)
redwood	western redcedar, western hemlock (Brown and Johnston 1976)
other softwood	ponderosa pine (Brown and Johnston 1976)
other hardwood	California black oak (Snell and Little 1983, Snell 1979)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.4.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. These data are from the values provided at the California variants workshop.

Table 4.4.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the CA-FFE variant.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
Port Orford cedar	4	3	10	15	20
incense cedar	5	1	10	15	20
western redcedar	5	3	10	15	20
white fir	7	3	10	15	15
California red fir	7	3	10	15	15
Shasta red fir	7	3	10	15	15
Douglas-fir	5	3	10	15	15
western hemlock	5	3	10	15	15
mountain hemlock	4	3	10	15	15
whitebark pine	3	3	10	15	15
knobcone pine	4	3	10	15	15
lodgepole pine	3	3	10	15	15
Coulter pine	3	3	10	15	15
limber pine	3	3	10	15	15
Jeffrey pine	3	3	10	15	15
sugar pine	3	3	10	15	15
western white pine	3	3	10	15	15
ponderosa pine	3	3	10	10	10
Monterey pine	3	3	10	15	15
California foothill pine	3	3	10	15	15
western juniper	4	3	10	15	20
Brewer spruce	8	3	10	15	15
giant sequoia	5	3	10	15	20
Pacific yew	7	3	10	15	15
California live oak	1	1	10	15	15

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
canyon live oak	1	1	10	15	15
blue oak	1	1	10	15	15
Engelmann oak	1	1	10	15	15
Oregon white oak	1	1	10	15	15
California black oak	1	1	10	15	15
valley oak	1	1	10	15	15
interior live oak	1	1	10	15	15
bigleaf maple	1	1	10	15	15
California buckeye	1	1	10	15	15
red alder	1	1	10	15	15
Pacific madrone	1	1	10	15	15
giant chinquapin	1	1	10	15	15
Pacific dogwood	1	1	10	15	15
Oregon ash	1	1	10	15	15
walnut	1	1	10	15	15
tanoak	1	1	10	15	15
California sycamore	1	1	10	15	15
quaking aspen	1	1	10	15	15
black cottonwood	1	1	10	15	15
willow	1	1	10	15	15
California nutmeg	1	1	10	15	15
California laurel	1	1	10	15	15
redwood	5	3	10	15	20
other softwood	3	3	10	10	10
other hardwood	1	1	10	15	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.4.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.4.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. When more than one species is present, the final estimate is computed by combining the interpolated estimates from the rows (Table 4.4.7) representing the two dominant species. Those two estimates are themselves weighted by the relative amount of the two dominant species. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Hardwood estimates are based on Gambel oak and quaking aspen (Ottmar and others 2000b). Many of the minor species are unlikely to be dominant: In these cases (Port Orford cedar, Monterey pine, gray pine, Pacific yew, California buckeye, red alder, Pacific madrone, Pacific dogwood, Oregon ash, walnut, California sycamore, California nutmeg and California laurel) values of the likely dominant overstory are used. Western juniper values are from Ottmar and others (1998).

Table 4.4.7 - Values (dry weight, tons/acre) for live fuels used in the CA-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		**Herbs**	**Shrubs**	**Notes**
Port Orford cedar	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
incense cedar	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
western redcedar	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
white fir	E	0.15	0.10	grand fir, NI-FFE

Species		Herbs	Shrubs	Notes
	I	0.30	2.00	
California red fir	E	0.15	0.10	grand fir, NI-FFE
	I	0.30	2.00	
Shasta red fir	E	0.15	0.10	grand fir, NI-FFE
	I	0.30	2.00	
Douglas-fir	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
western hemlock	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
mountain hemlock	E	0.15	0.20	subalpine fir, NI-FFE
	I	0.30	2.00	
whitebark pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
knobcone pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
lodgepole pine	E	0.20	0.10	NI-FFE
	I	0.40	1.00	
Coulter pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
limber pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
Jeffrey pine	E	0.20	0.25	ponderosa pine, NI-FFE
	I	0.25	1.00	
sugar pine	E	0.20	0.25	ponderosa pine, NI-FFE
	I	0.25	1.00	
western white pine	E	0.15	0.10	NI-FFE
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	NI-FFE
	I	0.25	1.00	
Monterey pine	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
California foothill pine	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
western juniper	E	0.14	0.35	Ottmar and others (1998)
	I	0.10	2.06	
Brewer spruce	E	0.15	0.20	Engelmann spruce, NI-FFE
	I	0.30	2.00	
giant sequoia	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
Pacific yew	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
California live oak	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
canyon live oak	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	
blue oak	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
Engelmann oak	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
Oregon white oak	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
California black oak	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
valley oak	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
interior live oak	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
bigleaf maple	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	

Species		Herbs	Shrubs	Notes
California buckeye	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
red alder	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
Pacific madrone	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
giant chinquapin	E I	0.25 0.18	0.25 2.00	Use quaking aspen - Ottmar and others 2000b (modified)
Pacific dogwood	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
Oregon ash	E I	0.20 0.25	0.25 1.00	ponderosa pine, NI-FFE
walnut	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
tanoak	E I	0.25 0.18	0.25 2.00	Use quaking aspen - Ottmar and others 2000b (modified)
California sycamore	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
quaking aspen	E I	0.25 0.18	0.25 1.32	Ottmar and others 2000b
black cottonwood	E I	0.25 0.18	0.25 1.32	Use quaking aspen - Ottmar and others 2000b
willow	E I	0.25 0.18	0.25 1.32	Use quaking aspen - Ottmar and others 2000b
California nutmeg	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
California laurel	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
redwood	E I	0.20 0.40	0.20 2.00	Douglas-fir, NI-FFE
other softwood	E I	0.20 0.25	0.20 1.00	ponderosa pine, NI-FFE
other hardwood	E I	0.23 0.55	0.22 0.35	Gambel oak, CR-FFE, Ottmar and others (2000b)

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.4.8). Western juniper values are from Ottmar and others (1998). If tree canopy cover is <10 percent, the DWD pools are assigned an "initiating" value and if cover is >60 percent they are assign the "established" value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. When more than one species is present, the final estimate is computed by combining the interpolated estimates from the rows (Table 4.4.8) representing the two dominant species. Those two estimates are themselves weighted by the relative amount of the two dominant species. All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.4.8 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

		Size Class (in)							
Species		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
Port Orford cedar	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
incense cedar	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
western redcedar	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
California red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Shasta red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
western hemlock	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
whitebark pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
knobcone pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
lodgepole pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Coulter pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
limber pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Jeffrey pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
sugar pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
ponderosa pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
Monterey pine	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California foothill pine	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
western juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0
Brewer spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
giant sequoia	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Pacific yew	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California live oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
canyon live oak	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
blue oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
Engelmann oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
Oregon white oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
California black oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
valley oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
interior live oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
bigleaf maple	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California buckeye	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
red alder	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Pacific madrone	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
giant chinquapin	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
Pacific dogwood	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Oregon ash	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
walnut	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
tanoak	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
California sycamore	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
willow	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
California nutmeg	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California laurel	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
redwood	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
other softwood	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
other hardwood	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0

4.4.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.4.9 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.4.9 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species	Multiplier (V_{sp})
Port Orford cedar	0.081	canyon live oak	0.024
incense cedar	0.060	blue oak	0.033
western redcedar	0.035	Engelmann oak	0.059
white fir	0.048	Oregon white oak	0.029
California red fir	0.039	California black oak	0.030
Shasta red fir	0.039	valley oak	0.043
Douglas-fir	0.063	interior live oak	0.034

Species	Multiplier (V_{sp})	Species	Multiplier (V_{sp})
western hemlock	0.35	bigleaf maple	0.024
mountain hemlock	0.40	California buckeye	0.036
whitebark pine	0.030	red alder	0.026
knobcone pine	0.030	Pacific madrone	0.062
lodgepole pine	0.028	giant chinquapin	0.045
Coulter pine	0.063	Pacific dogwood	0.062
limber pine	0.030	Oregon ash	0.042
Jeffrey pine	0.068	walnut	0.041
sugar pine	0.072	tanoak	0.052
western white pine	0.035	California sycamore	0.033
ponderosa pine	0.063	quaking aspen	0.044
Monterey pine	0.030	black cottonwood	0.044
California foothill pine	0.033	willow	0.041
western juniper	0.025	California nutmeg	0.025
Brewer spruce	0.025	California laurel	0.026
giant sequoia	0.081	redwood	0.081
Pacific yew	0.025	other softwood	0.063
California live oak	0.050	other hardwood	0.030

4.4.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5. Default decay rates differ for the Region 5 (California, Table 4.4.10) and Region 6 (Oregon, Table 4.4.12) portions of CA-FFE. Decay rates for California stands were revised at a California variants workshop (Stephanie Rebain, pers. comm., February 2003), based on the decay rates used in the Sierra Nevada Framework. These base decay rates are then modified based on the R5 site class code (Table 4.4.11). Decay rates for Oregon stands are based on values provided by Kim Mellen-McLean, Pacific Northwest Regional wildlife ecologist. They are from published literature with adjustment factors based on temperature and moisture as determined by an expert panel at the Dead Wood Decay Calibration workshop in July 2003. The habitat code set by the **STDINFO** keyword or read in from an input database determines the temperature and moisture class for a stand, as show in Table 4.4.13.

A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster. The decay rates for individual species vary based on the decay class of that species (Table 4.4.14) in the R6 portion of this variant. The decay rates may be modified for each decay class using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.4.10 - Default annual loss rates are applied based on size class for the Region 5 (California) portion of the CA-FFE. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.025	0.02
0.25 – 1		
1 – 3		
3 – 6	0.0125	
6 – 12		
> 12		
Litter	0.65	
Duff	0.002	0.0

Table 4.4.11 - The CA-FFE modifies default decay rate (Table 4.4.10) using the R5 Site Code to improve simulated decomposition. Lower Site Codes indicate moister sites.

R5 Site Class	Multiplier
0	1.5
1	1.5
2	1.0
3	1.0
4	1.0
5+	0.5

Table 4.4.12 - Default annual loss rates are applied based on size class, temperature and moisture class, and decay rate class for the Region 6 (Oregon) portion of CA-FFE. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster

	Size Class (inches)	**Annual Loss Rate**				**Proportion of Loss Becoming Duff**
		decay class 1	**decay class 2**	**decay class 3**	**decay class 4**	
hot, mesic	< 0.25	0.113	0.121	0.134	0.168	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.036	0.048	0.063	0.111	
	6 – 12					
	> 12	0.028	0.037	0.049	0.086	
hot, dry	< 0.25	0.057	0.061	0.068	0.085	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.021	0.028	0.049	
	6 – 12					
	> 12	0.014	0.019	0.025	0.044	
moderate, wet	< 0.25	0.103	0.109	0.122	0.153	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.035	0.046	0.061	0.107	
	6 – 12					
	> 12	0.026	0.034	0.045	0.078	
moderate, mesic	< 0.25	0.076	0.081	0.090	0.113	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.032	0.043	0.056	0.099	
	6 – 12					
	> 12	0.019	0.025	0.033	0.058	
moderate, dry	< 0.25	0.067	0.071	0.079	0.099	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.023	0.030	0.040	0.070	
	6 – 12					
	> 12	0.017	0.022	0.029	0.051	
cold, wet	< 0.25	0.092	0.098	0.109	0.137	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.034	0.045	0.059	0.104	
	6 – 12					
	> 12	0.023	0.030	0.040	0.070	
cold, mesic	< 0.25	0.087	0.092	0.103	0.129	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.033	0.044	0.058	0.102	
	6 – 12					
	> 12	0.022	0.029	0.038	0.066	
cold, dry	< 0.25	0.057	0.061	0.068	0.085	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.021	0.028	0.049	
	6 – 12					
	> 12	0.014	0.019	0.025	0.044	
All	Litter	0.50	0.50	0.50	0.50	0.02
	Duff	0.002	0.002	0.002	0.002	0.0

Table 4.4.13 - Habitat type - moisture and temperature regime relationships for the CA-FFE variant. The moisture and temperature classes affect the default decay rates for the Region 6 (Oregon) portion of this variant.

Habitat Type Code	Temperature	Moisture	Habitat Type Code	Temperature	Moisture
CDC411	moderate	mesic	CWC221	moderate	mesic
CDC412	moderate	dry	CWC231	moderate	dry
CDC421	moderate	dry	CWC232	hot	dry
CDC431	moderate	mesic	CWC233	hot	dry
CDC432	moderate	mesic	CWC241	hot	dry
CDC511	hot	dry	CWC521	cold	wet
CDC521	moderate	dry	CWC522	moderate	wet
CDF911	hot	dry	CWC523	moderate	mesic
CDH111	moderate	mesic	CWC611	moderate	mesic
CDH112	moderate	mesic	CWC612	moderate	mesic
CDH121	moderate	mesic	CWC721	cold	mesic
CDH131	moderate	mesic	CWC722	cold	mesic
CDH141	moderate	mesic	CWC723	cold	mesic
CDH142	hot	dry	CWC811	moderate	mesic
CDH511	moderate	mesic	CWC911	cold	wet
CDS111	hot	dry	CWF911	moderate	mesic
CDS112	hot	dry	CWH312	moderate	mesic
CDS511	moderate	mesic	CWH413	cold	mesic
CDS521	moderate	dry	CWH511	cold	wet
CHC111	moderate	wet	CWH521	moderate	mesic
CHC412	moderate	wet	CWH522	moderate	mesic
CHC461	moderate	mesic	CWH531	moderate	dry
CHC611	moderate	mesic	CWS331	moderate	mesic
CHH111	moderate	wet	CWS523	moderate	mesic
CHH511	moderate	mesic	HTC111	moderate	mesic
CHS131	moderate	mesic	HTC211	moderate	mesic
CHS331	moderate	mesic	HTC311	moderate	mesic
CMF211	cold	mesic	HTC411	moderate	mesic
CPC411	moderate	dry	HTC412	moderate	mesic
CPC511	moderate	mesic	HTH111	hot	dry
CPG141	moderate	dry	HTH112	hot	dry
CPH411	moderate	dry	HTH211	moderate	wet
CPS321	moderate	dry	HTH311	moderate	mesic
CPS611	moderate	dry	HTS111	moderate	mesic
CQF111	cold	mesic	HTS112	moderate	mesic
CRF211	cold	wet	HTS221	moderate	mesic
CRF311	moderate	mesic	HTS222	moderate	mesic
CRH111	moderate	mesic	HTS223	moderate	mesic
CRS211	moderate	mesic	HTS311	moderate	mesic
CTH111	cold	mesic	HTS312	hot	dry
CTH211	moderate	wet	HTS321	moderate	mesic
CTS111	moderate	mesic	HTS331	moderate	mesic
CTS112	moderate	mesic	HTS341	moderate	mesic
CTS211	moderate	mesic	HTS411	hot	dry
CTS311	moderate	mesic	HTS511	moderate	mesic

Table 4.4.14 - Default wood decay classes used in the CA-FFE variant. Classes are based on the advice of an expert panel at the Dead Wood Decay Calibration workshop organized by Kim Mellen-McLean in July 2003.

Species	Decay Class	Species	Decay Class
Port Orford cedar	1	canyon live oak	3
incense cedar	1	blue oak	3
western redcedar	1	Engelmann oak	3
white fir	3	Oregon white oak	3
California red fir	3	California black oak	3
Shasta red fir	3	valley oak	3
Douglas-fir	1	interior live oak	3
western hemlock	2	bigleaf maple	4
mountain hemlock	2	California buckeye	4
whitebark pine	1	red alder	4
knobcone pine	2	Pacific madrone	3
lodgepole pine	2	giant chinquapin	3
Coulter pine	3	Pacific dogwood	4
limber pine	1	Oregon ash	4
Jeffrey pine	3	walnut	4
sugar pine	1	tanoak	3
western white pine	1	California sycamore	4
ponderosa pine	3	quaking aspen	4
Monterey pine	2	black cottonwood	4
California foothill pine	3	willow	4
western juniper	1	California nutmeg	4
Brewer spruce	2	California laurel	4
giant sequoia	1	redwood	1
Pacific yew	1	other softwood	3
California live oak	3	other hardwood	3

4.4.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups shown in Table 4.4.15, or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.4.15 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1 hr.)	3	8	12	12
0.25 – 1.0 in. (10 hr.)	4	8	12	12
1.0 – 3.0 in. (100 hr.)	5	10	14	14
> 3.0 in. (1000+ hr.)	10	15	25	25
Duff	15	50	125	125
Live	70	110	150	150

4.4.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are determined in two steps: determination of cover classification and determination of dominant species. The first step uses tree cover attributes classified by the California Wildlife Habitat Relationships (CWHR) system (Mayer and Laudenslayer 1988) shown in Table 4.4.16. The table classifies stands by their canopy cover and the size of the larger trees in the stand, predicting CWHR size class and CWHR density class[1] (the third and fourth columns). Mayer and Laudenslayer's class definitions were modified to

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[1] A BASIC-language function named 'CWHRSizeDensity' was provided at the WS-FFE workshop. This function is incorporated into the CA-FFE with some minor housekeeping modifications.

reflect the tree species, tree size and canopy cover class breakpoints requested at the CA-FFE workshop (Nick Vagle, Rogue River and Siskiyou NF, personal communication). To meet the internal requirements of the CWHR, the largest tree size category provided at the CA-FFE workshop (>32 inches DBH) was merged with the 21–32" category, creating a single >21" category.

Table 4.4.16 - California Wildlife Habitat Relationships, as defined by Mayer and Laudenslayer (1988), with modifications to the tree size and canopy cover class breakpoints for the CA-FFE.

Tree size (DBH in.)	Canopy cover (%)	CWHR Size Class	CWHR Density Class	Stand Description
< 1	< 10	1	–	Seedlings
1 – 5	0 – 10	2	S	Sapling – sparse
1 – 5	11 – 40	2	P	Sapling – open cover
1 – 5	41 – 70	2	M	Sapling – moderate cover
1 – 5	> 70	2	D	Sapling – dense cover
5 – 9	0 – 10	3	S	Pole tree – sparse
5 – 9	11 – 40	3	P	Pole tree – open cover
5 – 9	41 – 70	3	M	Pole tree – moderate cover
5 – 9	> 70	3	D	Pole tree – dense cover
9 – 21	0 – 10	4	S	Small tree – sparse
9 – 21	11 – 40	4	P	Small tree – open cover
9 – 21	41 – 70	4	M	Small tree – moderate cover
9 – 21	> 70	4	D	Small tree – dense cover
> 21	0 – 10	5	S	Med/Lg tree – sparse
> 21	11 – 40	5	P	Med/Lg tree – open cover
> 21	41 – 70	5	M	Med/Lg tree – moderate cover
> 21	> 70	5	D	Med/Lg tree – dense cover
> 21	> 70	6	–	Multi-layer canopy, dense cover

*QMD of the 75 percent largest trees based on basal area.

The CA-FFE modifies the internal CWHR logic slightly, making use of two additional measures internal to the CWHR: unadjusted percent canopy cover and overlap-adjusted percent canopy cover, respectively. The two kinds of canopy estimate are used in combination with the CWHR logic to create weights for the predicted CWHR density class. Each stand's CWHR density class becomes a combination of one or two adjacent classes. Figure 4.4.1 shows how the two measures are used to weight the S, P, M or D classes at each timestep of the simulation. When a point (defined by the two kinds of canopy cover estimate) lies on a dashed line in the figure, that CWHR density class is given a 100% weight. Otherwise, the distance from the point to the nearest dashed lines is used to create weights for the nearest CWHR density classes.

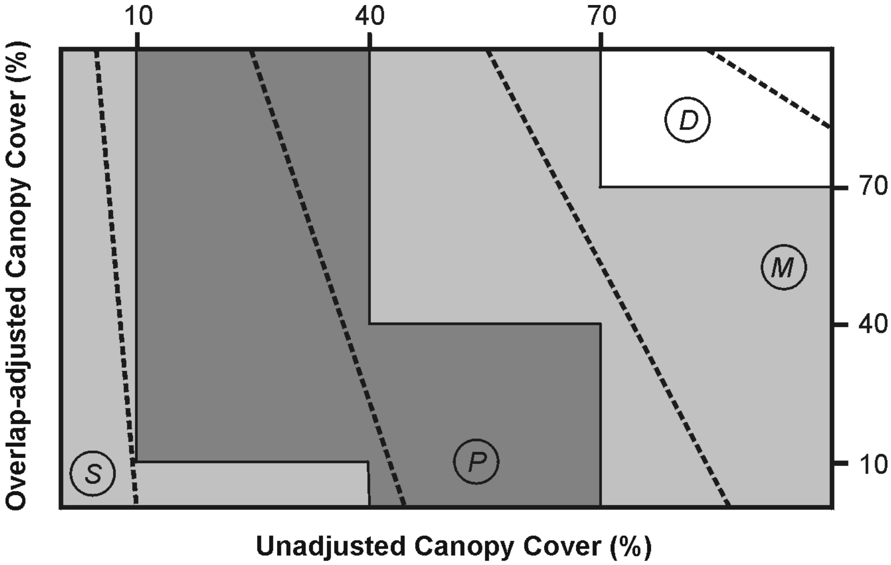


Figure 4.4.1 - Two measures of canopy cover, unadjusted and overlap-adjusted percent canopy cover, are used to derive weighted estimates of the four CWHR density classes. (S = sparse, P = open, M = moderate and D = dense)

The second step determines the dominant species. A species is considered dominant if it comprises more than 80 percent of the stand basal area. The search starts with pine and moves down the column of forest types listed in the leftmost column of Table 4.4.17. If no species is dominant, then fir-mixed conifer is the default cover type.

The rules governing Table 4.4.17 select one or two candidate (usually low) fuel models. These are used along with the high fuels models to select the final set of weighted fuel models. The table has been modified from Landram's original table so that with the exception of the right-most column (mature Size Class 6 stands), cells with fuel model 10 or 12 in the original table have been replaced with fuel model 8. This change was made so that when appropriate, the default FFE fuel model logic (described in section 2.4.8) is not constrained in its selection of a candidate high fuel models: combinations of fuel models 10, 11,12 and 13 may still be selected when fuel loads are high. Finally, in order to give Table 4.4.17 priority, FM10 is removed from the list of candidate models when FM11 has been selected from the table.

In some situations a thinning or disturbance may cause one of the selected fuel models to switch from FM8 or FM9 to FM5. When this happens, the transition to these brush fuel models is modified to simulate a delay in brush ingrowth. In the case where an FM8 or FM9 fuel model is predicted to change to FM5, the change is made over five years, gradually shifting from FM8 or FM9 to FM5.

Finally, flame length is calculated using the weights from above the appropriate fuel models. The **FLAMEADJ** keyword allows users to scale the calculated flame length or override the calculated flame length with a value they choose.

Table 4.4.17 - Fire behavior fuels models for the CA-FFE are determined using forest type and CWHR class, as described in the text. The modeling logic allows one or more fuel models to be selected.

Size Class	**1**	**2**				**3**				**4**				**5**				**6**
Density Class		**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	
Forest Type																		
Pine	5	6	6	6	6	2	2	9	9	2	2	2	9	2	2	9	9	10
Red fir	5	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
White fir – east side	5	5	5	8	8	11	11	11	8	8	8	8	8	8	8	8	8	10
White fir – west side	5	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
Douglas-fir	5	5	5	6	6	6	6	8	8	11	11	9	8	11	11	9	8	10
Hardwoods	5	5	5	6	6	11	11	11	9	9	9	9	9	9	9	9	9	10
Pine mixed – conifer	5	5	5	6	6	6	6	6	9	9	9	8	8	8	8	8	8	10
Fir mixed – conifer	5	5	5	6	6	6	6	6	8	6	6	8	8	6	6	8	8	10
Other softwood	5	5	5	6	6	6	6	6	8	6	6	8	8	6	6	8	8	10

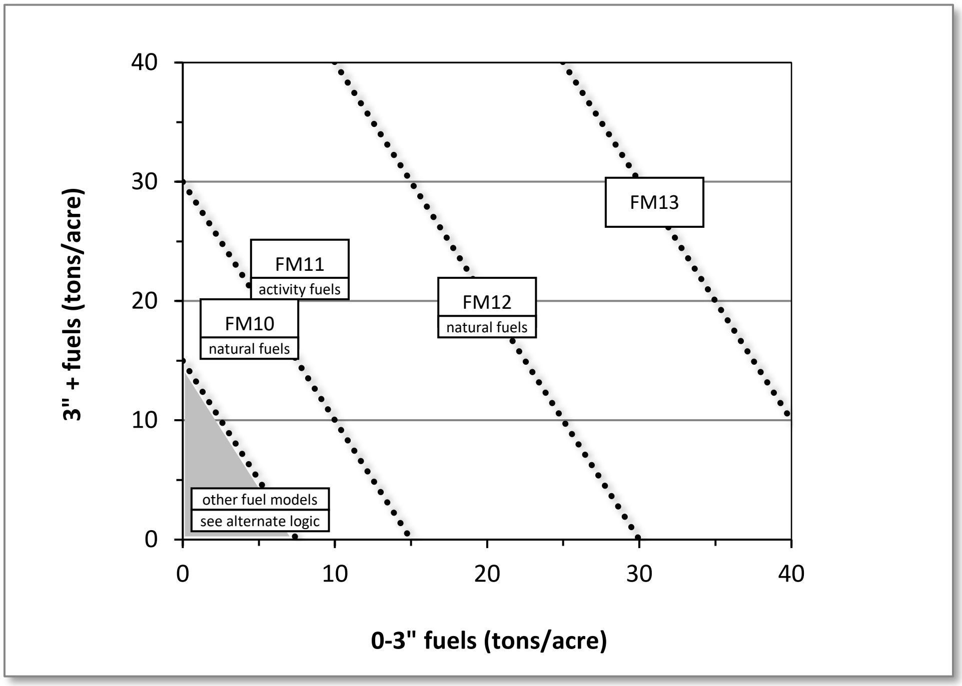


Figure 4.4.2 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.4.17. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

4.5 Central Idaho (CI)

4.5.1 Tree Species

The Central Idaho variant models the 17 tree species shown in Table 4.5.1. Two additional categories, 'other softwood'and 'other hardwood' are modeled using western hemlock and black cottonwood, respectively.

Table 4.5.1 - Tree species simulated by the Central Idaho variant.

Common Name	Scientific Name	Notes
western white pine	*Pinus monticola*	
western larch	*Larix occidentalis*	
Douglas-fir	*Pseudotsuga menziesii*	
grand fir	*Abies grandis*	
western hemlock	*Tsuga heterophylla*	
western redcedar	*Thuja plicata*	
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
subalpine fir	*Abies lasiocarpa*	
ponderosa pine	*Pinus ponderosa*	
whitebark pine	*Pinus albicaulis*	
Pacific yew	*Taxus brevifolia*	
quaking aspen	*Populus tremuloides*	
western juniper	*Juniperus occidentalis*	
curl-leaf mountain mahogany	*Cercocarpus ledifolius*	
limber pine	*Pinus flexilis*	
black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	
other softwood		= mountain hemlock
other hardwood		= black cottonwood

4.5.2 Snags

For western white pine, western larch, Douglas-fir, grand fir, western hemlock, western redcedar, lodgepole pine, Engelmann spruce, subalpine fir, and ponderosa pine, the majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the FFE design workshop. Snag fall parameters for whitebark pine, Pacific yew, quaking aspen, western juniper, curlleaf mountain-mahogany, limber pine, and black cottonwood were taken from other variants. A complete description of the Snag Submodel is provided in section 2.3.

Four variables are used to modify the Snag Submodel for the different species in the NI-FFE variant:

- A multiplier to modify the species' fall rate;
- A multiplier to modify the time required for snags to decay from a "hard" to "soft" state;
- The maximum number of years that snags will remain standing; and
- A multiplier to modify the species' height loss rate.

These variables are summarized in Table 4.5.2 and Table 4.5.3. Snag dynamics are similar to the NI-FFE variant, with the following exceptions:

- western larch, lodgepole pine, Engelmann spruce, subalpine fir and ponderosa pine snags experience no height loss, and their height loss multiplier is set to zero;
- western white pine and western redcedar lose 75 percent of their original height, after which their height does not change; and
- larch and spruce snags >18 inches dbh fall at a rate that is 32% of the rate predicted by Marcot's equation.

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.5.4 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

Table 4.5.2 - Default snag fall, snag height loss and soft-snag characteristics for 20" DBH snags in the CI-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.5.3.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - -	- Years -	- - - - - - - - - -	
western white pine	34	110	76	42
western larch	97§	150	–	42
Douglas-fir	34	75	30	42
grand fir	28	90	20	35
western hemlock	34	150	33	35
western redcedar	103	300	101	35
lodgepole pine	19	35	–	35
Engelmann spruce	81§	100	–	35
subalpine fir	39	40	–	35
ponderosa pine	31	90	–	39
whitebark pine	75	90	–	35
Pacific yew	31	100	30	39
quaking aspen	8	5	–	35
western juniper	31	150	311	35
curl-leaf mountain mahogany	31	90	–	39
limber pine	75	90	30	35
black cottonwood	8	5	–	35
other softwood	34	30	20	35
other hardwood	8	5	–	35

§ This value results from using 32% of the default rate for Douglas-fir and spruce snags >18" DBH, as described in the text.

Table 4.5.3 - Default snag fall, snag height loss and soft-snag multipliers for the CI-FFE. These parameters result in the values shown in Table 4.5.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
western white pine	0.9	0.4	1.1
western larch	1.0§	–	1.1
Douglas-fir	0.9	1.0	1.1
grand fir	1.1	1.5	0.9
western hemlock	0.9	0.9	0.9
western redcedar	0.3	0.3	0.9
lodgepole pine	1.6	–	0.9
Engelmann spruce	1.2§	–	0.9
subalpine fir	0.8	–	0.9
ponderosa pine	1.0	–	1.0
whitebark pine	0.41	–	0.9
Pacific yew	1.0	1.0	1.0
quaking aspen	4.0	–	0.9
western juniper	1.0	0.0978	0.9
curl-leaf mountain mahogany	1.0	1.0	1.0
limber pine	1.0	1.0	1.0
black cottonwood	4.0	–	0.9
other softwood	0.9	1.5	0.9
other hardwood	4.0	–	0.9

§ This value apples to Douglas-fir and spruce snags <18” DBH; see text for details.

4.5.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a Douglas-fir cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density values calculated from the green specific gravity values from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.5.4 for Douglas-fir is based on ‘Douglas-fir Interior north’.

Table 4.5.4 - Wood density (ovendry lb/ft^3) used in the CI-FFE variant.

Species	Density (lb/ft^3)
western white pine	22.5
western larch	29.9
Douglas-fir	28.1
grand fir	21.8
western hemlock	26.2
western redcedar	19.3
lodgepole pine	23.7
Engelmann spruce	20.6
subalpine fir	19.3
ponderosa pine	23.7
whitebark pine	22.5
Pacific yew	26.2
quaking aspen	21.8
western juniper	34.9
curl-leaf mountain mahogany	21.8
limber pine	22.5
black cottonwood	19.3
other softwood	26.2
other hardwood	19.3

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the CI-FFE. Mountain hemlock biomass is based on Gholz and others (1979), using western hemlock equations from Brown and Johnston to partition the biomass and also to provide estimates for trees under one inch diameter.

Table 4.5.5 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
western white pine	Brown and Johnston (1976)
western larch	Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
grand fir	Brown and Johnston (1976)
western hemlock	Brown and Johnston (1976)
western redcedar	Brown and Johnston (1976)
lodgepole pine	Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
whitebark pine	lodgepole pine: Brown and Johnston (1976)
Pacific yew	western redcedar: Brown and Johnston (1976)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
western juniper	oneseed juniper; Grier and others (1992)
curl-leaf mountain mahogany	aspen: Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
limber pine	lodgepole pine: Brown and Johnston (1976)
black cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other softwood	Gholz and others (1979); Brown and Johnston (1976)
other hardwood	cottonwood: Jenkins et. al. (2003); Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.5.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are from Keane and others (1989). Lifespans of western white pine and mountain hemlock are mapped using ponderosa pine, and western hemlock and western redcedar are based on Douglas-fir.

Table 4.5.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the CI-FFE variant.

	Live	**Dead**			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
western white pine	4	2	5	5	15
western larch	1	1	5	5	15
Douglas-fir	5	2	5	5	15
grand fir	7	2	5	5	15
western hemlock	5	2	5	5	15
western redcedar	5	2	5	5	20
lodgepole pine	3	2	5	5	15
Engelmann spruce	6	2	5	5	10
subalpine fir	7	2	5	5	15
ponderosa pine	4	2	5	5	10
whitebark pine	3	2	5	5	15
Pacific yew	7	2	5	5	15
quaking aspen	1	1	5	5	10
western juniper	4	2	10	15	20
curl-leaf mountain mahogany	1	1	5	5	15
limber pine	3	2	5	5	15
black cottonwood	1	1	5	5	10
other softwood	4	2	5	5	15
other hardwood	1	1	5	5	10

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.5.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.5.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Values for quaking aspen and western juniper are from Ottmar and others (2000a, 2000b).

Table 4.5.7 - Values (dry weight, tons/acre) for live fuels used in the CI-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		**Herbs**	**Shrubs**	**Notes**
western white pine	E	0.15	0.10	
	I	0.30	2.00	
western larch	E	0.20	0.20	
	I	0.40	2.00	
Douglas-fir	E	0.20	0.20	
	I	0.40	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
western hemlock	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
western redcedar	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Engelmann spruce	E	0.15	0.20	
	I	0.30	2.00	
subalpine fir	E	0.15	0.20	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	

Species		Herbs	Shrubs	Notes
	I	0.25	0.10	
whitebark pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
Pacific yew	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
quaking aspen	E	0.25	0.25	Ottmar et. al. 2000b
	I	0.18	1.32	
western juniper	E	0.04	0.05	Ottmar et. al. 2000a
	I	0.13	1.63	
curl-leaf mountain mahogany	E	0.25	0.25	
	I	0.18	1.32	
limber pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
black cottonwood	E	0.25	0.25	Use quaking aspen
	I	0.18	1.32	
other softwood	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	
other hardwood	E	0.25	0.25	Use quaking aspen
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.5.8). Values for quaking aspen are from Ottmar and others (2000b). The values for western juniper are from Ottmar and others (2000a), with the litter amounts lowered because the photo series values seemed too high. If tree canopy cover is <10 percent, the DWD pools are assigned an "initiating" value and if cover is >60 percent they are assign the "established" value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.5.8 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
western larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
western hemlock	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western redcedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
whitebark pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Pacific yew	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
western juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
curl-leaf mountain mahogany	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
limber pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other softwood	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
other hardwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.5.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.5.9 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.5.9 - Species-specific constants for determining single bark thickness.

Species	**Multiplier (V_{sp})**
western white pine	0.035
western larch	0.063
Douglas-fir	0.063
grand fir	0.046
western hemlock	0.040
western redcedar	0.035
lodgepole pine	0.028
Engelmann spruce	0.036
subalpine fir	0.041
ponderosa pine	0.063
whitebark pine	0.030
Pacific yew	0.025
quaking aspen	0.044
western juniper	0.025
curl-leaf mountain mahogany	0.044
limber pine	0.030
black cottonwood	0.038
other softwood	0.040
other hardwood	0.038

4.5.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.5.10). Default decay rates on mesic sites are based on Abbott and Crossley (1982). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.5.10 - Default annual loss rates on mesic sites are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.12	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.015	
6 – 12		
> 12		
Litter	0.50	
Duff	0.002	0.0

Decay rates on moist sites are one-third higher than the rates shown in Table 4.5.10; dry sites are one-third lower. The habitat code set by the **STDINFO** keyword determines whether a stand is defined as a moist, mesic or dry site, as shown in Table 4.5.11. These assignments were provided by Kathy Geier-Hayes, USFS Boise, ID (pers. comm., 2001).

Table 4.5.11 - Habitat type – moisture regime relationships for the CI-FFE variant.

Habitat Code	Regime	Habitat Code	Regime	Habitat Code	Regime	Habitat Code	Regime
50	Dry	330	Dry	525	Mesic	691	Mesic
60	Dry	331	Dry	526	Mesic	692	Mesic
70	Dry	332	Dry	527	Mesic	694	Mesic
80	Dry	334	Dry	580	Dry	700	Mesic
100	Dry	340	Dry	585	Dry	705	Dry
120	Dry	341	Dry	590	Mesic	720	Mesic
130	Dry	343	Dry	591	Mesic	721	Mesic
140	Dry	344	Dry	592	Mesic	723	Mesic
160	Dry	360	Dry	593	Mesic	730	Mesic
161	Dry	370	Dry	600	Mesic	731	Dry
162	Dry	371	Dry	605	Moist	732	Mesic
170	Dry	372	Dry	620	Mesic	734	Mesic
190	Dry	375	Dry	621	Mesic	740	Mesic
195	Dry	380	Dry	625	Mesic	745	Dry
200	Mesic	385	Dry	635	Moist	750	Dry
210	Dry	390	Mesic	636	Moist	780	Dry
220	Dry	392	Dry	637	Moist	790	Dry
221	Dry	393	Mesic	638	Mesic	791	Dry
222	Dry	395	Dry	640	Dry	793	Dry
250	Dry	396	Dry	645	Mesic	810	Mesic
260	Mesic	397	Dry	650	Moist	830	Mesic
262	Mesic	398	Dry	651	Moist	831	Mesic
264	Dry	400	Mesic	652	Moist	833	Mesic
265	Dry	410	Moist	654	Mesic	850	Mesic
280	Mesic	440	Mesic	655	Moist	870	Mesic
290	Mesic	490	Moist	660	Mesic	900	Mesic
310	Dry	493	Dry	661	Mesic	905	Dry
313	Dry	500	Mesic	662	Mesic	920	Dry
315	Dry	505	Dry	663	Mesic	940	Mesic
320	Dry	510	Mesic	670	Mesic	955	Dry
323	Dry	511	Mesic	671	Mesic	999	Mesic
324	Dry	515	Mesic	672	Mesic		
325	Dry	520	Mesic	690	Mesic		

The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.5.12 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.5.12 - Default wood decay classes used in the CI-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Class
western white pine	4
western larch	3
Douglas-fir	3
grand fir	4
western hemlock	4
western redcedar	2
lodgepole pine	4
Engelmann spruce	4
subalpine fir	4
ponderosa pine	4
whitebark pine	4
Pacific yew	1
quaking aspen	4
western juniper	2
curl-leaf mountain mahogany	4
limber pine	4
black cottonwood	4
other softwood	4
other hardwood	4

4.5.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.5.13) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.5.13 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1-hr)	4	8	12	16
0.25 – 1.0 in. (10-hr)	4	8	12	16
1.0 – 3.0 in. (100-hr)	5	10	14	18
> 3.0 in. (1000+ -hr)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.5.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger ‘Activity Fuels’ conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or

4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the CI-FFE to follow the third of these four options. The CI-FFE Fuel Model selection logic in the CI-FFE is based on one of the 11 Potential Vegetation Groups shown in Table 4.5.14. The CI habitat code is mapped to one of these groups using Table 4.5.15. Site classification information in Table 4.5.15 was provided by Kathy Geier-Hayes, Fire Ecologist, USFS Boise, ID (pers. comm., 2001).

Table 4.5.14 - Fuel model selection in the CI-FFE variant is based in part on classifying each stand into one of 11 site types.

Potential Vegetation Group	Class
Dry ponderosa pine – xeric Douglas-fir	1
Warm/dry Douglas-fir – moist ponderosa pine	2
Cool moist Douglas-fir	3
Cool dry Douglas-fir	4
Dry grand fir	5
Wet grand fir	6
Warm dry subalpine fir	7
Wet subalpine fir	8
High water table subalpine fir	9
Persistent lodgepole pine	10
High elevation subalpine fir with whitebark pine	11

Table 4.5.15 - Habitat code and corresponding Potential Vegetation Groups (PVG) in the CI-FFE variant.

Habitat Code	PVG	Habitat Code	PVG	Habitat Code	PVG	Habitat Code	PVG
50	10	330	2	525	6	691	7
60	10	331	4	526	6	692	10
70	10	332	4	527§	6	694	11
80	10	334	2	580	6	700	7
100	1	340	2	585	6	705	7
120	1	341	4	590	5	720	7
130	1	343	4	591	6	721	7
140	1	344	2	592	6	723	7
160	1	360	4	593	6	730	7
161	1	370	4	600	6	731	7
162	1	371	4	605	7	732	10
170§	2	372	4	620	9	734	11
190§	2	375	4	621	8	740	8
195	1	380	1	625	8	745	10
200	1	385	1	635	8	750	7
210	1	390	3	636	9	780	7
220	1	392	3	637	9	790	10
221	1	393	3	638	9	791	10
222	1	395	4	640	10	793	11
250	3	396	4	645	7	810	11
260§	2	397	4	650	9	830	10
262§	2	398	4	651	9	831	10
264§	2	400	7	652	9	833	11
265§	4	410	7	654	9	850	11
280	3	440	7	655	9	870	11
290	3	490	9	660	8	900	10
310§	2	493	7	661	8	905	10
313§	4	500	5	662	8	920	10
315§	2	505	5	663	10	940	10
320	2	510	6	670	8	955	10
323	4	511		671	8	999	4
324	2	515	6	672	8		
325	4	520	6	690	7		

Habitat Code	PVG	Habitat Code	PVG	Habitat Code	PVG	Habitat Code	PVG
§ These habitat codes map to Snowberry/Ninebark, as shown in Figure 4.7.2							

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.5.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The cover types described above, along with the flow diagrams in Figure 4.5.2, define which low fuel model(s) will become candidates. According to the logic of the figure, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by smooth linear transitions using percent canopy cover.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.5.1 or Figure 4.5.2. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

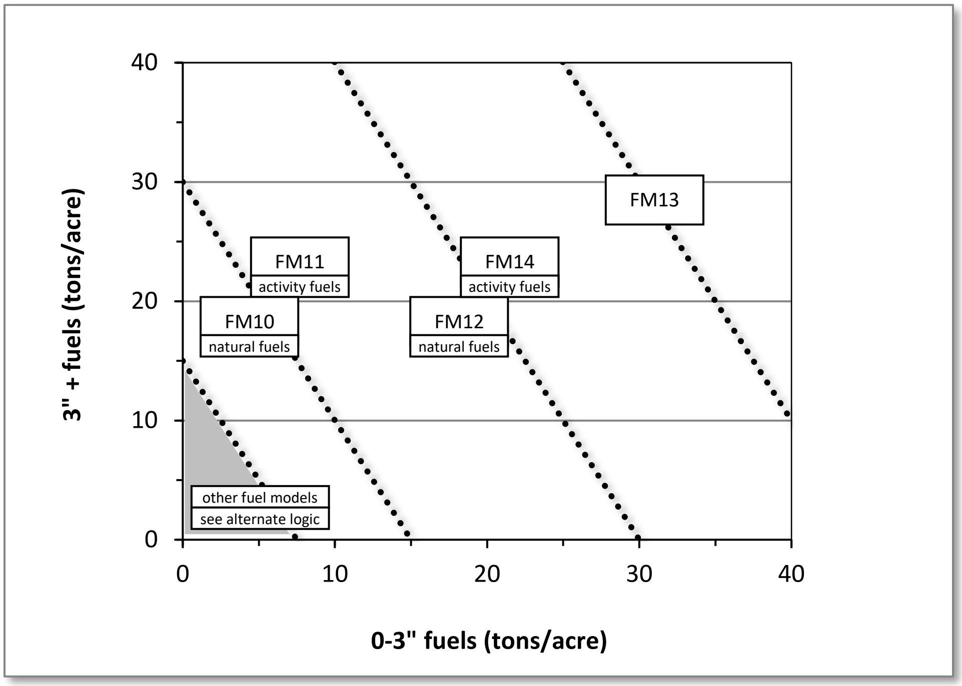


Figure 4.5.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.5.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

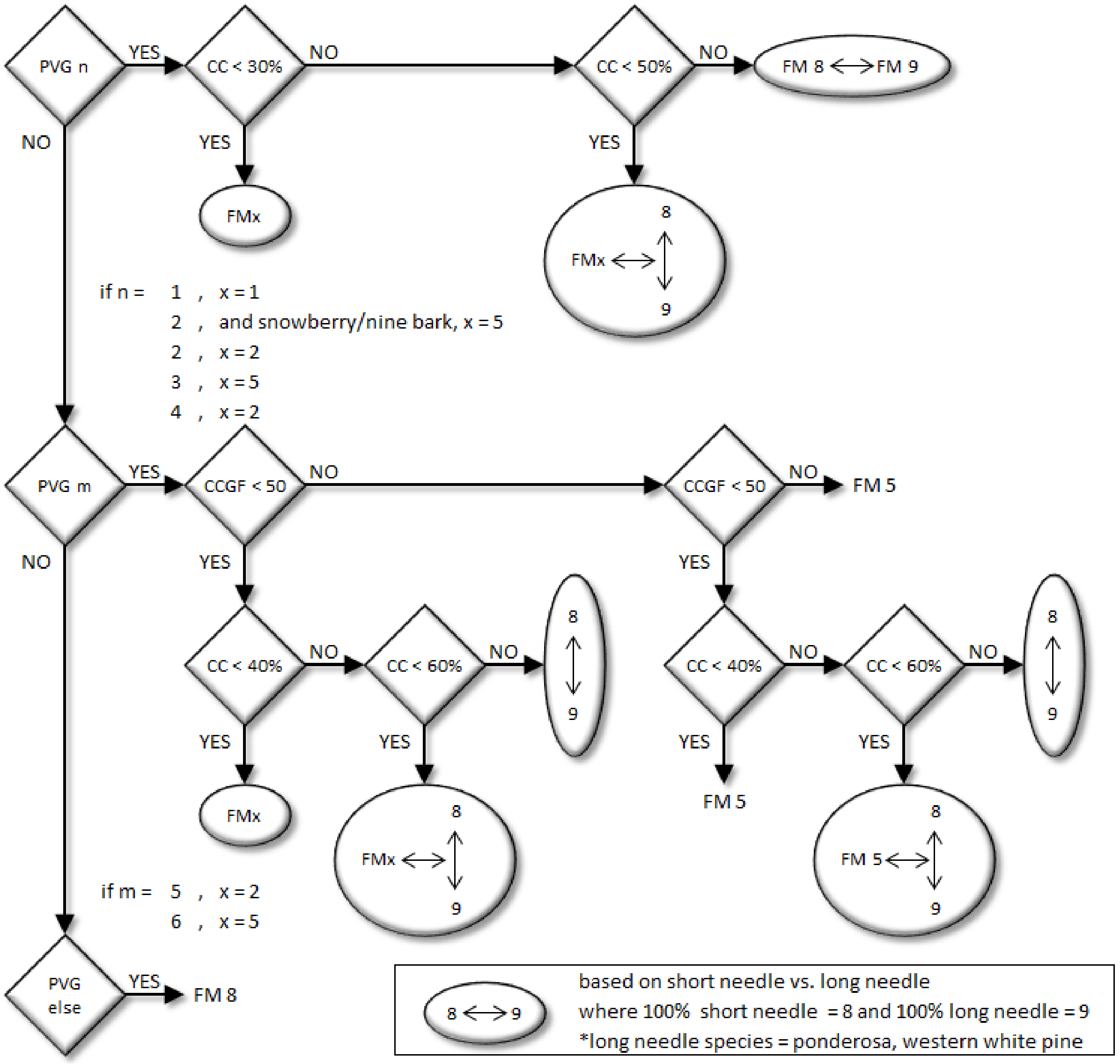


Figure 4.5.2 - Fuel models for the CI-FFE variant. The *n* and *m* indices are the PVG groups defined in Table 4.5.14.

4.6 Central Rockies (CR)

4.6.1 Tree Species

The Central Rockies variant models the 36 tree species shown in Table 4.6.1. Two additional categories, ‘other softwood’ and ‘other hardwood’ are modeled using pines and cottonwoods, respectively.

Table 4.6.1 - Tree species simulated by the Central Rockies variant.

Common Name	**Scientific Name**	**Notes**
subalpine fir	*Abies lasiocarpa*	
corkbark fir	*Abies lasiocarpa var. arizonica*	
Douglas-fir	*Pseudotsuga menziesii*	
grand fir	*Abies grandis*	
white fir	*Abies concolor*	
mountain hemlock	*Tsuga mertensiana*	
western redcedar	*Thuja plicata*	
western larch	*Larix occidentalis*	
bristlecone pine	*Pinus aristata*	
limber pine	*Pinus flexilis*	
lodgepole pine	*Pinus contorta*	
twoneedle pinyon	*Pinus edulis*	
ponderosa pine	*Pinus ponderosa*	
whitebark pine	*Pinus albicaulis*	
southwestern white pine	*Pinus strobiformis*	
Utah juniper	*Juniperus osteosperma*	
blue spruce	*Picea pungens*	
Engelmann spruce	*Picea engelmannii*	
white spruce	*Picea glauca*	
quaking aspen	*Populus tremuloides*	
narrowleaf cottonwood	*Populus angustifolia*	
plains cottonwood	*Populus deltoides* ssp. *monilifera*	Use narrowleaf cottonwood
Gambel oak	*Quercus gambelii*	
Arizona white oak	*Quercus arizonica*	Use gambel oak
Emory oak	*Quercus emoryi*	Use gambel oak
bur oak	*Quercus macrocarpa*	Use gambel oak
silverleaf oak	*Quercus hypoleucoides*	Use gambel oak
paper birch	*Betula papyrifera*	Use quaking aspen
alligator juniper	*Juniperus deppeana*	Use Utah juniper
Rocky Mountain juniper	*Juniperus scopulorum*	Use Utah juniper
oneseed juniper	*Juniperus monosperma*	Use Utah juniper
Eastern redcedar	*Juniperus virginiana*	Use Utah juniper
singleleaf pinyon	*Pinus monophylla*	Use common pinyon
border pinyon	*Pinus discolor*	Use common pinyon
Arizona twoneedle pinyon	*Pinus monophylla* var. *fallax*	Use common pinyon
Chihuahuan pine	*Pinus leiophylla*	Use ponderosa pine
other softwood		= pines
other hardwood		= cottonwoods

4.6.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the FFE design workshop. A complete description of the Snag Submodel is provided in section 2.3.

Four variables are used to modify the Snag Submodel for the different species in the CR-FFE variant:

- A multiplier to modify the species' fall rate;
- A multiplier to modify the time required for snags to decay from a "hard" to "soft" state;
- The maximum number of years that snags will remain standing; and
- A multiplier to modify the species' height loss rate.

These variables are summarized in Table 4.6.2 and Table 4.6.3. Height loss rate of quaking aspen, paper birch and cottonwoods are insignificant in comparison to their rapid snag fall rate, and are not modeled. The fall rate of these hardwoods is also halved in the ten years following a burn. In the case of Douglas-fir and spruce snags >18" DBH, the fall rate is reduced to 32% of the rate predicted by Marcot's equation.

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.6.4 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

Table 4.6.2 - Default snag fall, snag height loss and soft-snag characteristics for 20" DBH snags in the CR-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.6.3.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - - Years - - - - - - - - - -			
subalpine fir	12	40	20	35
corkbark fir	12	40	20	35
Douglas-fir	97§	100	33	42
grand fir	12	40	20	35
white fir	12	40	20	35
mountain hemlock	31	150	310	39
western redcedar	28	90	33	35
western larch	34	150	310	42
bristlecone pine	–	–	661	35
limber pine	31	150	310	35
lodgepole pine	31	150	661	35
twoneedle pinyon	31	150	310	35
ponderosa pine	31	150	310	39
whitebark pine	31	150	310	35
southwestern white pine	31	150	310	39
Utah juniper	31	150	310	35
blue spruce	97§	100	661	35
Engelmann spruce	97§	100	661	35
white spruce	97§	100	661	35
quaking aspen	8	5	–	35
narrowleaf cottonwood	8	5	–	35
plains cottonwood	8	5	–	35
Gambel oak	12	40	20	35
Arizona white oak	12	40	20	35

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
Emory oak	12	40	20	35
bur oak	12	40	20	35
silverleaf oak	12	40	20	35
paper birch	8	5	–	35
alligator juniper	31	150	310	35
Rocky Mountain juniper	31	150	310	35
oneseed juniper	31	150	310	35
Eastern redcedar	31	150	310	35
singleleaf pinyon	31	150	310	35
border pinyon	31	150	310	35
Arizona twoneedle pinyon	31	150	310	35
Chihuahuan pine	31	150	310	39
other softwood	31	150	660	35
other hardwood	8	5	–	35

§ This value results from using 32% of the default rate for Douglas-fir and spruce snags >18” DBH, as described in the text.

Table 4.6.3 - Default snag fall, snag height loss and soft-snag multipliers for the CR-FFE. These parameters result in the values shown in Table 4.6.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
subalpine fir	2.5	1.494	0.9
corkbark fir	2.5	1.494	0.9
Douglas-fir	1.0§	0.9	1.1
grand fir	2.5	1.494	0.9
white fir	2.5	1.494	0.9
mountain hemlock	1.0	0.098	1.0
western redcedar	1.1	0.9	0.9
western larch	0.9	0.098	1.1
bristlecone pine	–	0.046	0.9
limber pine	1.0	0.098	0.9
lodgepole pine	1.0	0.046	0.9
twoneedle pinyon	1.0	0.098	0.9
ponderosa pine	1.0	0.098	1.0
whitebark pine	1.0	0.098	0.9
southwestern white pine	1.0	0.098	1.0
Utah juniper	1.0	0.098	0.9
blue spruce	1.0§	0.046	0.9
Engelmann spruce	1.0§	0.046	0.9
white spruce	1.0§	0.046	0.9
quaking aspen	4.0	–	0.9
narrowleaf cottonwood	4.0	–	0.9
plains cottonwood	4.0	–	0.9
Gambel oak	2.5	1.494	0.9
Arizona white oak	2.5	1.494	0.9
Emory oak	2.5	1.494	0.9
bur oak	2.5	1.494	0.9
silverleaf oak	2.5	1.494	0.9
paper birch	4.0	–	0.9
alligator juniper	1.0	0.098	0.9
Rocky Mountain juniper	1.0	0.098	0.9
oneseed juniper	1.0	0.098	0.9
Eastern redcedar	1.0	0.098	0.9
singleleaf pinyon	1.0	0.098	0.9
border pinyon	1.0	0.098	0.9
Arizona twoneedle pinyon	1.0	0.098	0.9
Chihuahuan pine	1.0	0.098	1.0
other softwood	1.0	0.046	0.9
other hardwood	4.0	–	0.9

Species	Snag Fall	Height loss	Hard-to-Soft

§ This value apples to Douglas-fir and spruce snags <18” DBH; see text for details.

4.6.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the STDINFO keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a lodgepole pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density values calculated from the green specific gravity values from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999).

The coefficient in Table 4.6.4 for Douglas-fir is based on ‘Douglas-fir south’.

Table 4.6.4 - Wood density (ovendry lb/ft^3) used in the CR-FFE variant.

Species	Density (lb/ft3)	Species	Density (lb/ft3)
subalpine fir	19.3	quaking aspen	21.8
corkbark fir	19.3	narrowleaf cottonwood	19.3
Douglas-fir	26.8	plains cottonwood	19.3
grand fir	21.8	Gambel oak	39.6
white fir	23.1	Arizona white oak	39.6
mountain hemlock	26.2	Emory oak	39.6
western redcedar	19.3	bur oak	39.6
western larch	29.9	silverleaf oak	39.6
bristlecone pine	23.7	paper birch	21.8
limber pine	22.5	alligator juniper	34.9
lodgepole pine	23.7	Rocky Mountain juniper	34.9
twoneedle pinyon	31.8	oneseed juniper	34.9
ponderosa pine	23.7	Eastern redcedar	34.9
whitebark pine	22.5	singleleaf pinyon	31.8
southwestern white pine	22.5	border pinyon	31.8
Utah juniper	34.9	Arizona twoneedle pinyon	31.8
blue spruce	20.6	Chihuahuan pine	23.7
Engelmann spruce	20.6	other softwood	23.7
white spruce	23.1	other hardwood	21.8

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the CR-FFE (Table 4.6.5). Mountain hemlock biomass is based on Gholz and others (1979), using western hemlock equations from Brown and Johnston to partition the biomass and also to provide estimates for trees under one inch diameter. Pinyons, junipers, and oaks may have single or multiple stem forms: single stem equations were used to compute biomass in all cases. The FVS base model computes volume of these three species based on firewood utilization with a minimum branch of diameter of 1.5 inches. Crown and bole dynamics compatibility was maintained by defining tree crown as being made up of branches and twigs (including dead material) less than 1.5 inches, and foliage.

Table 4.6.5 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
subalpine fir	Brown and Johnston (1976)
corkbark fir	subalpine fir: Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
grand fir	Brown and Johnston (1976)
white fir	Grand fir: Brown and Johnston (1976)
mountain hemlock	Gholz and others (1979); Brown and Johnston (1976)
western redcedar	Brown and Johnston (1976)
western larch	Brown and Johnston (1976)
bristlecone pine	pinyon pine: Chojnacky (1999), Grier and others (1992)
limber pine	lodgepole pine: Brown and Johnston (1976)
lodgepole pine	Brown and Johnston (1976)
twoneedle pinyon	Grier and others (1992)
ponderosa pine	Brown and Johnston (1976), Keyser and Smith (2010) for foliage and 0-.25” branches in the Black Hills and Nebraska NFs (also for crown shape in the canopy fuels calculations)
whitebark pine	Brown (1978)
southwestern white pine	western white pine: Brown and Johnston (1976)
Utah juniper	oneseed juniper: Grier and others (1992)
blue spruce	Engelmann spruce: Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
white spruce	Engelmann spruce: Brown and Johnston (1976)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
narrowleaf cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
plains cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Gambel oak	Chojnacky (1992)
Arizona white oak	Use Gambel oak
Emory oak	Use Gambel oak
bur oak	Use Gambel oak
silverleaf oak	Use Gambel oak
paper birch	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
alligator juniper	oneseed juniper: Grier and others (1992)
Rocky Mountain juniper	oneseed juniper: Grier and others (1992)
oneseed juniper	Grier and others (1992)
Eastern redcedar	oneseed juniper: Grier and others (1992)
singleleaf pinyon	Use common pinyon
border pinyon	Use common pinyon
Arizona twoneedle pinyon	Use common pinyon
Chihuahuan pine	Use ponderosa pine
other softwood	lodgepole pine: Brown and Johnston (1976)
other hardwood	cottonwood: Jenkins et. al. (2003); Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.6.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are from Keane and others (1989).

Table 4.6.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the CR-FFE variant.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
subalpine fir	7	2	10	15	15
corkbark fir	7	2	10	15	15
Douglas-fir	5	2	10	15	15

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
grand fir	7	2	10	15	15
white fir	7	2	10	15	15
mountain hemlock	4	2	10	10	10
western redcedar	5	2	10	15	20
western larch	1	1	10	15	15
bristlecone pine	3	2	10	15	20
limber pine	3	2	10	15	15
lodgepole pine	3	2	10	15	15
twoneedle pinyon	3	2	10	15	15
ponderosa pine	4	2	10	10	10
whitebark pine	3	2	10	15	15
southwestern white pine	4	2	10	10	10
Utah juniper	4	2	10	15	20
blue spruce	6	2	10	10	10
Engelmann spruce	6	2	10	10	10
white spruce	6	2	10	10	10
quaking aspen	1	1	10	10	10
narrowleaf cottonwood	1	1	10	10	10
plains cottonwood	1	1	10	10	10
Gambel oak	1	1	10	15	15
Arizona white oak	1	1	10	15	15
Emory oak	1	1	10	15	15
bur oak	1	1	10	15	15
silverleaf oak	1	1	10	15	15
paper birch	1	1	10	10	10
alligator juniper	4	2	10	15	20
Rocky Mountain juniper	4	2	10	15	20
oneseed juniper	4	2	10	15	20
Eastern redcedar	4	2	10	15	20
singleleaf pinyon	3	2	10	15	15
border pinyon	3	2	10	15	15
Arizona twoneedle pinyon	3	2	10	15	15
Chihuahuan pine	4	2	10	10	10
other softwood	3	2	10	15	15
other hardwood	1	1	10	10	10

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.6.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.6.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Data on pinyon, juniper, quaking aspen and oaks were developed after examining live fuels reported in the Stereo Photo Guides for Quantifying Natural Fuels (Ottmar and others 2000a, Ottmar and others 2000b).

Table 4.6.7 - Values (dry weight, tons/acre) for live fuels used in the CR-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established” (E) values when canopy cover is between 10 and 60 percent.

Species		**Herbs**	**Shrubs**	**Comments**
subalpine fir	E	0.15	0.20	
	I	0.30	2.00	
corkbark fir	E	0.15	0.20	Use subalpine fir
	I	0.30	2.00	
Douglas-fir	E	0.20	0.20	

Species		Herbs	Shrubs	Comments
	I	0.40	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
white fir	E	0.15	0.10	Use subalpine fir
	I	0.30	2.00	
mountain hemlock	E	0.15	0.20	
	I	0.30	2.00	
western redcedar	E	0.20	0.20	
	I	0.40	2.00	
western larch	E	0.20	0.20	
	I	0.40	2.00	
bristlecone pine	E	0.04	0.05	Use pinyon pine
	I	0.13	1.63	
limber pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
twoneedle pinyon	E	0.04	0.05	Ottmar and others (2000a)
	I	0.13	1.63	
ponderosa pine	E	0.20	0.25	
	I	0.25	0.10	
whitebark pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
southwestern white pine	E	0.15	0.10	Use western white pine
	I	0.30	2.00	
Utah juniper	E	0.04	0.05	Ottmar and others (2000a)
	I	0.13	1.63	
blue spruce	E	0.15	0.20	Use Engelmann spruce
	I	0.30	2.00	
Engelmann spruce	E	0.15	0.20	
	I	0.30	2.00	
white spruce	E	0.15	0.20	Use Engelmann spruce
	I	0.30	2.00	
quaking aspen	E	0.25	0.25	Ottmar and others (2000b)
	I	0.18	1.32	
narrowleaf cottonwood	E	0.25	0.25	Ottmar and others (2000b)
	I	0.18	1.32	
plains cottonwood	E	0.25	0.25	Use narrowleaf cottonwood
	I	0.18	1.32	
Gambel oak	E	0.23	0.22	Ottmar and others (2000b)
	I	0.55	0.35	
Arizona white oak	E	0.23	0.22	Use Gambel oak
	I	0.55	0.35	
Emory oak	E	0.23	0.22	Use Gambel oak
	I	0.55	0.35	
bur oak	E	0.23	0.22	Use Gambel oak
	I	0.55	0.35	
silverleaf oak	E	0.23	0.22	Use Gambel oak
	I	0.55	0.35	
paper birch	E	0.25	0.25	Use quaking aspen
	I	0.18	1.32	
alligator juniper	E	0.04	0.05	Use Utah juniper
	I	0.13	1.63	
Rocky Mountain juniper	E	0.04	0.05	Use Utah juniper
	I	0.13	1.63	
oneseed juniper	E	0.04	0.05	Use Utah juniper
	I	0.13	1.63	
Eastern redcedar	E	0.04	0.05	Use Utah juniper

Species		Herbs	Shrubs	Comments
	I	0.13	1.63	
singleleaf pinyon	E	0.04	0.05	Use common pinyon
	I	0.13	1.63	
border pinyon	E	0.04	0.05	Use common pinyon
	I	0.13	1.63	
Arizona twoneedle pinyon	E	0.04	0.05	Use common pinyon
	I	0.13	1.63	
Chihuahuan pine	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
other softwood	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
other hardwood	E	0.25	0.25	Use quaking aspen
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.6.8). Data on pinyon, juniper, quaking aspen and oaks were developed based on fuel loadings reported in the Stereo Photo Guides for Quantifying Natural Fuels (Ottmar and others 2000a, Ottmar and others 2000b). (Litter values for pinyon and juniper were lowered because the photo series values seemed too high.) If tree canopy cover is <10 percent, the DWD pools are assigned an "initiating" value and if cover is >60 percent they are assign the "established" value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.6.8 - Canopy cover and cover type are used to assign default dead fuel loads (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
corkbark fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
western redcedar	E	1.6	1.6	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
bristlecone pine	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
limber pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
twoneedle pinyon	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
whitebark pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
southwestern white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
Utah juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
blue spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
white spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
narrowleaf cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
plains cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
Gambel oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
Arizona white oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
Emory oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
bur oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
silverleaf oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
paper birch	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
alligator juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Rocky Mountain juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
oneseed juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Eastern redcedar	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
singleleaf pinyon	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
border pinyon	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Arizona twoneedle pinyon	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Chihuahuan pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
other softwood	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
other hardwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

The live and dead surface fuel values for juniper, pinyon pine, and bristlecone pine in tables 4.3.7 and 4.3.8 were taken from Ottmar and others (2000a). The litter amounts were switched to 0.5 and 0.3 tons/acre for established and initiating stands, respectively, since the photo series values seemed too high. The live and dead surface fuel values for oaks, aspen, and cottonwoods in Table 4.6.7 and Table 4.6.8 were taken from Ottmar and others (2000b).

4.6.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires. The bark thickness multipliers in Table 4.6.9 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003). The pinyon pine coefficient is based on Pinus spp. And corkbark fir is based on subalpine fir, both from FOFEM.

Table 4.6.9 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
subalpine fir	0.041
corkbark fir	0.041
Douglas-fir	0.063
grand fir	0.046
white fir	0.048
mountain hemlock	0.040
western redcedar	0.035
western larch	0.063
bristlecone pine	0.030
limber pine	0.030
lodgepole pine	0.028
twoneedle pinyon	0.030
ponderosa pine	0.063
whitebark pine	0.030
southwestern white pine	0.035
Utah juniper	0.025
blue spruce	0.031
Engelmann spruce	0.036
white spruce	0.025
quaking aspen	0.044
narrowleaf cottonwood	0.038
plains cottonwood	0.038
Gambel oak	0.045
Arizona white oak	0.045
Emory oak	0.045
bur oak	0.045
silverleaf oak	0.045
paper birch	0.044
alligator juniper	0.025
Rocky Mountain juniper	0.025
oneseed juniper	0.025
Eastern redcedar	0.025
singleleaf pinyon	0.030
border pinyon	0.030
Arizona twoneedle pinyon	0.030
Chihuahuan pine	0.063
other softwood	0.030
other hardwood	0.038

4.6.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5. Table 4.6.10 shows the default annual loss rates for the CR variant. Workshop participants noted that material decays slower in the area covered by the CR-FFE, when compared with NI-FFE. This comment was support by data in Brown and others (1998). Decay rate for woody material was therefore reduced 55 percent from the default decay rates based on

Abbott and Crossley (1982) (the rates used in the NI-FFE variant). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.6.10 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.054	0.02
0.25 – 1		
1 – 3	0.0405	
3 – 6	0.00675	
6 – 12		
> 12		
Litter	0.225	
Duff	0.0009	0.0

By default, FFE decays all wood species at the rates shown in Table 4.6.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.6.11 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.6.11 - Default wood decay classes used in the CR-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Class	Species	Decay Class
subalpine fir	4	quaking aspen	4
corkbark fir	4	narrowleaf cottonwood	4
Douglas-fir	3	plains cottonwood	4
grand fir	4	Gambel oak	2
white fir	4	Arizona white oak	2
mountain hemlock	4	Emory oak	2
western redcedar	2	bur oak	2
western larch	3	silverleaf oak	2
bristlecone pine	4	paper birch	4
limber pine	4	alligator juniper	2
lodgepole pine	4	Rocky Mountain juniper	2
twoneedle pinyon	4	oneseed juniper	2
ponderosa pine	4	Eastern redcedar	2
whitebark pine	4	singleleaf pinyon	4
southwestern white pine	4	border pinyon	4
Utah juniper	2	Arizona twoneedle pinyon	4
blue spruce	4	Chihuahuan pine	4
Engelmann spruce	4	other softwood	4
white spruce	4	other hardwood	4

4.6.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.6.12) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.6.12 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups. In general they are drier than the default values used in the NI-FFE.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	4	5	8	10
0.25 – 1.0 in. (10-hr)	4	6	10	12
1.0 – 3.0 in. (100-hr)	5	8	12	15
> 3.0 in. (1000+ -hr)	10	15	16	18
Duff	15	50	125	200
Live	70	90	120	140

4.6.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger ‘Activity Fuels’ conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models; or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the CR-FFE to follow the third of these four options

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.6.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The logical flow shown in Figure 4.6.2 defines which low fuel model(s) will become candidates. According to the logic of Figure 4.6.2, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, snag density, etc.).

The program logic shown in Figure 4.6.2 also uses stand structure classes in some decision rules. The CR-FFE uses the structure class rules documented in Crookston and Stage (1999). The structure class parameters used in the fuel model logic are as follows:

% of tree ht. that must be exceeded for a gap in the ht. distribution = 20
diam breakpoint between seedlings/saplings and pole-sized trees = 5
diam breakpoint between pole-sized trees and large older trees = 18 (12 for lodgepole pine)
min cover % needed to qualify as a stratum = 5
min trees/acre needed to classify as stand initiation = 200
min % of maximum sdi to classify as stem exclusion = 30

These parameters are only assumed for the fuel model logic, so users can still enter the values they want on the **STRCLASS** keyword.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.6.1 or Figure 4.6.2. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

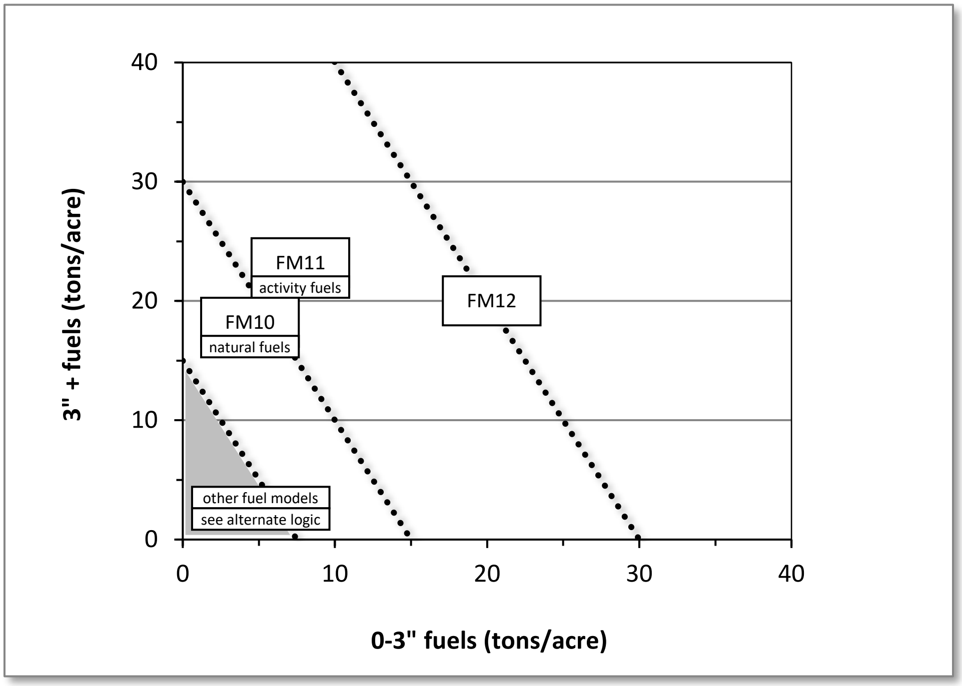
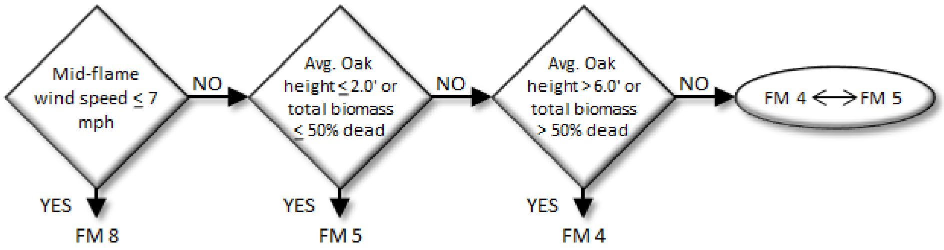
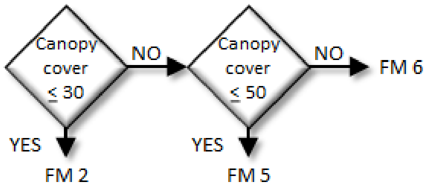


Figure 4.6.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.6.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

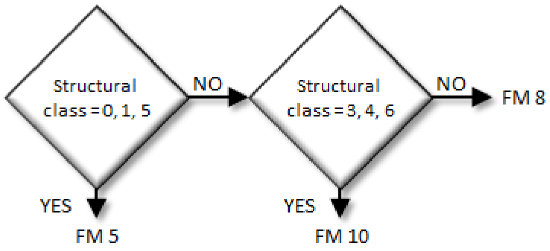
Oak Brush Cover Type



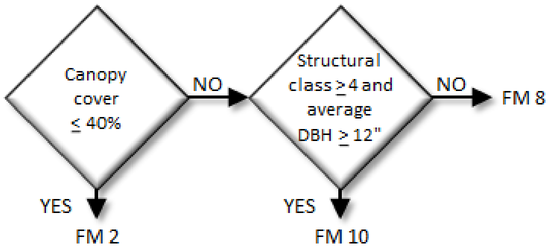
Pinyon Juniper Cover Type



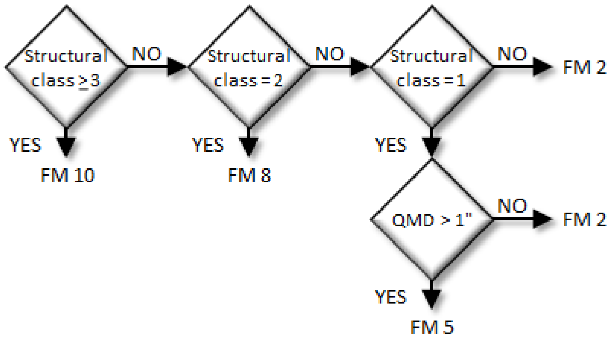
Lodgepole Pine Cover Type



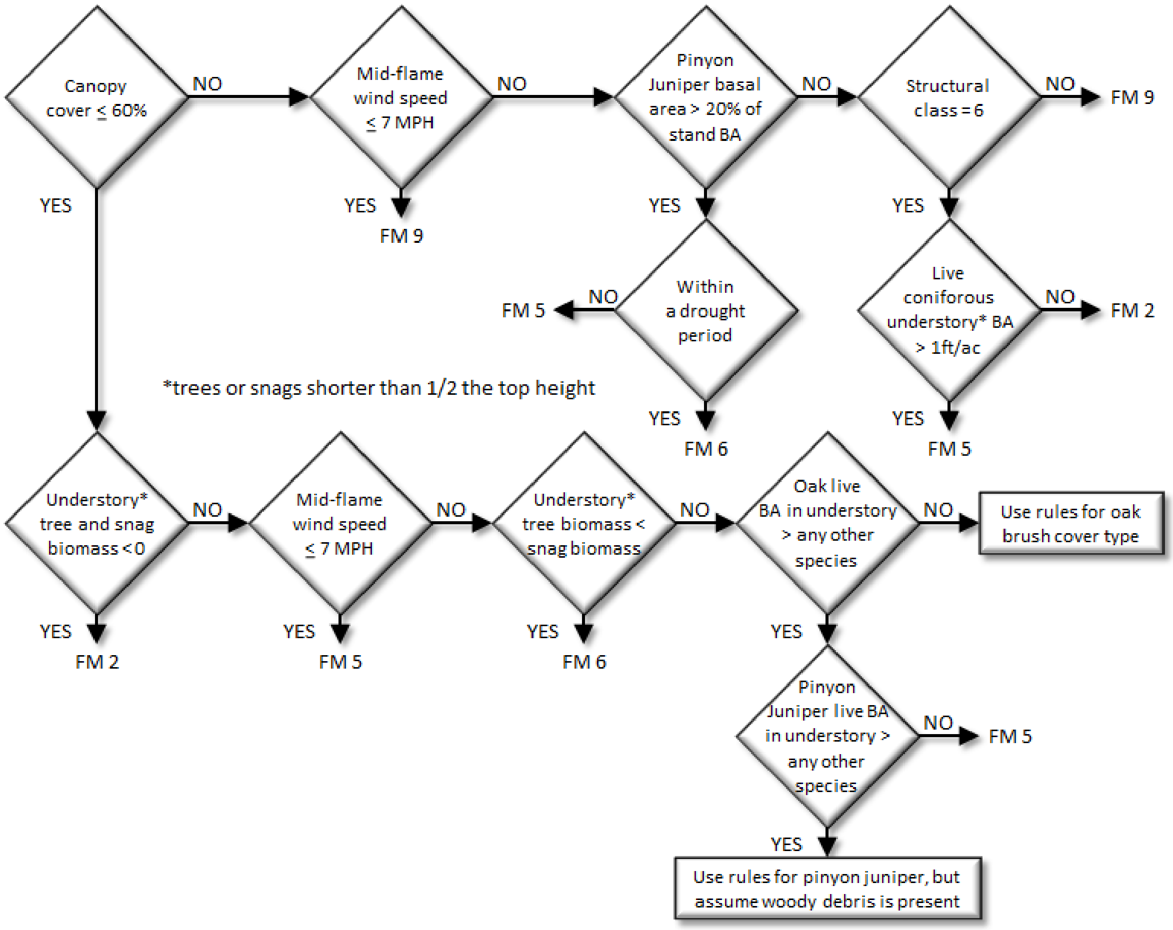
White Spruce Cover Type



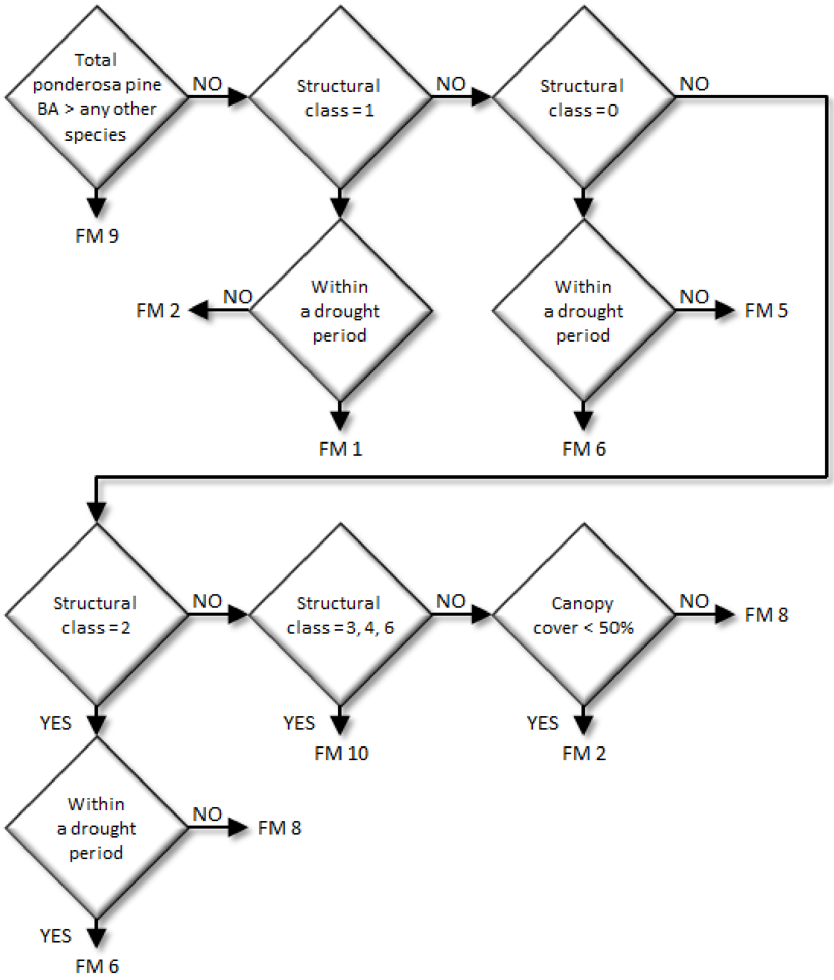
Spruce Fir Cover Type



Ponderosa Pine Cover Type



Mixed Conifer Cover Type



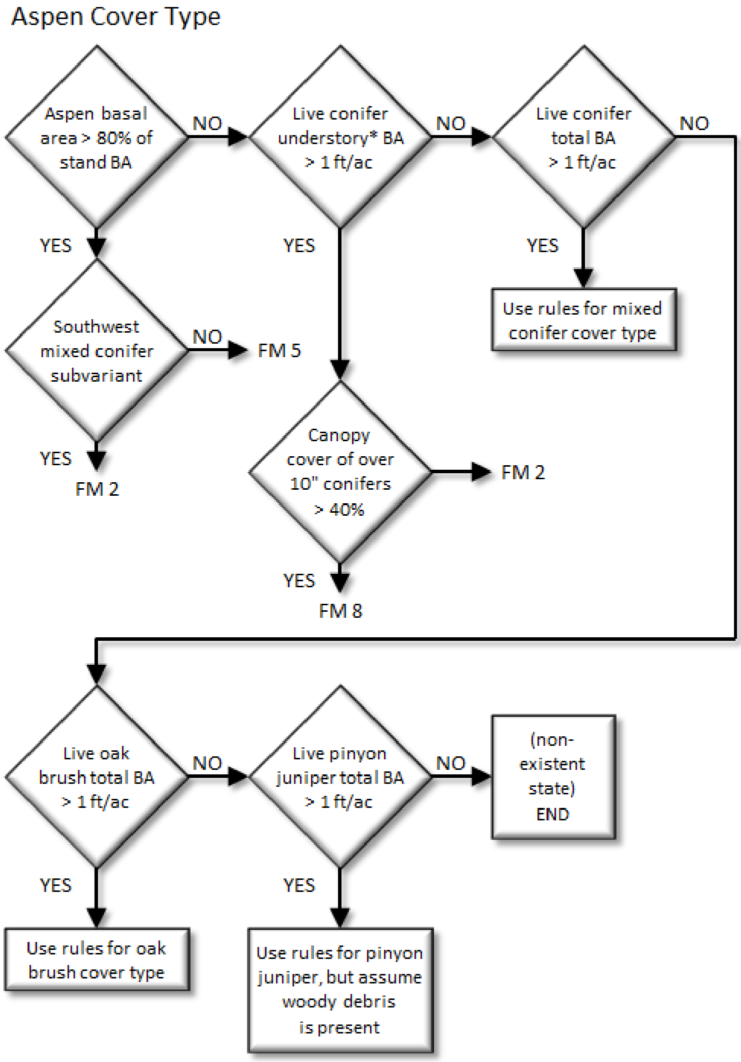


Figure 4.6.2 - Logic for modeling fire at “low” fuel load in the CR-FFE variant.

4.7 Central States (CS)

4.7.1 Tree Species

The Central States variant models the 91 tree species categories shown in Table 4.7.1. The "other softwood" category is modeled as eastern white pine and the "other hardwood" category is modeled as flowering dogwood.

Table 4.7.1 - Tree species simulated by the Central States variant.

Common name	**Scientific name**
eastern redcedar	*Juniperus virginiana*
juniper	*Juniperus*
shortleaf pine	*Pinus echinata*
Virginia pine	*Pinus viginiana*
loblolly pine	*Pinus taeda*
other softwood	
eastern white pine	*Pinus strobus*
black walnut	*Juglans nigra*
butternut	*Juglans cinerea*
tupelo	*Nyssa*
swamp tupelo	*Nyssa biflora*
water tupelo	*Nyssa aquatica*
blackgum	*Nyssa sylvatica*
shagbark hickory	*Carya ovata*
shellbark hickory	*Carya laciniosa*
mockernut hickory	*Carya tomentosa*
pignut hickory	*Carya glabra*
hybrid hickory	*Carya*
water hickory	*Carya aquatica*
bitternut hickory	*Carya cordiformis*
pecan	*Carya illinoinensis*
black hickory	*Carya texana*
American beech	*Fagus grandifolia*
black ash	*Fraxinus nigra*
pumpkin ash	*Fraxinus profunda*
blue ash	*Fraxinus quadrangulata*
eastern cottonwood	*Populus deltoides*
red maple	*Acer rubrum*
boxelder	*Acer negundo*
silver maple	*Acer saccharinum*
black cherry	*Prunus serotina*
American elm	*Ulmus americana*
sugarberry	*Celtis laevigata*
common hackberry	*Celtis occidentalis*
winged elm	*Ulmus alata*
elm	*Ulmus*
Siberian elm	*Ulmus pumila*
slippery elm	*Ulmus rubra*
rock elm	*Ulmus thomasii*
tuliptree	*Liriodendron tulipifera*
American basswood	*Tilia americana*
sugar maple	*Acer saccharum*
ash	*Fraxinus*
white ash	*Fraxinus americana*
green ash	*Fraxinus pennsylvanica*
white oak	*Quercus alba*
northern red oak	*Quercus rubra*
southern red oak	*Quercus falcata*
black oak	*Quercus velutina*
scarlet oak	*Quercus coccinea*
blackjack oak	*Quercus marilandica*
chinkapin oak	*Quercus muehlenbergii*
swamp white oak	*Quercus bicolor*
bur oak	*Quercus macrocarpa*
swamp chestnut oak	*Quercus michauxii*
post oak	*Quercus stellata*
bottomland post oak	*Quercus similis*
chestnut oak	*Quercus prinus*
pin oak	*Quercus palustris*
cherrybark oak	*Quercus pagoda*
shingle oak	*Quercus imbricaria*
overcup oak	*Quercus lyrata*
water oak	*Quercus nigra*
Nuttall oak	*Quercus texana*
willow oak	*Quercus phellos*
Shumard's oak	*Quercus shumardii*
sassafras	*Sassafras albidum*
Ohio buckeye	*Aesculus glabra*
catalpa	*Catalpa*
common persimmon	*Diospyros virginiana*
honeylocust	*Gleditsia triacanthos*
balsam poplar	*Populus balsamifera*
bigtooth aspen	*Populus grandidentata*
quaking aspen	*Populus tremuloides*
black locust	*Robinia pseudoacacia*
American sycamore	*Platanus occidentalis*
bald cypress	*Taxodium distichum*
river birch	*Betula nigra*
sweetgum	*Liquidamber styraciflua*
willow	*Salix*
black willow	*Salix nigra*
other hardwood	
American hornbeam	*Carpinus caroliniana*
eastern redbud	*Cercis canadensis*
flowering dogwood	*Cornus florida*
hawthorn	*Crataegus*
Kentucky coffeetree	*Gymnocladus dioicus*
Osage-orange	*Maclura pomifera*
cucumber tree	*Magnolia acuminata*
sweetbay	*Magnolia virginiana*
mulberry	*Morus*
hophornbeam	*Ostrya virginiana*
sourwood	*Oxydendrum arboreum*

4.7.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the SN-FFE development workshop. A complete description of the Snag Submodel is provided in section 2.3.

Three variables are used to modify the Snag Submodel for the different species in the CS-FFE variant:

- A multiplier to modify the species' fall rate;
- A multiplier to modify the time required for snags to decay from a "hard" to "soft" state; and
- The maximum number of years that snags will remain standing.

Initially, each species was put into a snag class (1, 2, or 3), as listed in Table 4.7.2. Then the above variables were determined for each snag class. Snag class 1 generally represents pines, snag class 2 generally represents black oak and similar species, and snag class 3 generally represents white oak species and redcedar species. These variables are summarized in Table 4.7.3 and Table 4.7.4.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.7.5 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

Table 4.7.2 – Snag class for tree species simulated by the Central States variant.

Species	Snag class	Species	Snag class
eastern redcedar	3	southern red oak	2
juniper	3	black oak	2
shortleaf pine	1	scarlet oak	2
Virginia pine	1	blackjack oak	3
loblolly pine	1	chinkapin oak	3
other softwood	1	swamp white oak	3
eastern white pine	1	bur oak	3
black walnut	2	swamp chestnut oak	2
butternut	2	post oak	3
tupelo	3	bottomland post oak	3
swamp tupelo	3	chestnut oak	2
water tupelo	3	pin oak	2
blackgum	3	cherrybark oak	2
shagbark hickory	3	shingle oak	2
shellbark hickory	3	overcup oak	2
mockernut hickory	3	water oak	3
pignut hickory	3	Nuttall oak	2
hybrid hickory	3	willow oak	2
water hickory	3	Shumard's oak	2
bitternut hickory	3	sassafras	2
pecan	3	Ohio buckeye	2
black hickory	3	catalpa	2
American beech	2	common persimmon	3
black ash	2	honeylocust	3
pumpkin ash	2	balsam poplar	1
blue ash	2	bigtooth aspen	1
eastern cottonwood	1	quaking aspen	1

Species	Snag class
red maple	2
boxelder	2
silver maple	2
black cherry	2
American elm	1
sugarberry	2
common hackberry	2
winged elm	1
elm	1
Siberian elm	1
slippery elm	1
rock elm	1
tuliptree	2
American basswood	1
sugar maple	2
ash	2
white ash	2
green ash	2
white oak	3
northern red oak	2

Species	Snag class
black locust	3
American sycamore	2
bald cypress	3
river birch	1
sweetgum	2
willow	1
black willow	1
other hardwood	2
American hornbeam	2
eastern redbud	2
flowering dogwood	2
hawthorn	2
Kentucky coffeetree	2
Osage-orange	2
cucumber tree	2
sweetbay	2
mulberry	2
hophornbeam	2
sourwood	2

Table 4.7.3 - Snag fall, snag height loss and soft-snag characteristics for 12” DBH snags in the CS-FFE variant. These characteristics directly coincide with the parameter values shown in Table 4.7.4.

Snag Class	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - -	- Years -	- - - - - - - - -	
1	3	6 (pines are 50)	0	2
2	7	15	0	6
3	11	25 (RC is 100)	0	10

Note: Snag height loss is not modeled in CS-FFE.

Table 4.7.4 - Default snag fall, snag height loss and soft-snag multipliers for the CS-FFE. These parameters result in the values shown in Table 4.7.3. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Snag Class	Snag Fall	Height loss	Hard-to-Soft
1	7.17	--	0.07
2	3.07	--	0.21
3	1.96	--	0.35

Additionally, the base fall rate diameter cutoff (diameter at which 5 percent of snags are assigned a slower fall rate) was changed from 18 in. to 12 in. DBH. Due to the dynamics of eastern redcedar, for redcedar snags, even those less than 12 inches, 5 percent are assigned a slower fall rate.

Figure 4.7.1, Figure 4.7.2, and Figure 4.7.3 show how these values translate for 10 and 20 inch snags of varying species.

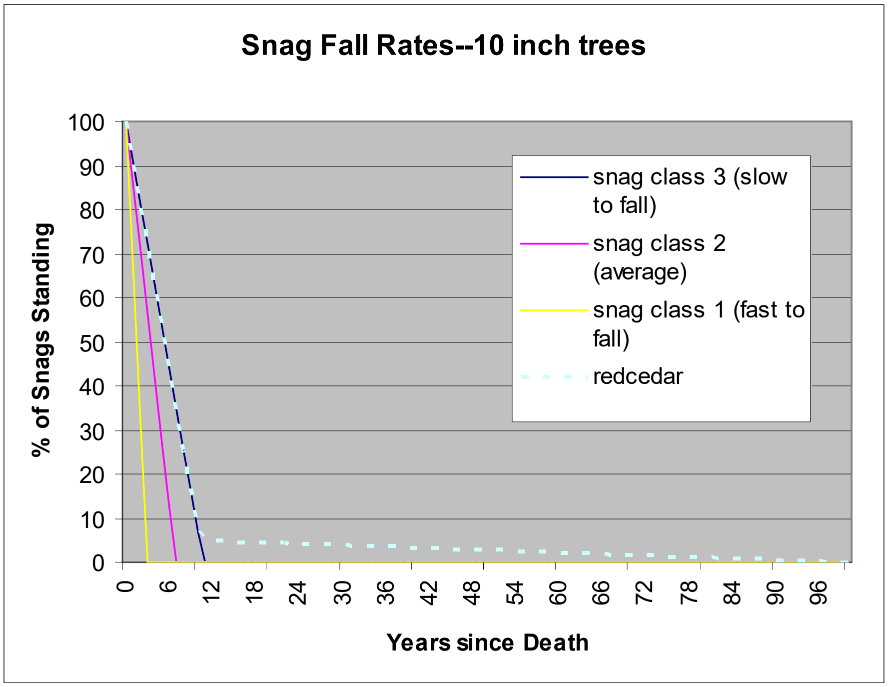


Figure 4.7.1 - Snag fall rates for 10 inch trees.

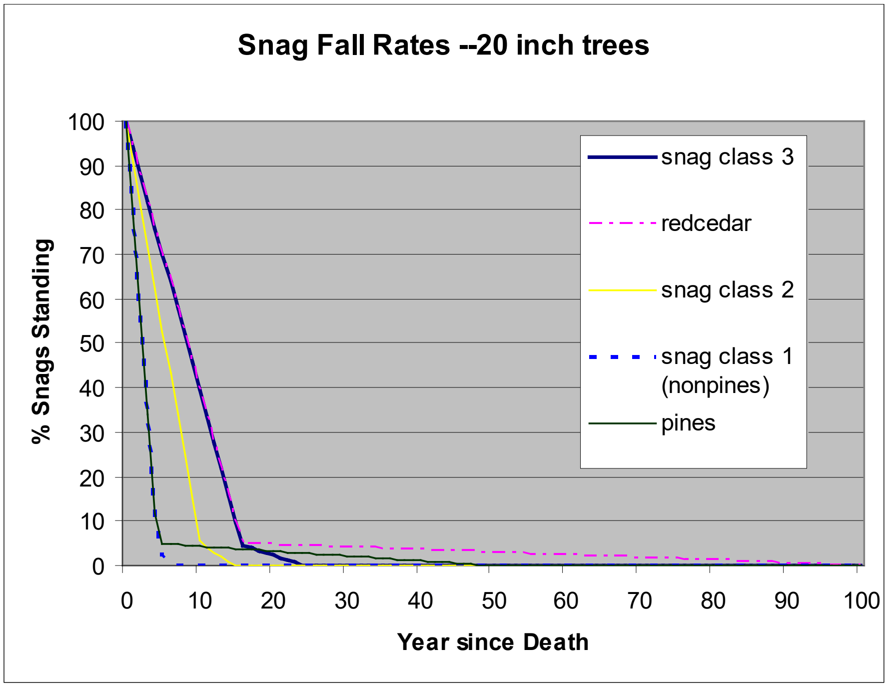


Figure 4.7.2 - Snag fall rates for 20 inch trees.

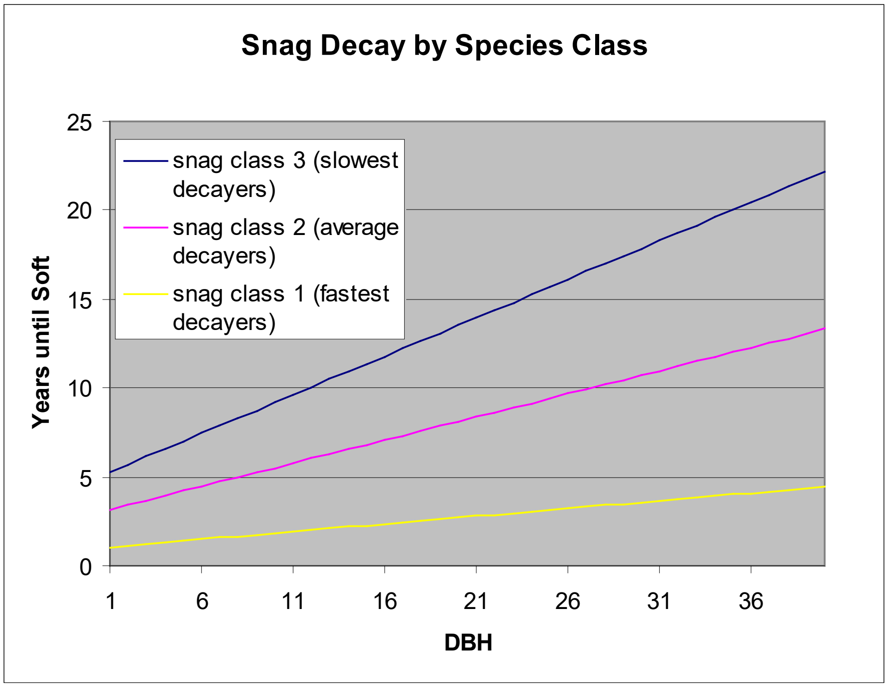


Figure 4.7.3 - The number of years until soft for various diameter snags.

4.7.3 Fuels

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and dead surface fuels. Live herb and shrub fuel load and the initial dead surface fuel load are assigned based on the Forest Type code, as reported in the Summary Statistics Table.

One difference between the implementation of FFE in the Central States variant, relative to its implementation in all of the western variants, is the distinction between crown material and stemwood. In the western variants, stemwood biomass is calculated by converting total cubic foot volume to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood and foliage alone. In the Central States variant, total cubic foot volume equations are not in use. As a result, stemwood biomass is calculated by converting merchantable cubic foot volume (to a 4 inch top diameter inside bark) to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood and foliage plus the unmerchantable portion of the main stem (stemwood above a 4 inch diameter). This has some effects that users should be aware of.

1) The default assumption in the western variants when harvesting is that the stems are taken and the crown material (branchwood) is left. In the eastern variants this corresponds to a default assumption that the merchantable material is taken and the unmerchantable material (branchwood, small trees, unmerchantable topwood) is left.
2) Surface fuel accumulation is predicted from a variety of processes including crown breakage and crown lift. Based on a default percentage and the change in crown ratio for each tree record, a certain amount of material is predicted to fall to the ground each year. This assumption changes slightly when using the Central States variant. Rather than predicting a certain percentage of the branchwood will fall each year, essentially the model is predicting a

certain percentage of the unmerchantable material (branchwood, small trees, unmerchantable topwood) will fall each year.

3) Other changes were made to handle this situation and are described in the section on Tree Crowns.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using wood density calculated from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999), Hardwoods of North America (Alden 1995), or Jenkins et. al (2004).

Table 4.7.5 - Wood density (ovendry lbs/green ft3) used in the CS-FFE variant.

Species	lbs/cuft	Species used
eastern redcedar	27.4	
juniper	27.4	eastern redcedar
shortleaf pine	29.3	
Virginia pine	28.1	
loblolly pine	29.3	
other softwood	21.2	
eastern white pine	21.2	e. white pine
black walnut	31.8	
butternut	22.5	
tupelo	28.7	black tupelo
swamp tupelo	28.7	black tupelo
water tupelo	28.7	
blackgum	28.7	
shagbark hickory	39.9	
shellbark hickory	38.7	
mockernut hickory	39.9	
pignut hickory	41.2	
hybrid hickory	39.9	shagbark hickory
water hickory	38.0	
bitternut hickory	37.4	
pecan	37.4	
black hickory	39.9	shagbark hickory
American beech	34.9	
black ash	28.1	
pumpkin ash	29.9	
blue ash	33.1	
eastern cottonwood	23.1	
red maple	30.6	
boxelder	25.9	
silver maple	27.4	
black cherry	29.3	
American elm	28.7	
sugarberry	30.6	hackberry
common hackberry	30.6	
winged elm	37.4	
elm	28.7	American elm
Siberian elm	28.7	American elm
slippery elm	29.9	
rock elm	35.6	
tuliptree	24.9	
American basswood	20.0	
sugar maple	34.9	
ash	33.1	green ash
white ash	34.3	
green ash	33.1	
white oak	37.4	
northern red oak	34.9	
southern red oak	32.4	
black oak	34.9	
scarlet oak	37.4	
blackjack oak	34.9	black oak
chinkapin oak	37.4	white oak
swamp white oak	39.9	
bur oak	36.2	
swamp chestnut oak	37.4	
post oak	37.4	
bottomland post oak	37.4	post oak
chestnut oak	35.6	
pin oak	36.2	
cherrybark oak	38.0	
shingle oak	34.9	northern red oak
overcup oak	35.6	
water oak	34.9	
Nuttall oak	34.9	black oak
willow oak	34.9	
Shumard’s oak	34.9	black oak
sassafras	26.2	
Ohio buckeye	20.6	yellow buckeye
catalpa	23.7	
common persimmon	39.9	
honeylocust	37.4	
balsam poplar	19.3	
bigtooth aspen	22.5	
quaking aspen	21.8	
black locust	41.2	
American sycamore	28.7	
bald cypress	26.2	
river birch	30.6	
sweetgum	28.7	
willow	22.5	black willow
black willow	22.5	
other hardwood	39.9	flowering dogwood
American hornbeam	36.2	
eastern redbud	36.2	
flowering dogwood	39.9	
hawthorn	38.7	
Kentucky coffeetree	33.1	
Osage-orange	47.4	
cucumber tree	27.4	
sweetbay	26.2	
mulberry	36.8	
hophornbeam	39.3	
sourwood	31.2	

Tree Crown: For merchantable trees, estimates of crown material, including foliage, branchwood and bolewood above a 4 inch top (DOB), are from Jenkins and others (2003). These equations do not provide information on how the crown material is distributed by size class.

Information on partitioning canopy fuel loads by size class was taken from several sources (Snell and Little (1983), Loomis and Blank (1981), Loomis and Roussopoulos (1978), Loomis et. al. (1966)). Species were mapped when necessary. Because information on how crown material is partitioned for different species is often based on different definitions of "crown" (branchwood only, branchwood plus stemwood above a 0.25 inch diameter, branchwood plus stemwood above a 1 inch diameter), the equations to predict the proportion of crown biomass in various size classes are adjusted. The basic assumption is that the biomass of the unmerchantable tip can be calculated from the volume of a cone, where the height of the cone is the difference between total height and height at a 4 inch top diameter and the bottom diameter of the cone is 4 inches. Jenkin's equations include branchwood and stem material above a 4 inch DOB top, while the Central States volume equations go up to a 4 inch DIB top. As a result, there is a small portion of biomass that is missing. This is estimated and added to the crown material estimates.

For unmerchantable trees, total above ground biomass is predicted by summing the estimate of crown biomass with an estimate of the bole biomass. This is done by estimating the volume of the breakpoint diameter tree with both the standard National Volume Estimator Library volume equation, as well as a simplified equation (Vol = 0.0015*D*D*H) to compute an adjustment factor that is used along with the simplified volume equation to estimate the volume and biomass of the unmerchantable tree bole. This was done to ensure smooth, non-erratic biomass estimates for trees as they grow and pass the merchantable dbh breakpoint. A similar method (to that for large trees) is used to adjust how the crown material is distributed by size class. In this case the main stem is assumed to be cone-shaped above breast height and cylinder-shaped below breast height.

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are primarily from Hardin et. al. (2001), except eastern redcedar which is from Barnes and Wagner (2002).

Dead foliage and branch materials also contribute to litter fall. Each species was categories into 1 of 6 crown fall rate categories and the life span of dead foliage and branches was determined for each category. These relationships were taken from SN-FFE.

Table 4.7.6 - Life span of live foliage and crown fall class (1 to 6) for species modeled in the CS-FFE variant.

Species	Leaf Life (years)	Crown Fall Class
eastern redcedar	5	1
juniper	5	1
shortleaf pine	4	6
Virginia pine	3	6
loblolly pine	3	6
other softwood	2	6
eastern white pine	2	6
black walnut	1	4
butternut	1	4
tupelo	1	3
swamp tupelo	1	3
water tupelo	1	3
blackgum	1	3
shagbark hickory	1	2
shellbark hickory	1	2
mockernut hickory	1	2
pignut hickory	1	2
hybrid hickory	1	2
water hickory	1	2
bitternut hickory	1	2
southern red oak	1	4
black oak	1	4
scarlet oak	1	4
blackjack oak	1	2
chinkapin oak	1	3
swamp white oak	1	3
bur oak	1	3
swamp chestnut oak	1	3
post oak	1	3
bottomland post oak	1	3
chestnut oak	1	3
pin oak	1	4
cherrybark oak	1	4
shingle oak	1	4
overcup oak	1	3
water oak	1	3
Nuttall oak	1	4
willow oak	1	4
Shumard's oak	1	4
sassafras	1	4

Species	Leaf Life (years)	Crown Fall Class
pecan	1	2
black hickory	1	2
American beech	1	4
black ash	1	5
pumpkin ash	1	5
blue ash	1	5
eastern cottonwood	1	5
red maple	1	5
boxelder	1	5
silver maple	1	5
black cherry	1	4
American elm	1	5
sugarberry	1	4
common hackberry	1	4
winged elm	1	5
elm	1	5
Siberian elm	1	5
slippery elm	1	5
rock elm	1	5
tuliptree	1	5
American basswood	1	5
sugar maple	1	5
ash	1	5
white ash	1	5
green ash	1	5
white oak	1	3
northern red oak	1	4
Ohio buckeye	1	5
catalpa	1	4
common persimmon	1	4
honeylocust	1	2
balsam poplar	1	5
bigtooth aspen	1	5
quaking aspen	1	5
black locust	1	2
American sycamore	1	5
bald cypress	1	1
river birch	1	5
sweetgum	1	5
willow	1	6
black willow	1	6
other hardwood	1	5
American hornbeam	1	4
eastern redbud	1	5
flowering dogwood	1	5
hawthorn	1	5
Kentucky coffeetree	1	5
Osage-orange	1	4
cucumber tree	1	4
sweetbay	1	4
mulberry	1	5
hophornbeam	1	4
sourwood	1	5

Table 4.7.7 - Years until all snag crown material of certain sizes has fallen by crown fall class

Crown fall class	Snag Crown Material Time to 100% Fallen (years)					
	Foliage	<0.25”	0.25–1”	1-3”	3-6”	6-12”
1	1 (RC is 3)	5	5	10	25	25
2	1	3	3	6	12	12
3	1	2	2	5	10	10
4	1	1	1	4	8	8
5	1	1	1	3	6	6
6	1	1	1	2	4	4

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on forest type. Data for pines and redcedar species are based on information from the Reference database for fuel loadings for the continental U.S. and Alaska (Scott Mincemoyer, on file at the Missoula Fire Lab). Data for hardwoods and oak-savannah are from Nelson and Graney (1996). (These values were taken from SN-FFE.)

Table 4.7.8 - Values (dry weight, tons/acre) for live fuels used in the CS-FFE.

Forest Type	Herbs	Shrubs
Pines	0.10	0.25
Hardwoods	0.01	0.03
Redcedar species	1.0	5.0
Oak-Savannah	0.02	0.13

Dead Fuels: Initial default DWD pools are based on forest type. Default woody fuel loadings were set based on FIA data collected in the Central States region (Table 4.7.9). All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.7.9 - Forest type is used to assign default down woody debris (tons/acre) by size class. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

Forest Type Group	FIA Forest Type codes	Size Class (in) < 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
Pines	100s	0.18	0.93	1.77	0.27	0.75	8.38	4.10	3.82
Redcedar	181, 402	0.19	0.86	1.58	0.11	0.31	0.67	4.89	4.40
Pine-hardwood	400s	0.18	0.75	2.42	0.59	0.67	1.34	5.37	3.07
Oak-hickory	500s	0.15	0.74	1.70	0.38	0.97	2.68	5.17	4.52
Elm-ash-cottonwood	700s	0.20	0.92	2.19	0.41	1.46	3.80	2.49	2.80
Maple-beech-birch	800s	0.19	0.88	1.95	0.56	1.62	1.82	3.88	3.41
Nonstocked	999	0.02	0.21	0.40	0.02	0.33	0.42	3.12	2.05

4.7.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.7.10 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003). For shortleaf pine, the bark thickness is based on an equation in Harmon (1984). For some species, (red oak, black oak, scarlet oak, white oak, chestnut oak, black and swamp tupelo, red maple, and hickories), fire-related mortality is predicted using height of stem-bark char, rather than bark thickness, based on equations in Regelbrugge and Smith (1994). It is assumed that height of stem-bark char is 70% of flame length (expert communication with Elizabeth Reinhardt, Cain (1984)).

Table 4.7.10 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species used
eastern redcedar	0.038	
juniper	0.033	
shortleaf pine	***	
Virginia pine	0.033	
loblolly pine	0.052	
other softwood	0.045	
eastern white pine	0.045	
black walnut	0.041	
butternut	0.041	
tupelo	0.025	
swamp tupelo	0.037	
water tupelo	0.03	
blackgum	0.039	
shagbark hickory	0.04	
shellbark hickory	0.043	
mockernut hickory	0.043	
pignut hickory	0.037	
hybrid hickory	0.044	
water hickory	0.044	hickory spp
bitternut hickory	0.037	
pecan	0.036	
black hickory	0.04	
American beech	0.025	
black ash	0.035	
pumpkin ash	0.037	
blue ash	0.03	
eastern cottonwood	0.04	
red maple	0.028	
boxelder	0.034	
silver maple	0.031	
black cherry	0.03	
American elm	0.031	
southern red oak	0.044	
black oak	0.045	
scarlet oak	0.04	
blackjack oak	0.037	
chinkapin oak	0.042	
swamp white oak	0.045	
bur oak	0.042	
swamp chestnut oak	0.046	
post oak	0.044	
bottomland post oak	0.044	post oak
chestnut oak	0.049	
pin oak	0.041	
cherrybark oak	0.044	s. red oak
shingle oak	0.041	
overcup oak	0.039	
water oak	0.036	
Nuttall oak	0.03	
willow oak	0.041	
Shumard's oak	0.037	
sassafras	0.035	
Ohio buckeye	0.036	
catalpa	0.037	
common persimmon	0.041	
honeylocust	0.038	
balsam poplar	0.04	
bigtooth aspen	0.039	
quaking aspen	0.044	
black locust	0.049	
American sycamore	0.033	
bald cypress	0.025	
river birch	0.029	
sweetgum	0.036	

Species	Multiplier (V_{sp})	Species used
sugarberry	0.036	
common hackberry	0.036	sugarberry
winged elm	0.031	
elm	0.039	
Siberian elm	0.038	
slippery elm	0.032	
rock elm	0.033	
tuliptree	0.041	
American basswood	0.038	
sugar maple	0.033	
ash	0.042	
white ash	0.042	
green ash	0.039	
white oak	0.04	
northern red oak	0.042	
willow	0.041	
black willow	0.04	
other hardwood	0.041	dogwood
American hornbeam	0.03	
eastern redbud	0.035	
flowering dogwood	0.041	
hawthorn	0.038	
Kentucky coffeetree	0.031	
Osage-orange	0.037	
cucumber tree	0.036	
sweetbay	0.04	
mulberry	0.033	
hophornbeam	0.037	
sourwood	0.036	

4.7.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.7.11). Default wood decay rates are based on Abbott and Crossley (1982) and Barber and VanLear (1984). The litter decay rate is based on Sharpe et. al. (1980) and Witkamp (1966). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.7.11 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.11	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.07	
6 – 12		
> 12		
Litter	0.65	
Duff	0.002	0.0

By default, FFE decays all wood species at the rates shown in Table 4.7.11. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.7.12 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword. The decay rate classes were generally determined from the Wood Handbook (1999) and from input given at the SN-FFE development workshop.

Table 4.7.12 - Default wood decay classes used in the CS-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Rate Class
eastern redcedar	2
juniper	2
shortleaf pine	4
Virginia pine	4
loblolly pine	4
other softwood	4
eastern white pine	4
black walnut	2
butternut	4
southern red oak	3
black oak	3
scarlet oak	3
blackjack oak	2
chinkapin oak	2
swamp white oak	2
bur oak	2
swamp chestnut oak	3
post oak	2

Species	Decay Rate Class
tupelo	2
swamp tupelo	2
water tupelo	2
blackgum	2
shagbark hickory	4
shellbark hickory	4
mockernut hickory	4
pignut hickory	4
hybrid hickory	4
water hickory	4
bitternut hickory	4
pecan	4
black hickory	4
American beech	4
black ash	4
pumpkin ash	4
blue ash	4
eastern cottonwood	4
red maple	4
boxelder	4
silver maple	4
black cherry	2
American elm	4
sugarberry	4
common hackberry	4
winged elm	4
elm	4
Siberian elm	4
slippery elm	4
rock elm	4
tuliptree	4
American basswood	4
sugar maple	4
ash	4
white ash	4
green ash	4
white oak	2
northern red oak	3

Species	Decay Rate Class
bottomland post oak	2
chestnut oak	3
pin oak	3
cherrybark oak	3
shingle oak	2
overcup oak	3
water oak	2
Nuttall oak	3
willow oak	2
Shumard's oak	3
sassafras	2
Ohio buckeye	4
catalpa	2
common persimmon	2
honeylocust	2
balsam poplar	4
bigtooth aspen	4
quaking aspen	4
black locust	1
American sycamore	4
bald cypress	3
river birch	4
sweetgum	4
willow	4
black willow	4
other hardwood	3
American hornbeam	3
eastern redbud	3
flowering dogwood	3
hawthorn	4
Kentucky coffeetree	4
Osage-orange	1
cucumber tree	4
sweetbay	4
mulberry	1
hophornbeam	3
sourwood	4

4.7.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.7.13) or they can specify moisture conditions using the MOISTURE keyword. These defaults were taken from the SN-FFE and are based on input from Gregg Vickers and Bennie Terrell. Duff moisture values are from FOFEM.

Table 4.7.13 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1-hr)	5	6	7	16
0.25 – 1.0 in. (10-hr)	7	8	9	16
1.0 – 3.0 in. (100-hr)	12	13	14	18
> 3.0 in. (1000+ -hr)	17	18	20	50
Duff	40	75	100	175
Live	55	80	100	150

4.7.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. Stand management actions such as thinning and harvesting can abruptly increase fuel loads, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the CS-FFE to follow the third of these four options.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.7.4, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. Table 4.7.14 and Table 4.7.15 define which low fuel model(s) will become candidates. According to the logic of this table, only a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, moisture levels, etc.).

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.7.4 or Table 4.7.15. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

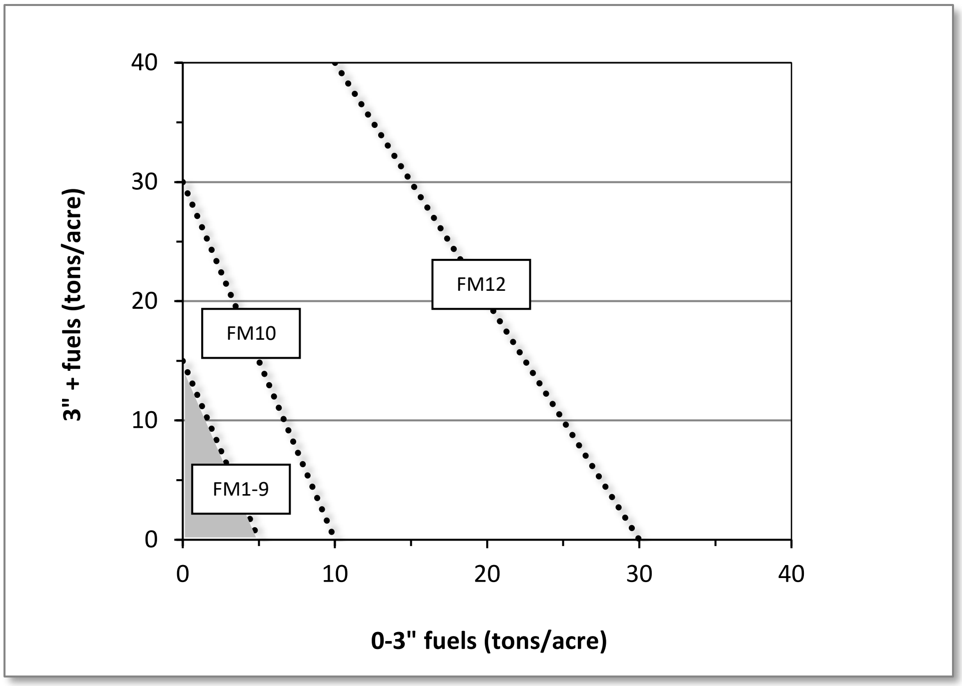


Figure 4.7.4 - If large and small fuels map to fuel models 1 - 9, candidate fuel models are determined using the logic shown in Table 4.7.14 and Table 4.7.15. Otherwise, fire behavior is based on the distance to the closest fuel models, identified by the dashed lines.

Table 4.7.14 - When low fuel loads are present in the CS-FFE, fire behavior fuel models are determined using forest type. This table shows how forest type is determined. A default of Hardwood is used when the forest type code does not key to any of the listed forest types.

Forest Type	Definition
Hardwood	Forest type code of 504, 505, 510, 512, 515, 519, 520 or 997; Forest type code 501 or 503 and not Oak Savannah;
Hardwood-Pine	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, 401, 403, 404, 405, 406, 407, 409, or 996, 50% or less BA in pine, and not Pine-Bluestem
Pine-Hardwood	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, 401, 403, 404, 405, 406, 407, 409, or 996, 50 - 70% BA in pine, and not Pine-Bluestem
Pine	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, 401, 403, 404, 405, 406, 407, 409, or 996, more than 70% BA in pine, and not Pine-Bluestem
Pine-Bluestem	Forest type code of 162, less than fully stocked and average top height > 50 ft.
Oak Savannah	Forest type code of 501 or 503, less than fully stocked and average top height > 30 ft.
Eastern Redcedar	Forest type code of 181 or 402
Bottomland Hardwoods	Forest type code of 602, 605, 701, 706, 708, or 807
Non-stocked	Forest type code of 999

Table 4.7.15 - Relationship between forest type and fuel model selected.

Forest type		Fuel model
Hardwood, Hardwood-Pine, and Pine-Hardwood	0-3” fuel > 5 tons	5
	0-3” fuel <=5 tons and 3”+ moisture >20%	8
	0-3” fuel <= 5 tons and 3”+ moisture <= 20%	9
Pine and Bottomland Hardwoods	3”+ moisture >20%	8
	3”+ moisture <= 20%	9
Pine-Bluestem		2
Oak Savannah		2
Eastern Redcedar	Avg. ht. of redcedar > 6 ft.	4
	Avg. ht. of redcedar <= 6 ft.	6
Non-stocked		6

4.7.8 Other

Crown fire is not modeled in the CS-FFE. As a result, every fire is seen as a surface fire, and crown fire hazard indices, such as the torching index and crowning index, are not reported. Canopy base height and canopy bulk density are reported, but keep in mind that these calculations do not include hardwoods (by default – users can adjust this with the CanCalc keyword). Also, when using the FlameAdj keyword to alter predicted fire behavior, users can override the flame length only. No matter what users enter for percent crowning (zero, blank, positive value, this will be overwritten internally with zero. If users would like to simulate additional mortality due to crowning, the FixMort keyword can be used to do so. Lastly, because the fuel models selected depend on fuel moisture, two sets of fuel models are reported in the potential fire report – one for the severe case and one for the moderate.

4.8 Eastern Cascades (EC)

4.8.1 Tree Species

The Eastern Cascades variant models the 30 tree species shown in Table 4.8.1. In also includes two additional categories; ‘other softwood’ is modeled using mountain hemlock, and ‘other hardwood’ is modeled using quaking aspen.

Table 4.8.1 - Tree species simulated by the Eastern Cascades variant.

Common Name	Scientific Name	Notes
western white pine	*Pinus monticola*	
western larch	*Larix occidentalis*	
Douglas-fir	*Pseudotsuga menziesii*	
Pacific silver fir	*Abies amabilis*	
western redcedar	*Thuja plicata*	
grand fir	*Abies grandis*	
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
subalpine fir	*Abies lasiocarpa*	
ponderosa pine	*Pinus ponderosa*	
western hemlock	*Tsuga heterophylla*	= WC western hemlock
mountain hemlock	*Tsuga mertensiana*	= EC mountain hemlock
Pacific yew	*Taxus brevifolia*	= WC Pacific yew
whitebark pine	*Pinus albicaulis*	= WC whitebark pine
noble fir	*Abies procera*	= WC noble fir
white fir	*Abies concolor*	= EC grand fir
subalpine larch	*Larix lyallii*	= WC subalpine larch
Alaska cedar	*Callitropsis nootkatensis*	= WC Alaska cedar
western juniper	*Juniperus occidentalis*	= WC western juniper
bigleaf maple	*Acer macrophyllum*	= WC bigleaf maple
vine maple	*Acer circinatum*	= WC bigleaf maple
red alder	*Alnus rubra*	= WC red alder
paper birch	*Betula papyrifera*	= WC paper birch
giant chinquapin	*Chrysolepis chrysophylla* var. *chrysophylla*	= WC giant chinquapin
Pacific dogwood	*Cornus nuttallii*	= WC Pacific dogwood
quaking aspen	*Populus tremuloides*	= WC quaking aspen
black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	= WC black cottonwood
Oregon white oak	*Quercus garryana*	= WC Oregon white oak
plum	*Prunus*	= WC bitter cherry
willow	*Salix*	= WC willow species
other softwood		= EC mountain hemlock
other hardwood		= WC quaking aspen

4.8.2 Snags

In the EC variant, the snag dynamics were modified based on the work of Kim Mellen-McLean, region 6 wildlife ecologist. These relationships are described in the following document: http://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/R6snags.pdf

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.8.2 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

4.8.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density values calculated from the green specific gravity values from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.8.2 for Douglas-fir is based on ‘Douglas-fir south’.

Table 4.8.2 - Wood density (ovendry lb/ft^3) used in the EC-FFE variant.

Species	Density (lbs/ft^3)	Species	Density (lbs/ft^3)
western white pine	22.5	subalpine larch	29.9
western larch	29.9	Alaska cedar	26.2
Douglas-fir	28.7	western juniper	34.9
Pacific silver fir	24.9	bigleaf maple	27.4
western redcedar	19.3	vine maple	27.4
grand fir	21.8	red alder	23.1
lodgepole pine	23.7	paper birch	29.9
Engelmann spruce	20.6	giant chinquapin	36.2
subalpine fir	19.3	Pacific dogwood	27.4
ponderosa pine	23.7	quaking aspen	21.8
western hemlock	26.2	black cottonwood	19.3
mountain hemlock	26.2	Oregon white oak	37.4
Pacific yew	26.2	plum	29.3
whitebark pine	22.5	willow	22.5
noble fir	23.1	other softwood	26.2
white fir	21.8	other hardwood	21.8

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the EC-FFE (Table 4.8.3). Mountain hemlock biomass is based on Gholz and others (1979), using western hemlock equations from Brown and Johnston to partition the biomass and also to provide estimates for trees under one inch diameter.

Table 4.8.3 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
western white pine	Brown and Johnston (1976)
western larch	Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
Pacific silver fir	grand fir; Brown and Johnston (1976)
western redcedar	Brown and Johnston (1976)
grand fir	Brown and Johnston (1976)
lodgepole pine	Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
western hemlock	Brown and Johnston (1976)
mountain hemlock	Gholz and others (1979); western hemlock (Brown and Johnston 1976)
Pacific yew	western redcedar; Brown and Johnston (1976)
whitebark pine	Johnston (1976)
noble fir	grand fir; Brown and Johnston (1976)
white fir	grand fir; Brown and Johnston (1976)
subalpine larch	subalpine fir; Brown and Johnston (1976)
Alaska cedar	western larch; Brown and Johnston (1976)
western juniper	oneseed juniper; Grier and others (1992)
bigleaf maple	Snell and Little (1983)
vine maple	bigleaf maple; Snell and Little (1983)
red alder	Snell and Little (1983)
paper birch	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
giant chinquapin	tanoak; Snell and Little (1983), Snell (1979)
Pacific dogwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
quaking aspen	Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
black cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Oregon white oak	tanoak; Snell and Little (1983), Snell (1979)
plum	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
willow	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other softwood	Gholz and others (1979); Brown and Johnston (1976)
other hardwood	aspen; Jenkins et. al. (2003), Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.8.4. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are from Keane and others (1989). Lifespans of western white pine and mountain hemlock are mapped using ponderosa pine, and western hemlock and western redcedar are based on Douglas-fir.

Table 4.8.4 - Life span of live and dead foliage (yr) and dead branches for species modeled in the EC-FFE variant.

	Live	**Dead**			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
western white pine	4	2	5	5	15
western larch	1	1	5	5	15
Douglas-fir	5	2	5	5	15
Pacific silver fir	7	2	5	5	15
western redcedar	5	2	5	5	20
grand fir	7	2	5	5	15
lodgepole pine	3	2	5	5	15
Engelmann spruce	6	2	5	5	10
subalpine fir	7	2	5	5	15
ponderosa pine	4	2	5	5	10
western hemlock	5	3	10	15	15
mountain hemlock	4	2	5	5	10
Pacific yew	7	3	10	15	20
whitebark pine	3	3	10	15	15
noble fir	7	2	5	5	15
white fir	7	2	5	5	15
subalpine larch	1	1	5	5	15
Alaska cedar	5	2	5	5	20
western juniper	4	2	5	5	15
bigleaf maple	1	1	10	15	15
vine maple	1	1	10	15	15
red alder	1	1	10	15	15
paper birch	1	1	10	15	15
giant chinquapin	1	1	10	15	15
Pacific dogwood	1	1	10	15	15
quaking aspen	1	1	10	15	15
black cottonwood	1	1	10	15	15
Oregon white oak	1	1	10	15	15
plum	1	1	10	15	15
willow	1	1	10	15	15
other softwood	4	2	5	5	10
other hardwood	1	1	10	15	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.8.5). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.8.5). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Western juniper values are from Ottmar and others (1998). Quaking aspen values are from Ottmar and others (2000b).

Table 4.8.5 - Values (dry weight, tons/acre) for live fuels used in the EC-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		**Herbs**	**Shrubs**	**Notes**
western white pine	E	0.15	0.10	
	I	0.30	2.00	
western larch	E	0.20	0.20	
	I	0.40	2.00	
Douglas-fir	E	0.20	0.20	

Species		**Herbs**	**Shrubs**	**Notes**
	I	0.40	2.00	
Pacific silver fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
western redcedar	E	0.20	0.20	
	I	0.40	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Engelmann spruce	E	0.15	0.20	
	I	0.30	2.00	
subalpine fir	E	0.15	0.20	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	
	I	0.25	0.10	
western hemlock	E	0.20	0.20	
	I	0.40	2.00	
mountain hemlock	E	0.15	0.20	
	I	0.30	2.00	
Pacific yew	E	0.20	0.20	
	I	0.40	2.00	
whitebark pine	E	0.20	0.10	
	I	0.40	1.00	
noble fir	E	0.15	0.10	
	I	0.30	2.00	
white fir	E	0.15	0.10	
	I	0.30	2.00	
subalpine larch	E	0.20	0.20	
	I	0.40	2.00	
Alaska cedar	E	0.20	0.20	
	I	0.40	2.00	
western juniper	E	0.14	0.35	Ottmar and others (1998)
	I	0.10	2.06	
bigleaf maple	E	0.20	0.20	
	I	0.40	2.00	
vine maple	E	0.20	0.20	
	I	0.40	2.00	
red alder	E	0.20	0.20	
	I	0.40	2.00	
paper birch	E	0.20	0.20	
	I	0.40	2.00	
giant chinquapin	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	
Pacific dogwood	E	0.20	0.20	
	I	0.40	2.00	
quaking aspen	E	0.25	0.25	Ottmar and others 2000b
	I	0.18	1.32	
black cottonwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
Oregon white oak	E	0.23	0.22	
	I	0.55	0.35	
plum	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
willow	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other softwood	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	

Species		Herbs	Shrubs	Notes
other hardwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.8.6). Western juniper values are from Ottmar and others (1998). Quaking aspen values are from Ottmar and others (2000b). If tree canopy cover is <10 percent, the DWD pools are assigned an “initiating” value and if cover is >60 percent they are assign the “established” value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.8.6 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

		Size Class (in)							
Species		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
western larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Pacific silver fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
western redcedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
western hemlock	E	0.7	0.7	3.0	7.0	7.0	10.0	1.0	35.0
	I	0.5	0.5	2.0	2.8	2.8	6.0	0.5	12.0
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
Pacific yew	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.1	1.1	3.6	6.0	8.0	6.0	0.5	12.0
whitebark pine	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
noble fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
subalpine larch	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Alaska cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.1	1.1	3.6	6.0	8.0	6.0	0.5	12.0
western juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
bigleaf maple	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.1	1.1	3.6	6.0	8.0	6.0	0.5	12.0
vine maple	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.1	1.1	3.6	6.0	8.0	6.0	0.5	12.0
red alder	E	0.7	0.7	1.6	2.5	2.5	5.0	0.8	30.0
	I	0.1	0.1	0.2	0.5	0.5	3.0	0.4	12.0
paper birch	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.1	1.1	3.6	6.0	8.0	6.0	0.5	12.0
giant chinquapin	E	0.7	0.7	0.8	1.2	1.2	0.5	1.4	0.0
	I	0.1	0.1	0.1	0.2	0.2	0.0	0.5	0.0
Pacific dogwood	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.1	1.1	3.6	6.0	8.0	6.0	0.5	12.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
Oregon white oak	E	0.7	0.7	0.8	1.2	1.2	0.5	1.4	0.0
	I	0.1	0.1	0.1	0.2	0.2	0.0	0.5	0.0
plum	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
willow	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other softwood	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
other hardwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.8.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.8.7 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.8.7 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species	Multiplier (V_{sp})
western white pine	0.035	subalpine larch	0.050
western larch	0.063	Alaska cedar	0.022
Douglas-fir	0.063	western juniper	0.025
Pacific silver fir	0.047	bigleaf maple	0.024
western redcedar	0.035	vine maple	0.024
grand fir	0.046	red alder	0.026
lodgepole pine	0.028	paper birch	0.027
Engelmann spruce	0.036	giant chinquapin	0.045
subalpine fir	0.041	Pacific dogwood	0.062
ponderosa pine	0.063	quaking aspen	0.044
western hemlock	0.040	black cottonwood	0.044
mountain hemlock	0.040	Oregon white oak	0.029
Pacific yew	0.025	plum	0.062
whitebark pine	0.030	willow	0.041
noble fir	0.045	other softwood	0.040
white fir	0.046	other hardwood	0.044

4.8.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5. Default decay rates (Table 4.8.8) are based on values provided by Kim Mellen-McLean, Pacific Northwest Regional wildlife ecologist, for the Pacific Northwest area. They are from published literature with adjustment factors based on temperature and moisture as determined by an expert panel at the Dead Wood Decay Calibration workshop in July 2003. The habitat code set by the **STDINFO** keyword or read in from an input database determines the temperature and moisture class for a stand, as shown in Table 4.8.9.

A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster. The decay rates for individual species vary based on the decay rate class of that species (Table 4.8.10). The decay rates may be modified for each decay class using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.8.8 - Default annual loss rates are applied based on size class, temperature and moisture class, and decay rate class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

	Size Class (inches)	Annual Loss Rate				Proportion of Loss Becoming Duff
		decay class 1	decay class 2	decay class 3	decay class 4	
hot, mesic	< 0.25	0.113	0.121	0.134	0.168	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.036	0.048	0.063	0.111	
	6 – 12					
	> 12	0.028	0.037	0.049	0.086	
hot, dry	< 0.25	0.057	0.061	0.068	0.085	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.021	0.028	0.049	
	6 – 12					
	> 12	0.014	0.019	0.025	0.044	
moderate, wet	< 0.25	0.103	0.109	0.122	0.153	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.035	0.046	0.061	0.107	
	6 – 12					
	> 12	0.026	0.034	0.045	0.078	
moderate, mesic	< 0.25	0.076	0.081	0.090	0.113	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.032	0.043	0.056	0.099	
	6 – 12					
	> 12	0.019	0.025	0.033	0.058	
moderate, dry	< 0.25	0.067	0.071	0.079	0.099	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.023	0.030	0.040	0.070	
	6 – 12					
	> 12	0.017	0.022	0.029	0.051	
cold, wet	< 0.25	0.092	0.098	0.109	0.137	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.034	0.045	0.059	0.104	
	6 – 12					
	> 12	0.023	0.030	0.040	0.070	
cold, mesic	< 0.25	0.087	0.092	0.103	0.129	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.033	0.044	0.058	0.102	
	6 – 12					
	> 12	0.022	0.029	0.038	0.066	
cold, dry	< 0.25	0.057	0.061	0.068	0.085	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.021	0.028	0.049	
	6 – 12					
	> 12	0.014	0.019	0.025	0.044	
All	Litter	0.50	0.50	0.50	0.50	0.02
	Duff	0.002	0.002	0.002	0.002	0.0

Table 4.8.9 - Habitat type - moisture and temperature regime relationships for the EC-FFE variant. The moisture and temperature classes affect the default decay rates. The original class is an older classification still used in the fuel model selection logic of this variant and was provided by Tom DeMeo, USFS, Portland, OR (pers. comm. 2001).

Habitat Type Code	Orig. Class	Temperature	Moisture	Habitat Type Code	Orig. Class	Temperature	Moisture
CAG112	Dry	cold	dry	CFS553	Moist	moderate	wet
CAS311	Mesic	cold	dry	CFS556	Moist	cold	wet
CCF211	Moist	moderate	mesic	CFS558	Moist	moderate	mesic
CCF212	Moist	moderate	mesic	CFS621	Moist	moderate	mesic
CCF221	Mesic	moderate	mesic	CHC311	Moist	moderate	mesic
CCF222	Moist	moderate	mesic	CHF223	Moist	moderate	mesic
CCS211	Moist	moderate	wet	CHF311	Moist	moderate	mesic
CCS311	Mesic	moderate	mesic	CHF312	Moist	moderate	mesic
CDF411	Dry	moderate	mesic	CHF313	Moist	moderate	mesic
CDG123	Dry	moderate	mesic	CHF422	Moist	moderate	mesic
CDG131	Dry	moderate	dry	CHF521	Mesic	moderate	dry
CDG132	Dry	moderate	dry	CHS142	Mesic	moderate	mesic
CDG134	Dry	moderate	dry	CHS143	Moist	moderate	mesic
CDG141	Dry	moderate	dry	CHS144	Moist	moderate	mesic
CDG311	Dry	hot	dry	CHS225	Moist	moderate	mesic
CDG321	Mesic	moderate	mesic	CHS226	Moist	moderate	mesic
CDG322	Dry	moderate	dry	CHS227	Moist	moderate	mesic
CDG323	Dry	moderate	dry	CHS411	Moist	moderate	mesic
CDS231	Dry	moderate	dry	CHS711	Moist	moderate	wet
CDS241	Mesic	moderate	dry	CLS521	Mesic	moderate	mesic
CDS411	Dry	moderate	mesic	CMF131	Moist	cold	dry
CDS412	Dry	moderate	mesic	CMG221	Moist	cold	mesic
CDS631	Dry	moderate	dry	CMS121	Moist	cold	dry
CDS632	Dry	moderate	dry	CMS122	Moist	cold	mesic
CDS633	Mesic	moderate	mesic	CMS256	Moist	cold	wet
CDS636	Mesic	moderate	mesic	CMS257	Moist	cold	wet
CDS637	Dry	moderate	dry	CMS258	Moist	cold	mesic
CDS638	Dry	moderate	mesic	CMS259	Moist	cold	mesic
CDS639	Dry	moderate	mesic	CMS354	Moist	cold	mesic
CDS640	Dry	moderate	mesic	CMS355	Moist	cold	wet
CDS653	Dry	moderate	mesic	CMS356	Moist	cold	mesic
CDS654	Dry	moderate	dry	CPG141	Dry	hot	dry
CDS655	Dry	moderate	mesic	CPG231	Dry	hot	dry
CDS661	Mesic	moderate	mesic	CPH211	Dry	hot	dry
CDS662	Dry	moderate	mesic	CPH212	Dry	moderate	dry
CDS673	Dry	moderate	dry	CPS241	Dry	hot	dry
CDS674	Dry	moderate	dry	CWC511	Moist	moderate	mesic
CDS675	Dry	moderate	dry	CWF321	Moist	moderate	mesic
CDS715	Dry	moderate	dry	CWF444	Mesic	moderate	mesic
CDS716	Mesic	moderate	dry	CWF521	Moist	moderate	mesic
CDS811	Mesic	moderate	mesic	CWF522	Moist	moderate	mesic
CDS813	Mesic	moderate	mesic	CWF523	Moist	moderate	mesic
CDS814	Mesic	moderate	mesic	CWF524	Moist	moderate	mesic
CDS831	Moist	moderate	mesic	CWG121	Dry	moderate	dry
CDS832	Mesic	moderate	mesic	CWG122	Dry	moderate	dry
CDS833	Mesic	moderate	mesic	CWG123	Dry	moderate	dry
CEF111	Mesic	cold	dry	CWG124	Dry	moderate	dry
CEF211	Moist	cold	mesic	CWG125	Mesic	moderate	dry
CEF222	Moist	cold	mesic	CWS214	Moist	moderate	mesic
CEF421	Moist	cold	mesic	CWS221	Moist	moderate	mesic
CEF422	Moist	cold	wet	CWS222	Moist	moderate	mesic
CEF423	Moist	cold	mesic	CWS223	Moist	moderate	mesic
CEF424	Moist	cold	mesic	CWS224	Mesic	moderate	mesic
CEG121	Moist	cold	mesic	CWS225	Mesic	moderate	mesic

Habitat Type Code	Orig. Class	Temperature	Moisture	Habitat Type Code	Orig. Class	Temperature	Moisture
CEG310	Mesic	cold	dry	CWS226	Mesic	moderate	mesic
CEG311	Mesic	cold	dry	CWS331	Dry	moderate	mesic
CEM211	Moist	cold	wet	CWS332	Moist	moderate	mesic
CES111	Moist	cold	mesic	CWS335	Dry	moderate	mesic
CES113	Moist	cold	mesic	CWS336	Dry	moderate	mesic
CES210	Mesic	cold	dry	CWS337	Dry	moderate	dry
CES211	Mesic	cold	wet	CWS338	Dry	moderate	mesic
CES213	Mesic	cold	mesic	CWS421	Dry	moderate	dry
CES312	Mesic	cold	mesic	CWS422	Moist	moderate	mesic
CES313	Mesic	cold	mesic	CWS531	Dry	moderate	dry
CES342	Mesic	cold	mesic	CWS532	Moist	moderate	mesic
CES412	Mesic	cold	dry	CWS533	Dry	moderate	dry
CES413	Mesic	cold	dry	CWS534	Dry	moderate	dry
CES422	Moist	cold	mesic	CWS535	Mesic	moderate	mesic
CES423	Moist	cold	mesic	CWS536	Moist	moderate	mesic
CES424	Mesic	cold	dry	CWS537	Moist	moderate	mesic
CES425	Mesic	cold	dry	CWS551	Moist	moderate	mesic
CES426	Mesic	cold	dry	CWS552	Mesic	moderate	mesic
CFF162	Moist	moderate	mesic	CWS553	Moist	moderate	mesic
CFF254	Moist	moderate	mesic	CWS554	Dry	moderate	dry
CFS232	Moist	moderate	mesic	CWS821	Moist	moderate	mesic
CFS233	Moist	cold	mesic	HQG111	Dry	moderate	dry
CFS234	Moist	cold	mesic	HQS211	Dry	moderate	mesic
CFS542	Moist	moderate	wet				

Table 4.8.10 - Default wood decay classes used in the EC-FFE variant. Classes are based on the advice of an expert panel at the Dead Wood Decay Calibration workshop organized by Kim Mellen-McLean in July 2003.

Species	Decay Rate Class	Species	Decay Rate Class
western white pine	1	subalpine larch	1
western larch	1	Alaska cedar	1
Douglas-fir	1	western juniper	1
Pacific silver fir	3	bigleaf maple	4
western redcedar	1	vine maple	4
grand fir	3	red alder	4
lodgepole pine	2	paper birch	4
Engelmann spruce	2	giant chinquapin	3
subalpine fir	3	Pacific dogwood	4
ponderosa pine	3	quaking aspen	4
western hemlock	2	black cottonwood	4
mountain hemlock	2	Oregon white oak	3
Pacific yew	1	plum	4
whitebark pine	1	willow	4
noble fir	3	other softwood	2
white fir	3	other hardwood	4

4.8.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.8.11) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.8.11 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	4	8	12	16
0.25 – 1.0 in. (10-hr)	4	8	12	16
1.0 – 3.0 in. (100-hr)	5	10	14	18
> 3.0 in. (1000+ -hr)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.8.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger ‘Activity Fuels’ conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the EC-FFE to follow the third of these four options. The fuel model selection logic is based on information provided by Tom Leuschen, USFS, Okanogan, WA (pers. comm. 2001) and Eric Watrud, USFS, Regional Silviculturist (pers. comm. 2012). The appropriate fuel model is determined using combinations of categorical measures of cover type, canopy cover (CC), size (QMD) and whether the canopy is composed of a single stratum or is multi-storied (Single). The FVS base model provides measures of canopy cover and size, and the base model structural stage logic from Crookston and Stage (1999) determines whether the canopy is single- or multi-storied.

There are 11 sets of logical rules, each based on cover type. As described below, one of 15 cover types is used to select from among the eleven flowcharts shown below. If one of these species groupings:

- Douglas-fir
- subalpine fir (includes noble fir and white fir)
- Pacific silver fir
- lodgepole pine (includes whitebark pine)
- ponderosa pine
- white pine
- Engelmann spruce
- western larch (includes subalpine larch)
- mountain hemlock (includes western hemlock)

comprises more than half the stand basal area, the flowchart for the first species listed will be used. Failing that, these combinations of species are searched for:

- Douglas-fir/grand fir;
- ponderosa pine/Douglas-fir; then
- lodgepole pine/western larch (includes whitebark pine and subalpine larch)

and the corresponding cover type flowchart used. If a cover type has not been selected yet, these three cover types are searched in order:

- subalpine fir leading;
- moist habitat mixed conifer; then
- dry habitat mixed conifer.

Moist and dry habitat are based on the habitat code provided by the **STDINFO** keyword, using the classification shown in Table 4.8.9.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.8.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The cover types described above, along with the flow diagrams below, define which low fuel model(s) will become candidates. According to the logic of the figure, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, snag density, etc.).

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.8.1 or the flow diagrams. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

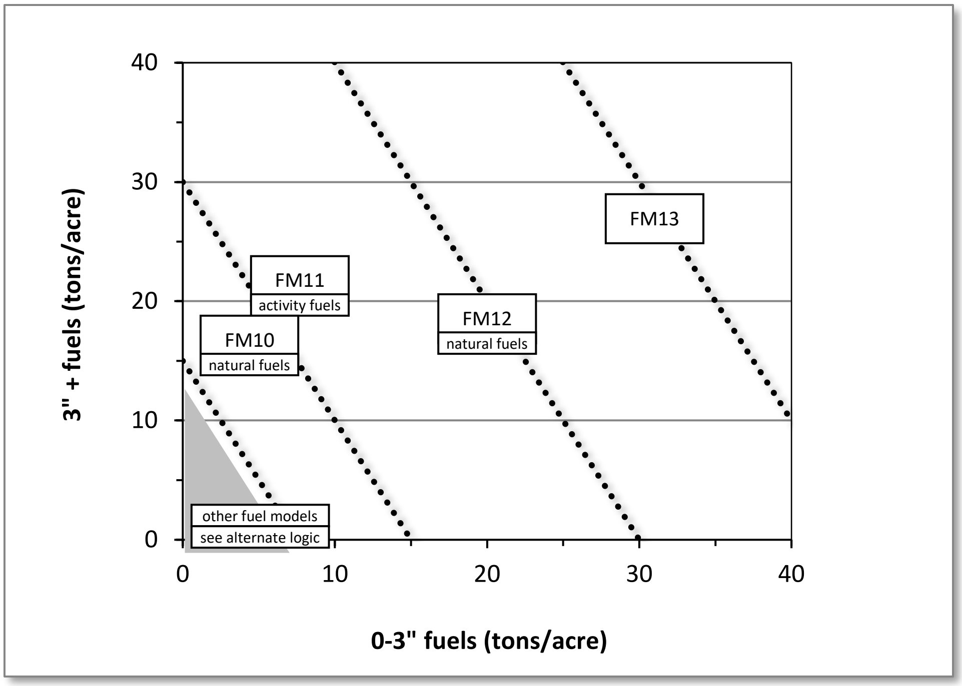
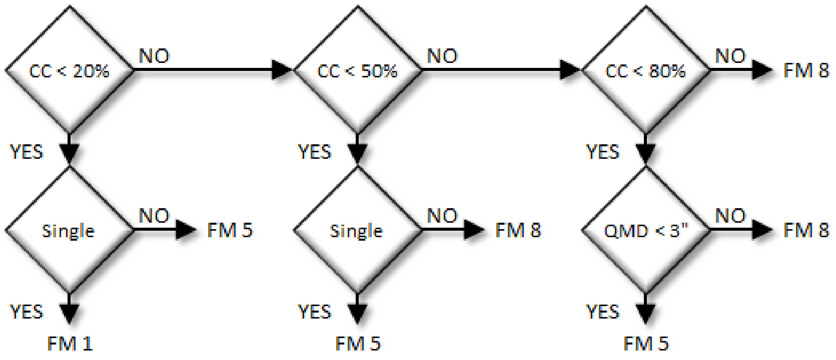
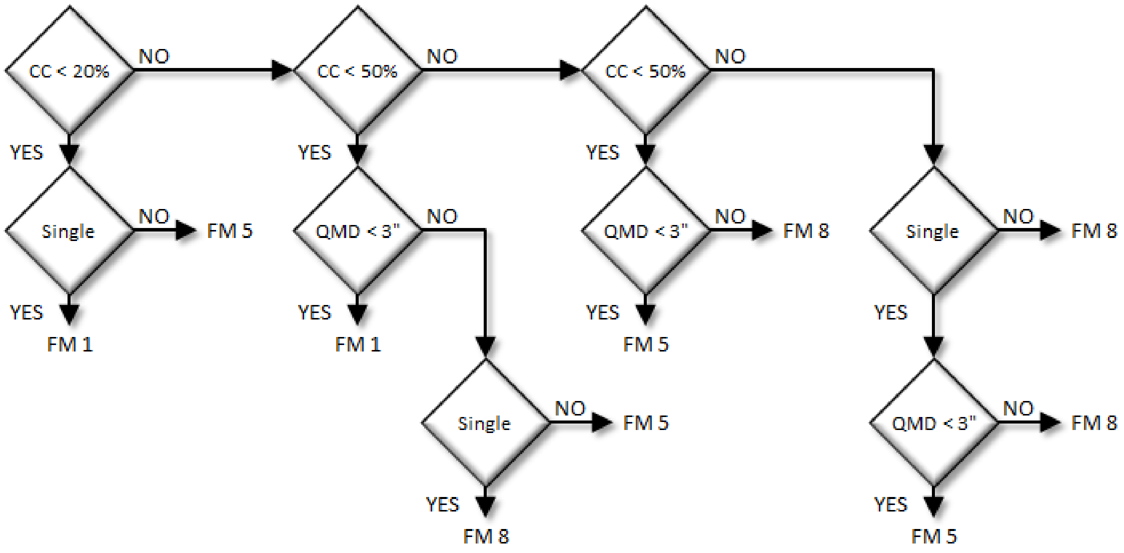


Figure 4.8.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in the figures below. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

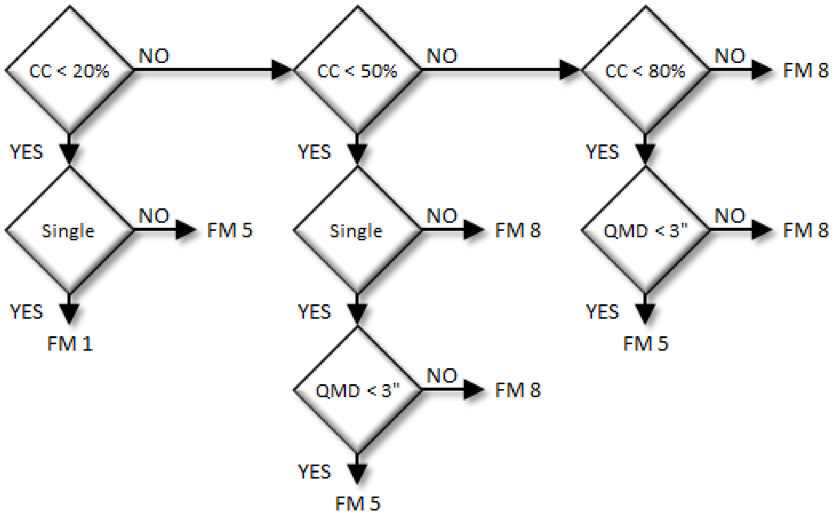
Douglas fir



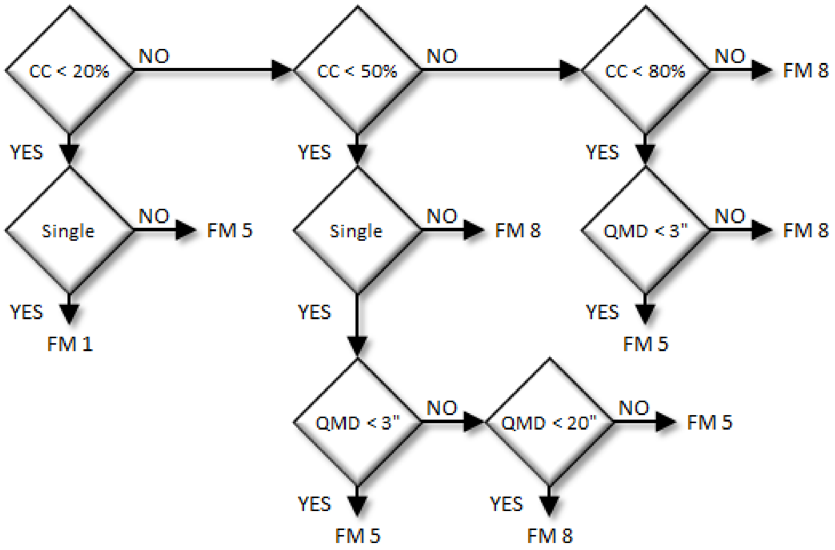
Lodgepole Pine, White Pine



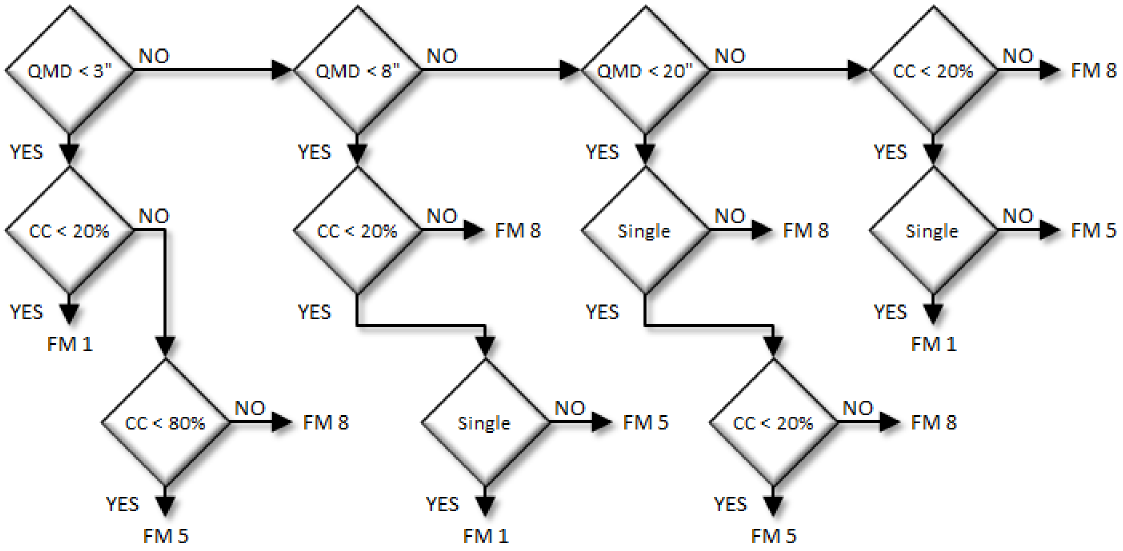
Subalpine fir, subalpine fir mixture



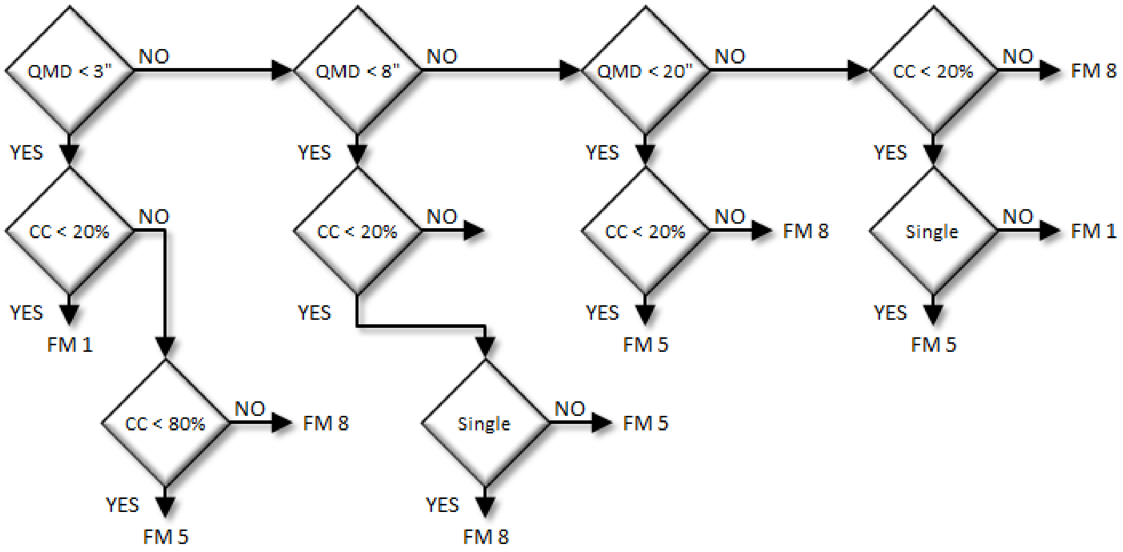
Mountain hemlock, pacific silver fir, Douglas fir/grand fir



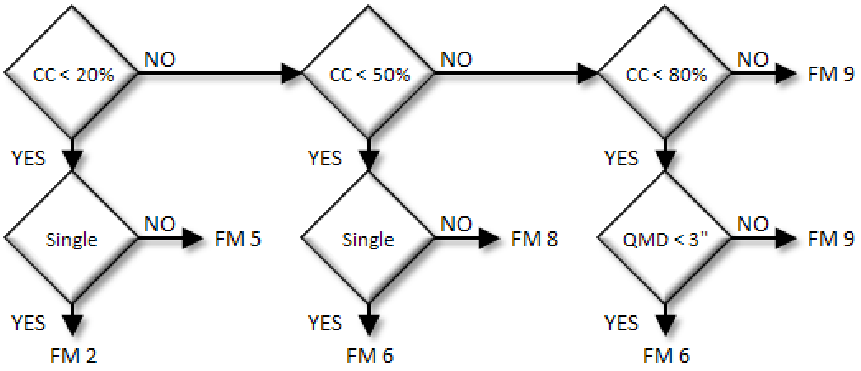
Engelmann spruce



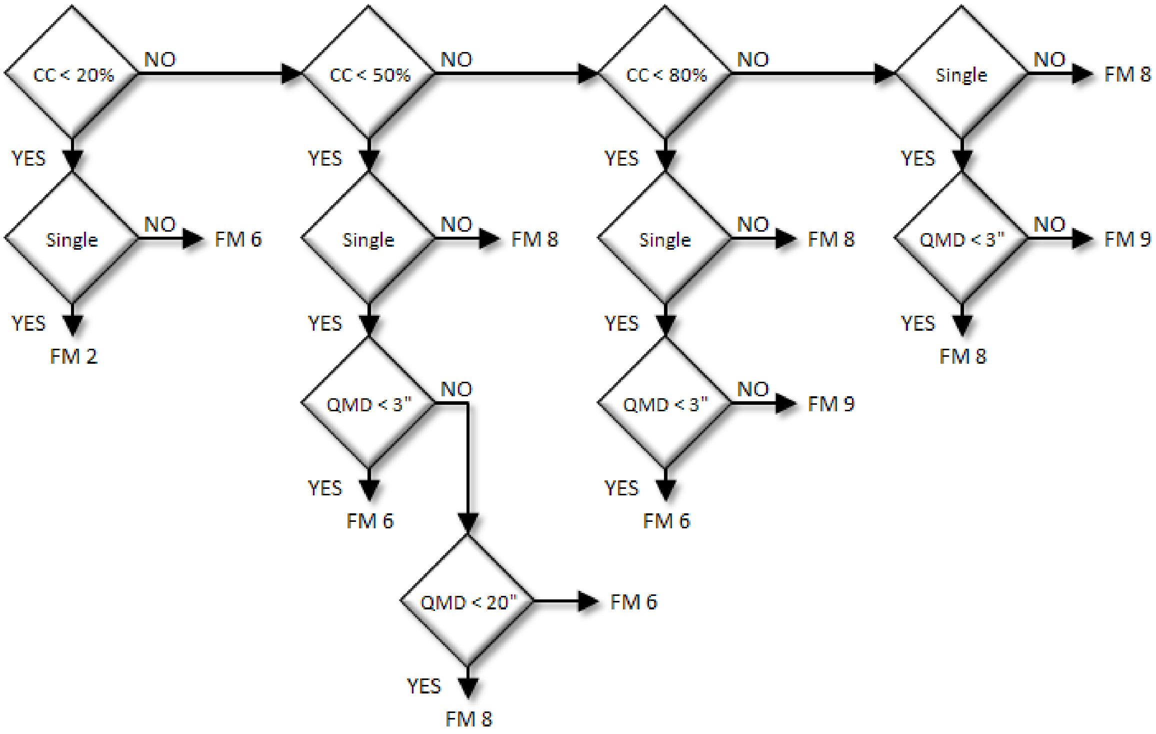
Western larch



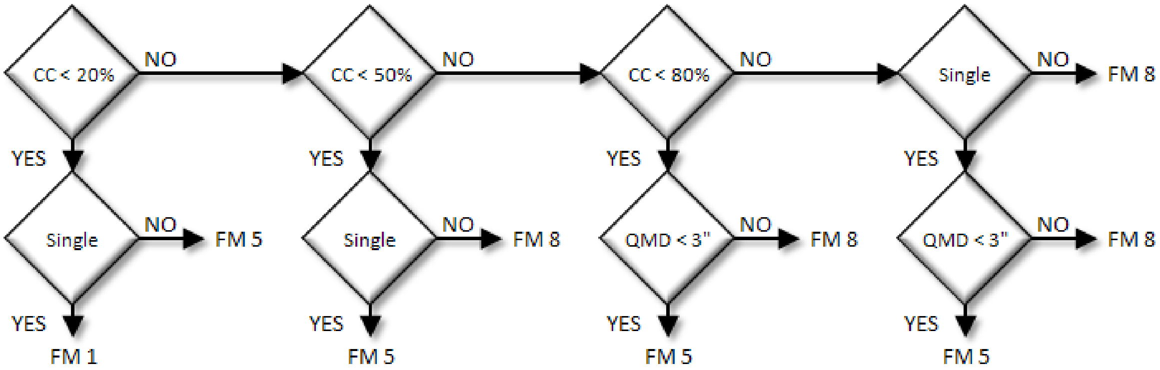
Ponderosa pine



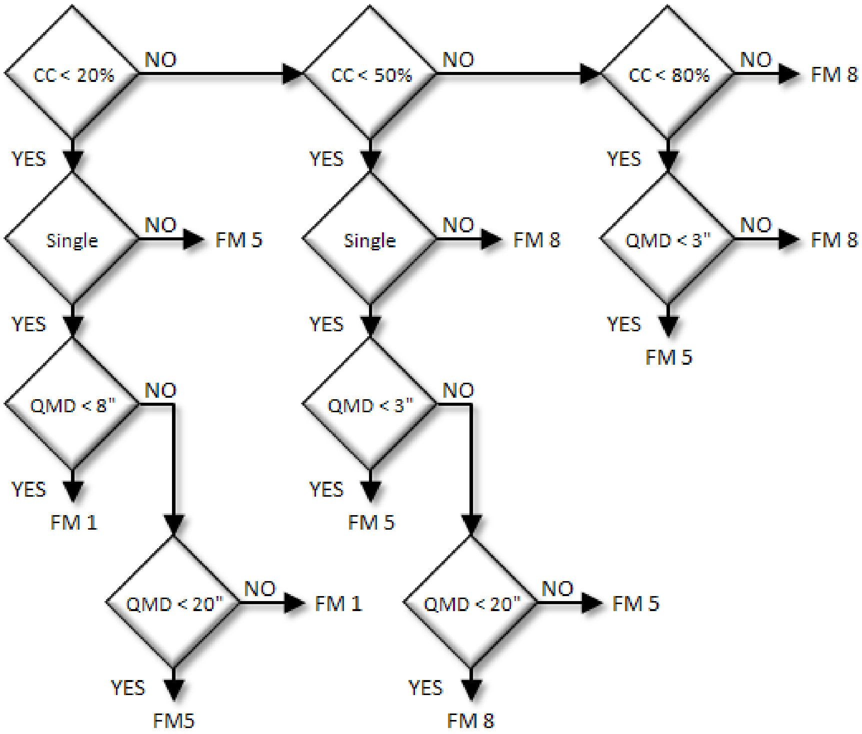
Ponderosa pine/Douglas fir

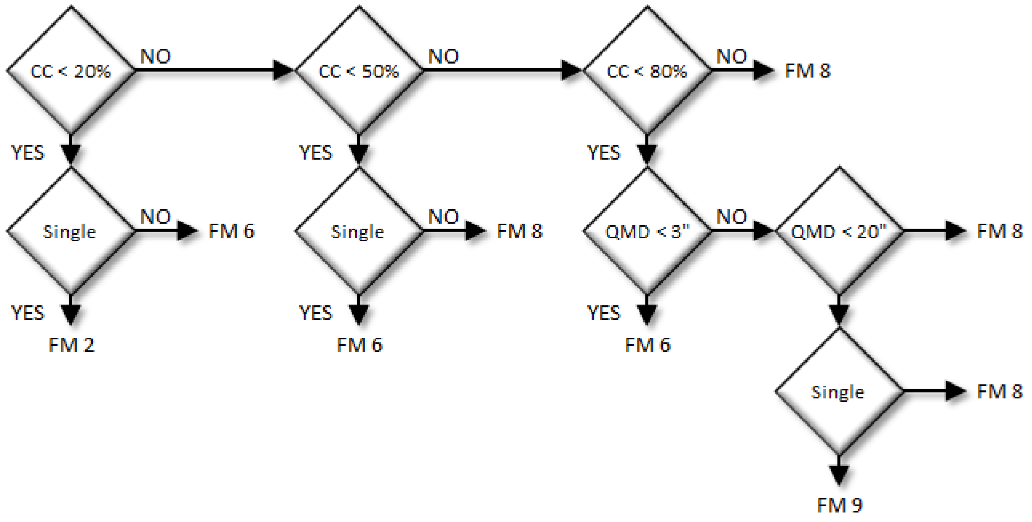


Lodgepole pine/Western larch



Moist habitat mixture





Dry habitat mixture

4.9 Eastern Montana (EM)

4.9.1 Tree Species

The Eastern Montana variant models the 17 tree species shown in Table 4.9.1. Two additional categories, ‘other softwood’ and ‘other hardwood’, are modeled using whitebark pine and cottonwood, respectively.

Table 4.9.1 - Tree species simulated by the Eastern Montana variant.

Common Name	Scientific Name	Notes
whitebark pine	*Pinus albicaulis*	
western larch	*Larix occidentalis*	
Douglas-fir	*Pseudotsuga menziesii*	
limber pine	*Pinus flexilis*	= IE/TT limber pine
subalpine larch	*Larix lyallii*	= IE subalpine larch; NI subalpine fir
Rocky Mountain juniper	*Juniperus scopulorum*	= IE/UT Rky Mtn juniper
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
subalpine fir	*Abies lasiocarpa*	
ponderosa pine	*Pinus ponderosa*	
green ash	*Fraxinus pennsylvanica*	= IE/CR cottonwood
quaking aspen	*Populus tremuloides*	= IE/UT quaking aspen
black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	= IE/CR cottonwood
balsam poplar	*Populus balsamifera*	= IE/CR cottonwood
plains cottonwood	*Populus deltoides* ssp. *monolifera*	= IE/CR cottonwood
narrowleaf cottonwood	*Populus angustifolia*	= IE/CR cottonwood
paper birch	*Betula papyrifera*	= IE paper birch
other softwood		= UT quaking aspen
other hardwood		= IE/CR cottonwood

4.9.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the FFE design workshop. A complete description of the Snag Submodel is provided in section 2.3.

Four variables are used to modify the Snag Submodel for the different species in the EM-FFE variant:

- a multiplier to modify the species’ fall rate;
- a multiplier to modify the time required for snags to decay from a “hard” to “soft” state;
- the maximum number of years that snags will remain standing; and
- a multiplier to modify the species’ height loss rate.

These variables are summarized in Table 4.9.2 and Table 4.9.3.

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.9.4 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

Table 4.9.2 - Default snag fall, snag height loss and soft-snag characteristics for 20" DBH snags in the EM-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.9.3.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - -	- Years -	- - - - - - - - - -	
whitebark pine	34	110	33	42
western larch	34	110	33	42
Douglas-fir	34	110	33	42
limber pine	31	100	31	39
subalpine larch	31	100	31	39
Rocky Mountain juniper	31	100	31	39
lodgepole pine	28	90	27	35
Engelmann spruce	28	90	27	35
subalpine fir	28	90	27	35
ponderosa pine	31	100	31	39
green ash	31	100	31	39
quaking aspen	31	100	31	39
black cottonwood	31	100	31	39
balsam poplar	31	100	31	39
plains cottonwood	31	100	31	39
narrowleaf cottonwood	31	100	31	39
paper birch	31	100	31	39
other softwood	31	100	31	39
other hardwood	31	100	31	39

Table 4.9.3 - Default snag fall, snag height loss and soft-snag multipliers for the EM-FFE. These parameters result in the values shown in Table 4.9.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
whitebark pine	0.9	0.9	1.1
western larch	0.9	0.9	1.1
Douglas-fir	0.9	0.9	1.1
limber pine	1.0	1.0	1.0
subalpine larch	1.0	1.0	1.0
Rocky Mountain juniper	1.0	1.0	1.0
lodgepole pine	1.1	1.1	0.9
Engelmann spruce	1.1	1.1	0.9
subalpine fir	1.1	1.1	0.9
ponderosa pine	1.0	1.0	1.0
green ash	1.0	1.0	1.0
quaking aspen	1.0	1.0	1.0
black cottonwood	1.0	1.0	1.0
balsam poplar	1.0	1.0	1.0
plains cottonwood	1.0	1.0	1.0
narrowleaf cottonwood	1.0	1.0	1.0
paper birch	1.0	1.0	1.0
other softwood	1.0	1.0	1.0
other hardwood	1.0	1.0	1.0

Additionally, the base fall rate diameter cutoff (diameter at which 5 percent of snags are assigned a slower fall rate) was changed from 18 in. to 12 in. DBH and the fire fall rate cutoff (diameter at which 10 percent of the snags are assigned a slower fall rate after fire) was changed from 12 in. to 10 in. dbh. Both of these changes were made to better represent the smaller trees modeled in the EM variant.

4.9.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the STDINFO keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density values calculated from the green specific gravity values from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.9.4 for whitebark pine is based on western white pine; Douglas-fir is based on Douglas-fir Interior north.

Table 4.9.4 - Wood density (ovendry lb/ft^3) used in the EM-FFE variant.

Species	Density (lb/ft3)
whitebark pine	22.5
western larch	29.9
Douglas-fir	28.1
limber pine	22.5
subalpine larch	19.3
Rocky Mountain juniper	34.9
lodgepole pine	23.7
Engelmann spruce	20.6
subalpine fir	19.3
ponderosa pine	23.7
green ash	19.3
quaking aspen	21.8
black cottonwood	19.3
balsam poplar	19.3
plains cottonwood	19.3
narrowleaf cottonwood	19.3
paper birch	29.9
other softwood	34.9
other hardwood	19.3

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the EM-FFE (Table 4.9.5). Western juniper equations are based on a single-stem form.

Table 4.9.5 - The crown biomass equations listed here determine the biomass of foliage and branches.

Species	Species Mapping and Equation Source
whitebark pine	Brown and Johnston (1976)
western larch	Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
limber pine	lodgepole pine: Brown and Johnston (1976)
subalpine larch	Brown and Johnston (1976)

Species	Species Mapping and Equation Source
Rocky Mountain juniper	oneseed juniper; Grier and others (1992)
lodgepole pine	Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976), Keyser and Smith (2010) for crown shape in the canopy fuels calculations
green ash	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
black cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
balsam poplar	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
plains cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
narrowleaf cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
paper birch	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other softwood	Grier and others (1992)
other hardwood	cottonwood: Jenkins et. al. (2003); Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.9.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are from Keane and others (1989). Lifespan of western white pine

Table 4.9.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the EM-FFE variant.

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
whitebark pine	7	2	5	5	15
western larch	1	1	5	5	15
Douglas-fir	5	2	5	5	15
limber pine	3	2	5	5	15
subalpine larch	1	1	5	5	15
Rocky Mountain juniper	4	2	5	5	15
lodgepole pine	3	2	5	5	15
Engelmann spruce	6	2	5	5	10
subalpine fir	7	2	5	5	15
ponderosa pine	4	2	5	5	10
green ash	1	1	5	5	15
quaking aspen	1	1	5	5	15
black cottonwood	1	1	5	5	15
balsam poplar	1	1	5	5	15
plains cottonwood	1	1	5	5	15
narrowleaf cottonwood	1	1	5	5	15
paper birch	1	1	5	5	15
other softwood	4	2	5	5	20
other hardwood	1	1	5	5	15

Live Herbs and Shrub: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.9.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.9.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Values for “other softwoods” are modelled as juniper and are from Ottmar and others (1998). Values for quaking aspen are from Ottmar and others (2000b).

Table 4.9.7 - Values (dry weight, tons/acre) for live fuels used in the EM-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established” (E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
whitebark pine	E	0.20	0.05	
	I	0.40	0.50	
western larch	E	0.20	0.10	
	I	0.40	1.00	
Douglas-fir	E	0.20	0.10	
	I	0.40	1.00	
limber pine	E	0.20	0.25	Use IE limber pine
	I	0.25	0.10	
subalpine larch	E	0.15	0.20	Use IE subalpine larch
	I	0.30	2.00	
Rocky Mountain juniper	E	0.20	0.25	Use IE RM juniper
	I	0.25	0.10	
lodgepole pine	E	0.20	0.05	
	I	0.40	0.50	
Engelmann spruce	E	0.15	0.10	
	I	0.30	1.00	
subalpine fir	E	0.15	0.10	
	I	0.30	1.00	
ponderosa pine	E	0.20	0.125	
	I	0.25	0.05	
green ash	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
quaking aspen	E	0.25	0.25	Ottmar and others 2000b
	I	0.18	1.32	
black cottonwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
balsam poplar	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
plains cottonwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
narrowleaf cottonwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
paper birch	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other softwood	E	0.14	0.35	Ottmar and others (1998)
	I	0.10	2.06	
other hardwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.9.8). Values for “other softwoods” are modelled as juniper and are from Ottmar and others (1998). Values for quaking aspen are from Ottmar and others (2000b). If tree canopy cover is <10 percent, the DWD pools are assigned an “initiating” value and if cover is >60 percent they are assign the “established” value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.9.8 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

Species		**Size Class (in)**							
		< 0.25	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
whitebark pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
western larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
limber pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
subalpine larch	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
Rocky Mountain juniper	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
green ash	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
balsam poplar	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
plains cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
narrowleaf cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
paper birch	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other softwood	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0
other hardwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.9.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires. The bark thickness multipliers in Table 4.9.9 are used to calculate single bark thickness and are used in the mortality equations (2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.9.9 - Species-specific constants for determining single bark thickness.

Species	**Multiplier (V_{sp})**
whitebark pine	0.030
western larch	0.063
Douglas-fir	0.063
limber pine	0.030
subalpine larch	0.050

Species	Multiplier (V_{sp})
Rocky Mountain juniper	0.025
lodgepole pine	0.028
Engelmann spruce	0.036
subalpine fir	0.041
ponderosa pine	0.063
green ash	0.038
quaking aspen	0.044
black cottonwood	0.038
balsam poplar	0.038
plains cottonwood	0.038
narrowleaf cottonwood	0.038
paper birch	0.027
other softwood	0.025
other hardwood	0.038

4.9.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.9.10). Default decay rates are based on Abbott and Crossley (1982). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.9.10 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.12	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.015	
6 – 12		
> 12		
Litter	0.50	
Duff	0.002	0.0

By default, FFE decays all wood species at the rates shown in Table 4.9.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.9.11 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.9.11 - Default wood decay classes used in the EM-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Class
whitebark pine	4
western larch	3
Douglas-fir	3
limber pine	4
subalpine larch	4
Rocky Mountain juniper	2
lodgepole pine	4
Engelmann spruce	4
subalpine fir	4
ponderosa pine	4
green ash	4
quaking aspen	4

Species	Decay Class
black cottonwood	4
balsam poplar	4
plains cottonwood	4
narrowleaf cottonwood	4
paper birch	4
other softwood	2
other hardwood	4

4.9.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.9.12) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.9.12 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1-hr)	4	8	12	16
0.25 – 1.0 in. (10-hr)	4	8	12	16
1.0 – 3.0 in. (100-hr)	5	10	14	18
> 3.0 in. (1000+ -hr)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.9.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger 'Activity Fuels' conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;

2) Defining the choice of fuel models and weights;

3) Allowing FFE to determine a weighted set of fuel models, or

4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the EM-FFE to follow the third of these four options.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.9.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The habitat types shown in Table Table 4.9.13 define which of eight groups of low fuel model(s) will become candidates. According to the logic of the table, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, snag density, etc.).

If the **STATFUEL** keyword is selected, fuel model is determined using only the closest-match fuel model identified by either Figure 4.9.1 or Table 4.9.13. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

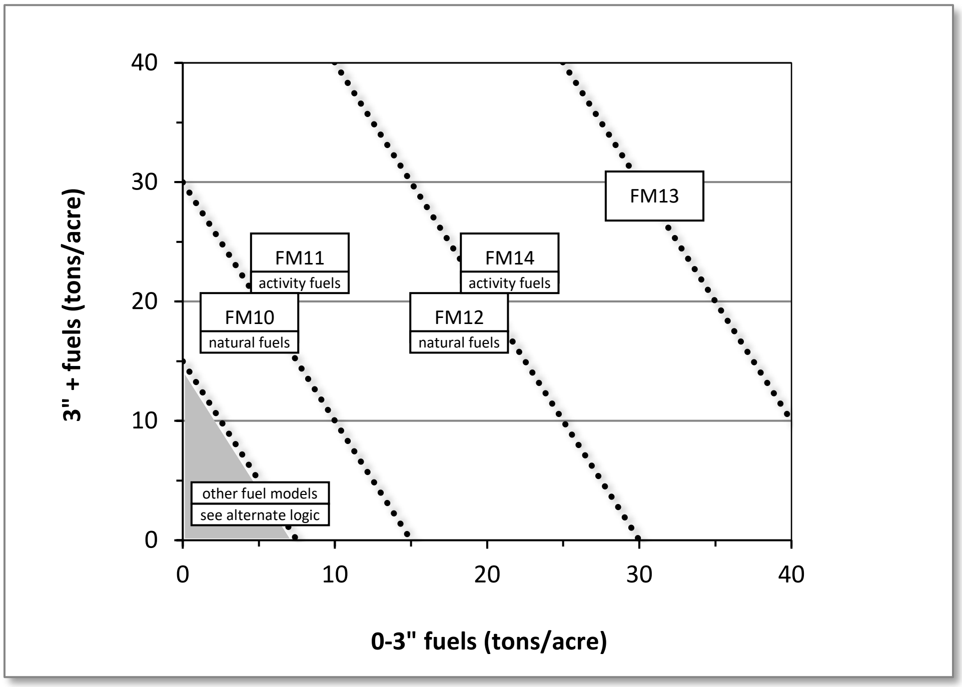


Figure 4.9.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.9.13. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

Table 4.9.13 - When low fuel loads are present in the EM-FFE, fire behavior fuel models are determined using one of eight habitat categories: scree, dry grassy, grassy tall shrub, grassy shrub, long needle shrubby, short needle shrubby, short needle grassy and other. Fuel model is linearly interpolated between the two low fuel models when canopy cover falls between 30 and 50 percent.

Habitat Type Number	Habitat Type Name	FFE Habitat Category	Tree Cover < 30 percent	Tree Cover > 50 percent
			Fuel Model	
10	Scree	Scree	8	8
66	Unknown	Dry Grassy	1	2
70	PIFL/JUCO	Grassy Tall Shrub	2	6
74	Unknown	Dry Grassy	1	2
79	Unknown			
91	Unknown			
92	Unknown			
93	Unknown			
95	Unknown			
100	PIPO			
110	PIPO-AND			
120	Unknown			
130	PIPO-AGSP			
140	PIPO-FEID			
141	PIPO-FEID-FEID			
161	PIPO-PUTR-AGSP	Grassy Shrub	1	9
170	PIPO-SYAL	Long Needle Shrubby	2	9
171	PIPO-SYAL-SYAL			
172	PIPO-SYAL-BERE			
180	PIPO-PRVI	Grassy Tall Shrub	2	6

Habitat Type Number	Habitat Type Name	FFE Habitat Category	Tree Cover < 30 percent	Tree Cover > 50 percent
			Fuel Model	
181	PIPO-PRVI-PRVI			
182	PIPO-PRVI-SHCA			
200	PSME	Short Needle Shrubby	2	8
210	PSME-AGSP	Short Needle Grassy	1	8
220	PSME-FEID			
221	Unknown			
230	PSME-FESC			
250	PSME-VACA	Short Needle Shrubby	2	8
260	PSME-PHMA			
261	PSME-PHMA-PHMA			
262	PSME-PHMA-CARU			
280	PSME-VAGL			
281	PSME-VAGL-VAGL			
282	PSME-VAGL-ARUV			
283	PSME-VAGL-XETE			
290	PSME-LIBO			
291	PSME-LIBO-SYAL			
292	PSME-LIBO-CARU			
293	PSME-LIBO-VAGL			
310	PSME-SYAL			
311	PSME-SYAL-AGSP			
312	PSME-SYAL-CARU			
313	PSME-SYAL-SYAL			
315	Unknown			
320	PSME-CARU			
321	PSME-CARU-AGSP			
322	PSME-CARU-ARUV			
323	PSME-CARU-CARU			
330	PSME-CAGE			
331	Unknown			
332	Unknown			
340	PSME-SPBE			
350	PSME-ARUV			
360	PSME-JUCO			
370	PSME-ARCO			
371	Unknown			
All others		Other	5	8

4.10 Inland Empire (IE)

4.10.1 Tree Species

The Inland Empire variant models the 21 tree species shown in Table 4.10.1. Two additional categories, ‘other hardwood’ and ‘other softwood’ are modeled using red alder and mountain hemlock.

Table 4.10.1 - Tree species simulated by the Inland Empire variant.

Common Name	Scientific Name	Notes
western white pine	*Pinus monticola*	
western larch	*Larix occidentalis*	
Douglas-fir	*Pseudotsuga menziesii*	
grand fir	*Abies grandis*	
western hemlock	*Tsuga heterophylla*	
western redcedar	*Thuja plicata*	
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea Engelmannii*	
subalpine fir	*Abies lasiocarpa*	
ponderosa pine	*Pinus ponderosa*	
mountain hemlock	*Tsuga mertensiana*	
whitebark pine	*Pinus albicaulis*	
limber pine	*Pinus flexilis*	
subalpine larch	*Larix lyallii*	
singleleaf pinyon	*Pinus monophylla*	
Rocky Mountain juniper	*Juniperus scopulorum*	
Pacific yew	*Taxus brevifolia*	
quaking aspen	*Populus tremuloides*	
cottonwood	*Populus*	
Rocky Mountain maple	*Acer glabrum*	
paper birch	*Betula papyrifera*	
other hardwood		*= red alder*
other softwood		*= mountain hemlock*

4.10.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the FFE design workshop. A complete description of the Snag Submodel is provided in section 2.3.

Four variables are used to modify the Snag Submodel for the different species in the IE-FFE variant:

- a multiplier to modify the species’ fall rate;
- a multiplier to modify the time required for snags to decay from a “hard” to “soft” state;
- the maximum number of years that snags will remain standing; and
- a multiplier to modify the species’ height loss rate.

These variables are summarized in Table 4.10.2 and Table 4.10.3.

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.10.4 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

Table 4.10.2 - Default snag fall, snag height loss and soft-snag characteristics for 20” DBH snags in the IE-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.10.3.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - - - Years - - - - - - - - - - -			
western white pine	34	110	33	42
western larch	34	110	33	42
Douglas-fir	34	110	33	42
grand fir	28	90	27	35
western hemlock	28	90	27	35
western redcedar	28	90	27	35
lodgepole pine	28	90	27	35
Engelmann spruce	28	90	27	35
subalpine fir	28	90	27	35
ponderosa pine	31	100	30	39
mountain hemlock	31	100	30	39
whitebark pine	31	100	30	39
limber pine	31	100	30	39
subalpine larch	31	100	30	39
singleleaf pinyon	31	100	30	39
Rocky Mountain juniper	31	100	30	39
Pacific yew	31	100	30	39
quaking aspen	31	100	30	39
cottonwood	31	100	30	39
Rocky Mountain maple	31	100	30	39
paper birch	31	100	30	39
other hardwood	31	100	30	39
other softwood	31	100	30	39

Table 4.10.3 - Default snag fall, snag height loss and soft-snag multipliers for the IE-FFE. These parameters result in the values shown in Table 4.10.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
western white pine	0.9	0.9	1.1
western larch	0.9	0.9	1.1
Douglas-fir	0.9	0.9	1.1
grand fir	1.1	1.1	0.9
western hemlock	1.1	1.1	0.9
western redcedar	1.1	1.1	0.9
lodgepole pine	1.1	1.1	0.9
Engelmann spruce	1.1	1.1	0.9
subalpine fir	1.1	1.1	0.9
ponderosa pine	1.0	1.0	1.0
mountain hemlock	1.0	1.0	1.0
whitebark pine	1.0	1.0	1.0
limber pine	1.0	1.0	1.0
subalpine larch	1.0	1.0	1.0
singleleaf pinyon	1.0	1.0	1.0
Rocky Mountain juniper	1.0	1.0	1.0
Pacific yew	1.0	1.0	1.0
quaking aspen	1.0	1.0	1.0
cottonwood	1.0	1.0	1.0
Rocky Mountain maple	1.0	1.0	1.0
paper birch	1.0	1.0	1.0
other hardwood	1.0	1.0	1.0
other softwood	1.0	1.0	1.0

4.10.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density calculated from Table 4-3a and Equation 3-5 of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.10.4 for Douglas-fir is based on ‘Douglas-fir Interior north’.

The values for pinyon pine and juniper are from Chojnacky and Moisen (1993).

Table 4.10.4 - Wood density (ovendry lb/ft^3) used in the IE-FFE variant.

Species	Density (lb/ft^3)
western white pine	22.5
western larch	29.9
Douglas-fir	28.1
grand fir	21.8
western hemlock	26.2
western redcedar	19.3
lodgepole pine	23.7
Engelmann spruce	20.6
subalpine fir	19.3
ponderosa pine	23.7
mountain hemlock	26.2
whitebark pine	22.5
limber pine	22.5
subalpine larch	19.3
singleleaf pinyon	31.8
Rocky Mountain juniper	34.9
Pacific yew	26.2
quaking aspen	21.8
cottonwood	19.3
Rocky Mountain maple	30.6
paper birch	29.9
other hardwood	23.1
other softwood	26.2

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the IE-FFE. Mountain hemlock biomass is based on Gholz and others (1979), using western hemlock equations from Brown and Johnston to partition the biomass and also to provide estimates for trees under one inch diameter.

Table 4.10.5 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
western white pine	Brown and Johnston (1976)
western larch	Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
grand fir	Brown and Johnston (1976)
western hemlock	Brown and Johnston (1976)
western redcedar	Brown and Johnston (1976)
lodgepole pine	Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976), Keyser and Smith (2010) for crown shape in the canopy fuels calculations
mountain hemlock	Gholz and others (1979); Brown and Johnston (1976)
whitebark pine	Brown (1978)
limber pine	lodgepole pine: Brown and Johnston (1976)
subalpine larch	subalpine fir: Brown and Johnston (1976)
singleleaf pinyon	Grier and others (1992)
Rocky Mountain juniper	oneseed juniper; Grier and others (1992)
Pacific yew	western redcedar: Brown and Johnston (1976)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Rocky Mountain maple	big-leaf maple: Snell and Little (1983)
paper birch	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other hardwood	red alder: Snell and Little (1983)
other softwood	mountain hemlock: Gholz and others (1979); Brown and Johnston (1976)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.10.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are from Keane and others (1989). Lifespans of western white pine and mountain hemlock are mapped using ponderosa pine, and western hemlock and western redcedar are based on Douglas-fir. The leaflife values for species not in the NI variant were taken from other variants.

Table 4.10.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the IE-FFE variant.

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
western white pine	4	2	5	5	15
western larch	1	1	5	5	15
Douglas-fir	5	2	5	5	15
grand fir	7	2	5	5	15
western hemlock	5	2	5	5	15
western redcedar	5	2	5	5	20
lodgepole pine	3	2	5	5	15
Engelmann spruce	6	2	5	5	10
subalpine fir	7	2	5	5	15
ponderosa pine	4	2	5	5	10
mountain hemlock	4	2	5	5	15
whitebark pine	3	2	5	5	15
limber pine	3	2	5	5	15
subalpine larch	1	1	5	5	15
singleleaf pinyon	3	2	5	5	15
Rocky Mountain juniper	4	2	5	5	15
Pacific yew	7	2	5	5	15
quaking aspen	1	1	5	5	15
cottonwood	1	1	5	5	15

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
Rocky Mountain maple	1	1	5	5	15
paper birch	1	1	5	5	15
other hardwood	1	1	5	5	15
other softwood	4	2	5	5	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.10.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.10.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Values for quaking aspen are from Ottmar and others (2000b).

Table 4.10.7 - Values (dry weight, tons/acre) for live fuels used in the IE-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
western white pine	E	0.15	0.10	
	I	0.30	2.00	
western larch	E	0.20	0.20	
	I	0.40	2.00	
Douglas-fir	E	0.20	0.20	
	I	0.40	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
western hemlock	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
western redcedar	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Engelmann spruce	E	0.15	0.20	
	I	0.30	2.00	
subalpine fir	E	0.15	0.20	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	
	I	0.25	0.10	
mountain hemlock	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	
whitebark pine	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	
limber pine	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
subalpine larch	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	
singleleaf pinyon	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
Rocky Mountain juniper	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
pacific yew	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
quaking aspen	E	0.25	0.25	Ottmar and others 2000b
	I	0.18	1.32	

Species		Herbs	Shrubs	Notes
cottonwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
Rocky mountain maple	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
paper birch	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other hardwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other softwood	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.10.8). Values for quaking aspen are from Ottmar and others (2000b). If tree canopy cover is <10 percent, the DWD pools are assigned an "initiating" value and if cover is >60 percent they are assign the "established" value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords. Mappings are the same as with the live herb and shrub estimates.

Table 4.10.8 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
western larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
western hemlock	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western redcedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
whitebark pine	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
limber pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
subalpine larch	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
singleleaf pinyon	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
Rocky Mountain juniper	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
pacific yew	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
Rocky mountain maple	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
paper birch	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other hardwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other softwood	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0

4.10.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.10.9 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.10.9 - Species specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
western white pine	0.035
western larch	0.063
Douglas-fir	0.063
grand fir	0.046
western hemlock	0.040
western redcedar	0.035
lodgepole pine	0.028
Engelmann spruce	0.036
subalpine fir	0.041
ponderosa pine	0.063
mountain hemlock	0.040
whitebark pine	0.030
limber pine	0.030
subalpine larch	0.050
singleleaf pinyon	0.030
Rocky Mountain juniper	0.025
Pacific yew	0.025
quaking aspen	0.044
cottonwood	0.038
Rocky Mountain maple	0.040
paper birch	0.027
other hardwood	0.026
other softwood	0.040

4.10.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.10.10). Default decay rates are based on Abbott and Crossley (1982). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.10.10 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.12	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.015	
6 – 12		
> 12		
Litter	0.50	
Duff	0.002	0.0

By default, FFE decays all wood species at the rates shown in Table 4.10.8. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.10.11 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.10.11 - Default wood decay classes used in the IE-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Class
western white pine	4
western larch	3
Douglas-fir	3
grand fir	4
western hemlock	4
western redcedar	2
lodgepole pine	4
Engelmann spruce	4
subalpine fir	4
ponderosa pine	4
mountain hemlock	4
whitebark pine	4
limber pine	4
subalpine larch	4
singleleaf pinyon	4
Rocky Mountain juniper	2
Pacific yew	1
quaking aspen	4
cottonwood	4
Rocky Mountain maple	4
paper birch	4
other hardwood	4
other softwood	4

4.10.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.10.12) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.10.12 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	4	8	12	16
0.25 – 1.0 in. (10-hr)	4	8	12	16
1.0 – 3.0 in. (100-hr)	5	10	14	18
> 3.0 in. (1000+ -hr)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.10.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger 'Activity Fuels' conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the IE-FFE to follow the third of these four options.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.10.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The habitat types shown in Table 4.10.13 define which low fuel model(s) will become candidates. According to the logic of this table, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, snag density, etc.).

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.10.1 or Table 4.10.11. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

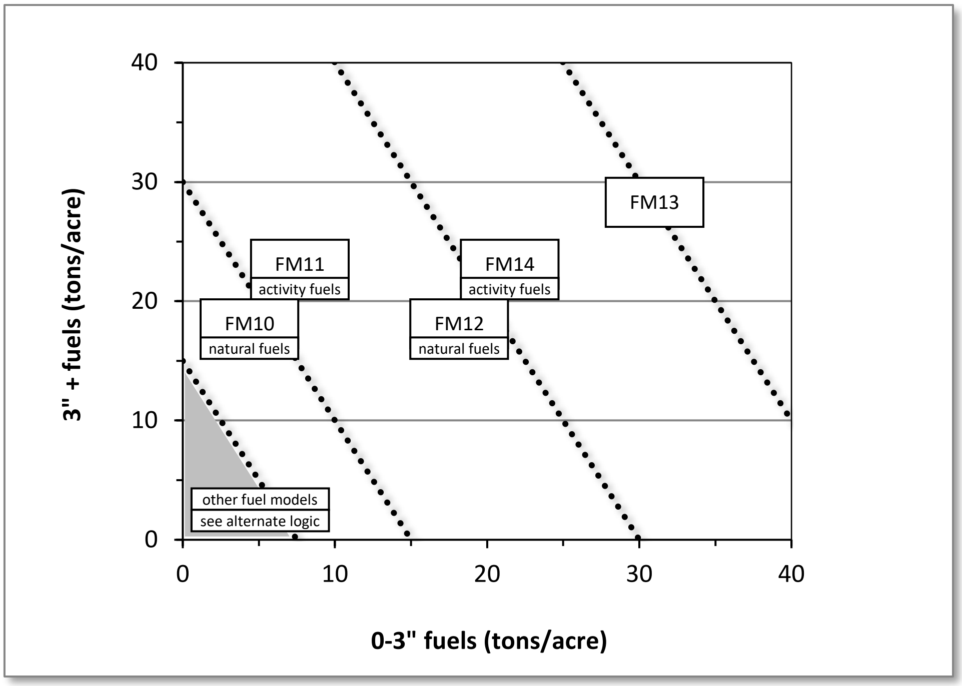


Figure 4.10.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.10.13. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

Table 4.10.13 - When low fuel loads are present in the IE-FFE, fire behavior fuel models are determined using one of three habitat groups: dry grassy, dry shrubby and other. Fuel model is linearly interpolated between the two low fuel models when canopy cover falls between 30 and 50 percent.

Habitat Type Number	Habitat Type Name	FFE Habitat Category	Canopy Cover < 30%	Canopy Cover > 50%
			Fuel Model	
130	PIPO/AGSP	Dry Grassy	1	9
140	PIPO/FEID			
210	PSME/AGSP			
220	PSME/FEID			
230	PSME/FESC			
161	PIPO/PUTR	Dry Shrubby	2	9
170	PIPO/SYAL			
171	PIPO/SYAL-SYAL			
172	PIPO/SYAL-BERE			
180	PIPO/PRVI			
181	PIPO/PRVI-PRVI			
182	PIPO/PRVI-SHCA			
310	PSME/SYAL			
311	PSME/SYAL-AGSP			
312	PSME/SYAL-CARU			
313	PSME/SYAL-SYAL			
All others		Other	8	8

4.11 Lake States (LS)

4.11.1 Tree Species

The Lake States variant models the 65 tree species, plus two other composite species categories shown in Table 4.11.1.

Table 4.11.1 - Tree species simulated by the Lake States variant.

Common name	**Scientific name**
jack pine	*Pinus banksiana*
Scots pine	*Pinus sylvestris*
red pine (natural)	*Pinus resinosa*
red pine (plantation)	*Pinus resinosa*
eastern white pine	*Pinus strobus*
white spruce	*Picea glauca*
Norway spruce	*Picea abies*
balsam fir	*Abies balsamea*
black spruce	*Picea mariana*
tamarack	*Larix laricina*
arborvitae	*Thuja occidentalis*
eastern hemlock	*Tsuga canadensis*
other softwood	
eastern redcedar	*Juniperus virginiana*
black ash	*Fraxinus nigra*
green ash	*Fraxinus pennsylvanica*
eastern cottonwood	*Populus deltoides*
silver maple	*Acer saccharinum*
red maple	*Acer rubrum*
black cherry	*Prunus serotina*
American elm	*Ulmus americana*
slippery elm	*Ulmus rubra*
rock elm	*Ulmus thomasii*
yellow birch	*Betula alleghaniensis*
American basswood	*Tilia americana*
sugar maple	*Acer saccharum*
black maple	*Acer nigrum*
American beech	*Fagus grandifolia*
white ash	*Fraxinus americana*
white oak	*Quercus alba*
swamp white oak	*Quercus bicolor*
bur oak	*Quercus macrocarpa*
chinkapin oak	*Quercus muehlenbergii*
northern red oak	*Quercus rubra*
black oak	*Quercus velutina*
northern pin oak	*Quercus ellipsoidalis*
bitternut hickory	*Carya cordiformis*
pignut hickory	*Carya glabra*
shagbark hickory	*Carya ovata*
bigtooth aspen	*Populus grandidentata*
quaking aspen	*Populus tremuloides*
balsam poplar	*Populus balsamifera*
paper birch	*Betula papyrifera*
butternut	*Juglans cinerea*
black walnut	*Juglans nigra*
hophornbeam	*Ostrya virginiana*
black locust	*Robinia pseudoacacia*
other hardwood[3]	
boxelder	*Acer negundo*
striped maple	*Acer pensylvanicum*
mountain maple	*Acer spicatum*
American hornbeam	*Carpinus caroliniana*
American chestnut	*Castanea dentata*
common hackberry	*Celtis occidentalis*
flowering dogwood	*Cornus florida*
hawthorn	*Crataegus*
apple	*Malus*
blackgum	*Nyssa sylvatica*
American sycamore	*Platanus occidentalis*
pin cherry	*Prunus pensylvanica*
chokecherry	*Prunus virginiana*
plum	*Prunus*
willow	*Salix*
black willow	*Salix nigra*
Missouri River willow	*Salix eriocephala*
sassafras	*Sassafras albidum*
American mountain ash	*Sorbus americana*

4.11.2 Snags

The snag model logic is based on input given at the Lake States FFE development meeting, which was held in Grand Rapids, MN in April 2005. A complete description of the Snag Submodel is provided in section 2.3.

Initially, each species was put into a snag class (1 - 6), as listed in Table 4.11.2Table 4.11.2 - Snag class for each species in LS-FFE.. The snag class is defined as follows:

1 - aspen, birch, spruce, fir, poplar, basswood (fastest fallers)
2 - jack pine
3 - eastern white pine
4 - red pine
5 - ash, maple, beech, elm
6 - cedar taramarck, oak, hickory, hemlock (slowest fallers)

Species were put in snag class 5 by default.

Table 4.11.2 - Snag class for each species in LS-FFE.

Species	Snag class
jack pine	2
Scots pine	4
red pine (natural)	4
red pine (plantation)	4
eastern white pine	3
white spruce	1
Norway spruce	1
balsam fir	1
black spruce	1
tamarack	6
arborvitae	6
eastern hemlock	6
other softwood	6
eastern redcedar	6
black ash	5
green ash	5
eastern cottonwood	1
silver maple	5
red maple	5
black cherry	5
American elm	5
slippery elm	5
rock elm	5
yellow birch	1
American basswood	1
sugar maple	5
black maple	5
American beech	5
white ash	5
white oak	6
swamp white oak	6
bur oak	6
chinkapin oak	6
northern red oak	6

Species	Snag class
black oak	6
northern pin oak	6
bitternut hickory	6
pignut hickory	6
shagbark hickory	6
bigtooth aspen	1
quaking aspen	1
balsam poplar	1
paper birch	1
butternut	5
black walnut	5
hophornbeam	5
black locust	5
other hardwood[3]	5
boxelder	5
striped maple	5
mountain maple	5
American hornbeam	5
American chestnut	5
common hackberry	5
flowering dogwood	5
hawthorn	5
apple	5
blackgum	5
American sycamore	5
pin cherry	5
chokecherry	5
plum	5
willow	5
black willow	5
Missouri River willow	5
sassafras	5
American mountain ash	5

The snag class is used to modify the Snag Submodel for the different species in the LS-FFE variant thru:

- a multiplier to modify the species' fall rate;
- a multiplier to modify the time required for snags to decay from a "hard" to "soft" state;
- the maximum number of years that snags will remain standing; and
- a multiplier to modify the species' height loss rate.

Unlike most FFE variants, the LS-FFE base snag fall rate was modified from the one used in the NI-FFE model. The base snag fall rate is calculated as:

$$R = 0.18 - 0.006*d$$

$$F = mRN_0$$

where:

R = rate of fall
d = initial dbh of the snag (inches)
N_0 = initial density (stems/acre) of snags in the record
m = multiplier that changes the rate of fall; based on the snag class listed in Table 4.11.4
F = density of snags (stems/acre) that fall each year from that record
$mR \geq 0.01$

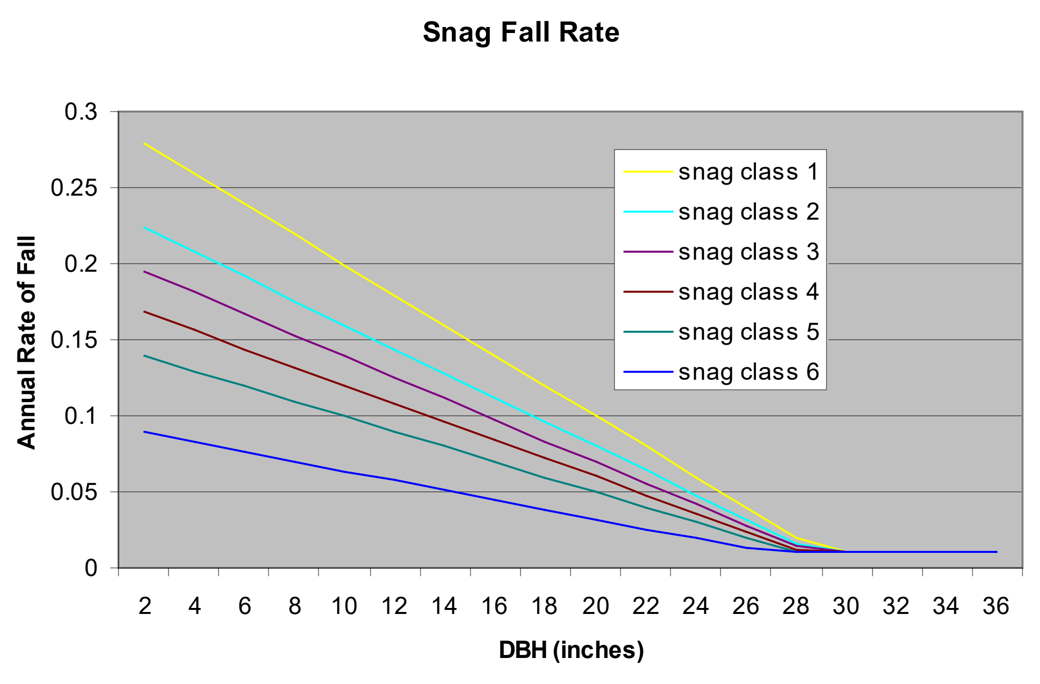


Figure 4.11.1 - The rate of fall of small snags and the first 95% of large snags.

For the last 5 percent of snags over 18 inches (12 inches for cedars and tamarack), the number of snags falling each year is:

$$F = 0.05/(A - T)* No$$

where:

F = density of snags (stems/acre) that fall each year from that record
A = maximum number of years that snags will remain standing (the time when all snags will have fallen)
T = time when 95 percent of the snags have fallen
N_0 = initial density (stems/acre) of snags in the record

This equation ensure that some large snags persist throughout the period of time A, but that none persist beyond this time. The values of A can be found in Table 4.11.4.

Figure 4.11.2 and Figure 4.11.3 show the proportion of 12 and 20 inch trees still standing after various amounts of time. From Figure 4.11.3, you can see how the last 5% of these large snags fall at a slower rate and that some persist for as long as 50 years.

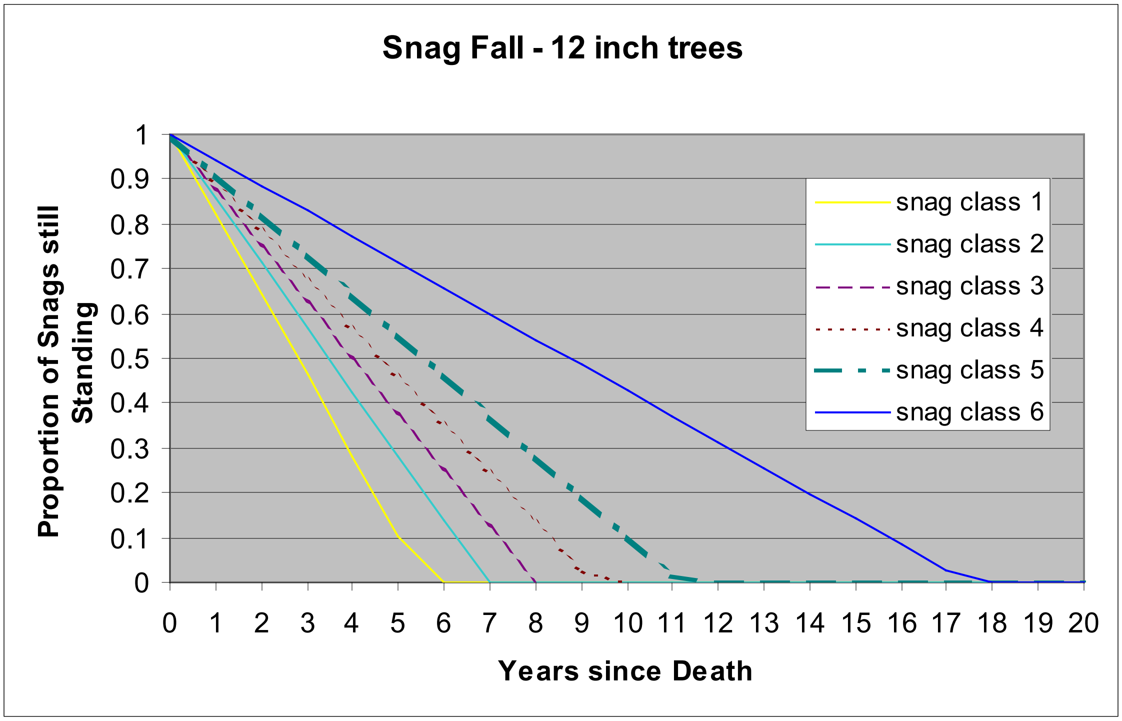


Figure 4.11.2 - Snag fall rates for 12 inch trees.

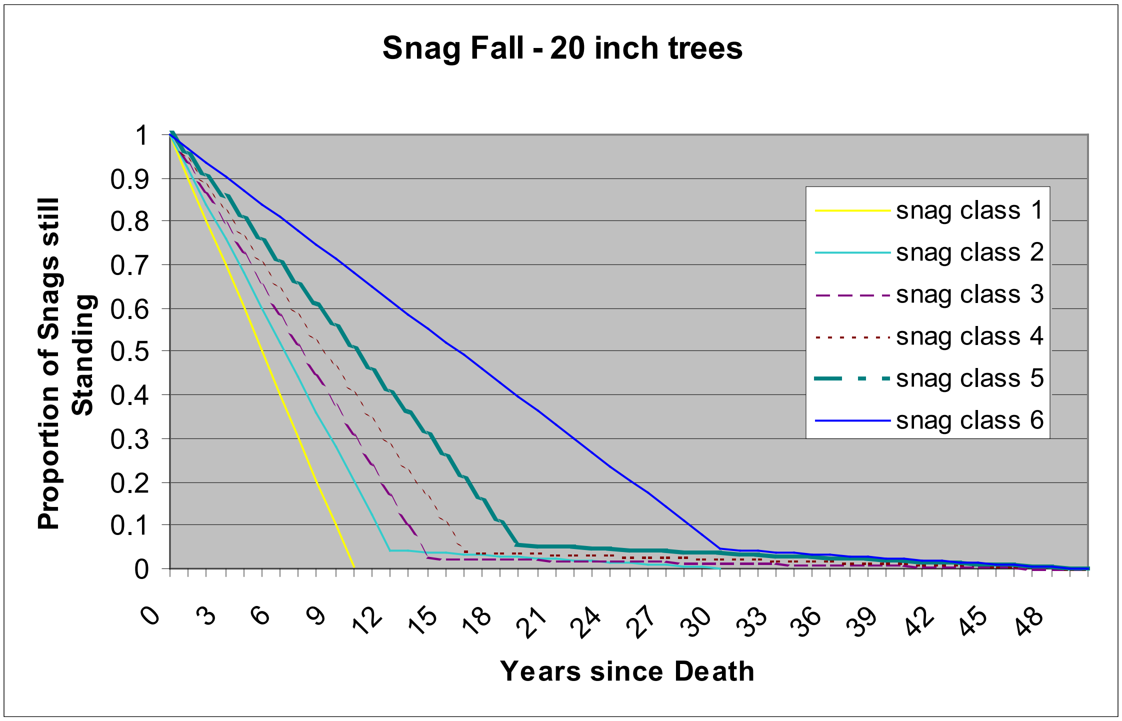


Figure 4.11.3 - Snag fall rates for 20 inch trees.

The base height loss rate for snags is 10%, which corresponds to a snag losing 50% of its height in about 6 years. The height loss rate multipliers that adjust this based on the snag class of the species are in Table 4.11.4. The corresponding number of years until a snag reaches 50% of its original height are found in Table 4.11.3. The base height loss rate after 50% of a snag's height is lost is 1%. Soft snags lose height twice as fast as hard snags.

LS-FFE also models the decay of snags from a hard to a soft state. The number of years this is predicted to take is:

$$DecayTime = m(0.65*d)$$

where:

DecayTime = number of years it takes for a hard snag to become soft (the time from death to transition to soft)

d = initial dbh of the snag (inches)

m = multiplier used to scale the equation to increase or decrease the decay rate for different species (see Table 4.11.4)

Figure 4.11.4 shows the number of years it takes a hard snag to become soft for different diameter snags.

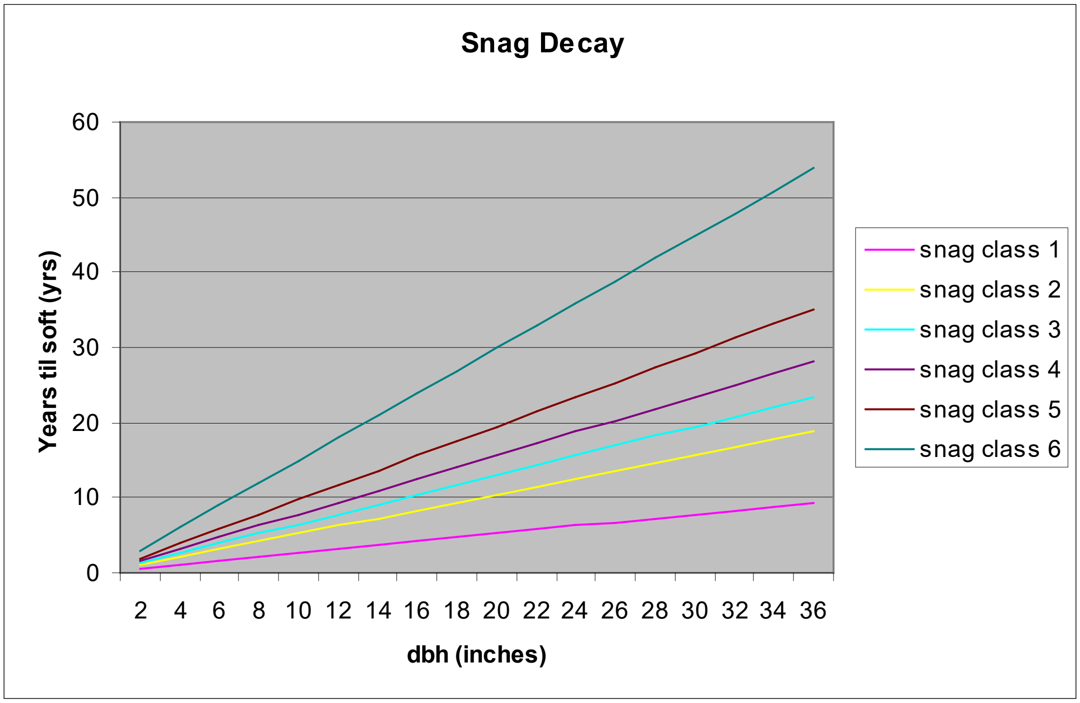


Figure 4.11.4 - The number of years until soft for various diameter snags.

Table 4.11.3 - Snag fall, snag height loss and soft-snag characteristics for 12” DBH snags in the LS-FFE variant. These characteristics directly coincide with the parameter values shown in Table 4.11.4.

Snag Class	95% Fallen	50% Height	Hard-to-Soft
	- - - - - - - - - - - - - - - Years	- - - - - - - - - - - - - - -	
1	6	2	3.1
2	7	6	6.2
3	8	no height loss	7.8
4	9	no height loss	9.4
5	11	10	11.7
6	17	15 (except hemlock, which has no height loss)	17.9

Table 4.11.4 - Default snag fall, snag height loss and soft-snag multipliers, and all down values for the LS-FFE. These parameters result in the values shown in Table 4.19.3. (These columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords.)

Snag Class	Snag Fall	Height loss	Hard-to-Soft	All Down (yr)
1	1.66	3.0	0.4	10
2	1.33	1.0	0.8	30
3	1.16	0	1.0	50
4	1.0	0	1.2	50
5	0.83	0.65	1.5	50
6	0.53	0.45 (except hemlock, which is 0)	2.3	50

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.11.5 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

4.11.3 Fuels

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and dead surface fuels. Live herb and shrub fuel load and the initial dead surface fuel load are assigned based on the Forest Type code, as reported in the Summary Statistics Table.

One difference between the implementation of FFE in the Lake States variant, relative to its implementation in all of the western variants, is the distinction between crown material and stemwood. In the western variants, stemwood biomass is calculated by converting total cubic foot volume to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood and foliage alone. In the Lake States variant, total cubic foot volume equations are not in use. As a result, stemwood biomass is calculated by converting merchantable cubic foot volume (to a 4 inch top diameter inside bark) to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood and foliage plus the unmerchantable portion of the main stem (stemwood above a 4 inch diameter). This has some effects that users should be aware of.

1) The default assumption in the western variants when harvesting is that the stems are taken and the crown material (branchwood) is left. In the Lake States variants this corresponds to a default assumption that the merchantable material is taken and the unmerchantable material (branchwood, small trees, unmerchantable topwood) is left.

2) Surface fuel accumulation is predicted from a variety of processes including crown breakage and crown lift. Based on a default percentage and the change in crown ratio for each tree record, a certain amount of material is predicted to fall to the ground each year. This assumption changes slightly when using the Lake States variant. Rather than predicting a certain percentage of the branchwood will fall each year, essentially the model is predicting a certain percentage of the unmerchantable material (branchwood, small trees, unmerchantable topwood) will fall each year.
3) Other changes were made to handle this situation and are described in the section on Tree Crowns.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using wood density calculated from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). Generally, species not listed were given a default value of 28.7 lbs/cuft.

Table 4.11.5 - Wood density (ovendry lbs/green ft^3) used in the LS-FFE variant.

Species	lbs/cuft	Species used
jack pine	24.9	
Scots pine	25.6	red pine
red pine (natural)	25.6	
red pine (plantation)	25.6	
eastern white pine	21.2	
white spruce	23.1	
Norway spruce	23.1	white spruce
balsam fir	20.6	
black spruce	23.7	
tamarack	30.6	
arborvitae	18.1	
eastern hemlock	23.7	
other softwood	27.4	eastern redcedar
eastern redcedar	27.4	
black ash	28.1	
green ash	33.1	
eastern cottonwood	23.1	
silver maple	27.4	
red maple	30.6	
black cherry	29.3	
American elm	28.7	
slippery elm	29.9	
rock elm	35.6	
yellow birch	34.3	
American basswood	20.0	
sugar maple	34.9	
black maple	32.4	
American beech	34.9	
white ash	34.3	
white oak	37.4	
swamp white oak	39.9	
bur oak	36.2	
chinkapin oak	37.4	white oak
northern red oak	34.9	
black oak	34.9	
northern pin oak	36.2	
bitternut hickory	37.4	
pignut hickory	41.2	
shagbark hickory	39.9	
bigtooth aspen	22.5	
quaking aspen	21.8	
balsam poplar	19.3	
paper birch	29.9	
butternut	22.5	
black walnut	31.8	
hophornbeam	31.8	black walnut
black locust	41.2	
other hardwood[3]	28.7	default
boxelder	30.6	red maple
striped maple	30.6	red maple
mountain maple	30.6	red maple
American hornbeam	28.7	default
American chestnut	28.7	default
common hackberry	30.6	
flowering dogwood	28.7	default
hawthorn	28.7	default
apple	29.3	black cherry
blackgum	28.7	
American sycamore	28.7	
pin cherry	29.3	black cherry
chokecherry	29.3	black cherry
plum	29.3	black cherry
willow	22.5	black willow
black willow	22.5	
Missouri River willow	22.5	black willow
sassafras	26.2	
American mountain ash	28.7	default

Tree Crown: For merchantable trees, estimates of crown material, including foliage, branchwood and bolewood above a 4 inch top (DOB), are from Jenkins and others (2003). These equations do not provide information on how the crown material is distributed by size class.

Information on partitioning canopy fuel loads by size class was taken from several sources (Snell and Little (1983), Loomis and Blank (1981), Loomis and Roussopoulos (1978), Loomis et. al. (1966)). Species were mapped, when necessary, based on workshop input. Because information on how crown material is partitioned for different species is often based on different definitions of “crown” (branchwood only, branchwood plus stemwood above a 0.25 inch diameter, branchwood plus stemwood above a 1 inch diameter), the equations to predict the proportion of crown biomass in various size classes are adjusted. The basic assumption is that the biomass of the unmerchantable tip can be calculated from the volume of a cone, where the height of the cone is the difference between total height and height at a 4 inch top diameter and the bottom diameter of the cone is 4 inches. There are some additions made to these estimates of crown biomass. Jenkin’s equations include branchwood and stem material above a 4 inch DOB top, while the lake states volume equations go up to a 4 inch DIB top. As a result, there is a small portion of biomass that is missing. This is estimated and added to the crown material estimates.

For unmerchantable trees, total above ground biomass is predicted by summing the estimate of crown biomass with an estimate of the bole biomass. This is done by estimating the volume of the breakpoint diameter tree with both the standard National Volume Estimator Library volume equation, as well as a simplified equation (Vol = 0.0015*D*D*H) to compute an adjustment factor that is used along with the simplified volume equation to estimate the volume and biomass of the unmerchantable tree bole. This was done to ensure smooth, non-erratic biomass estimates for trees as they grow and pass the merchantable dbh breakpoint. A similar method (to that for large trees) is used to adjust how the crown material is distributed by size class. In this case the main stem is assumed to be cone-shaped above breast height and cylinder-shaped below breast height.

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are primarily from Hardin et. al. (2001). Exceptions include eastern redcedar and northern white-cedar, which are from Barnes and Wagner (2002).

Dead foliage and branch materials also contribute to litter fall. Each species was categorized into 1 of 4 crown fall rate categories and the life span of dead foliage and branches was determined for each category. By default, species were classed as a 3. This categorization was based on rates developed for the SN-FFE, as well as general input from the LS development workshop.

Table 4.11.6 - Life span of live foliage and crown fall class (1 to 4) for species modeled in the LS-FFE variant.

Species	Leaf Life (years)	Crown Fall Class
jack pine	2	4
Scots pine	3	4
red pine (natural)	4	4
red pine (plantation)	4	4
eastern white pine	2	4
white spruce	8	4
Norway spruce	8	4
balsam fir	8	4
black spruce	8	4
tamarack	1	1
arborvitae	2	1
eastern hemlock	3	1
other softwood	5	1
eastern redcedar	5	1
black oak	1	2
northern pin oak	1	2
bitternut hickory	1	1
pignut hickory	1	1
shagbark hickory	1	1
bigtooth aspen	1	4
quaking aspen	1	4
balsam poplar	1	4
paper birch	1	4
butternut	1	3
black walnut	1	3
hophornbeam	1	3
black locust	1	3
other hardwood[3]	1	3

Species	Leaf Life (years)	Crown Fall Class
black ash	1	3
green ash	1	3
eastern cottonwood	1	4
silver maple	1	3
red maple	1	3
black cherry	1	3
American elm	1	3
slippery elm	1	3
rock elm	1	3
yellow birch	1	4
American basswood	1	4
sugar maple	1	3
black maple	1	3
American beech	1	3
white ash	1	3
white oak	1	1
swamp white oak	1	1
bur oak	1	1
chinkapin oak	1	1
northern red oak	1	2
boxelder	1	3
striped maple	1	3
mountain maple	1	3
American hornbeam	1	3
American chestnut	1	3
common hackberry	1	3
flowering dogwood	1	3
hawthorn	1	3
apple	1	3
blackgum	1	3
American sycamore	1	3
pin cherry	1	3
chokecherry	1	3
plum	1	3
willow	1	3
black willow	1	3
Missouri River willow	1	3
sassafras	1	3
American mountain ash	1	3

Table 4.11.7 - Years until all snag crown material of certain sizes has fallen by crown fall class

	Snag Crown Material Time to 100% Fallen (years)					
Crown fall class	Foliage	<0.25”	0.25–1”	1-3”	3-6”	6-12”
1 (white oak, hemlock, cedar, tamarack, hickory)	1	2	2	5	10	10
2 (red oaks)	1	1	1	4	8	8
3 (ash, elm, maple, beech, other)	1	1	1	3	6	6
4 (conifers, aspen, poplar, birch, basswood)	1	1	1	2	4	4

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on the FIA forest type and size class, as reported in the Summary Statistics report. Data are from Ottmar et. al. (2002) and Ottmar and Vihnanek (1999).

Table 4.11.8 - Values (dry weight, tons/acre) for live fuels used in the LS-FFE.

FIA Forest Type	FIA Size Class	Herbs	Shrubs
all conifers except jack pine	1 (sawtimber)	0.12	0.17
	2 (poletimber)	0.08	0.02
	3 (seedling-sapling)	0.06	0.00
jack pine	1 (sawtimber)	0.06	0.63
	2 (poletimber)	0.10	0.04
	3 (seedling-sapling)	0.14	0.35
hardwoods	1 (sawtimber)	0.00	0.00
	2 (poletimber)	0.00	0.00
	3 (seedling-sapling)	0.00	0.01

Dead Fuels: Initial default fuel pools are based on FIA forest type and size class. Default fuel loadings are based on FIA fuels data collected in the Lake States and were provided by Chris Woodall. All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.11.9 - FIA forest type and size class are used to assign default surface fuel values (tons/acre) by size class. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

FIA Forest Type	FIA Size Class	Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
white-red pine	1	0.09	0.51	1.76	0.78	1.89	1.95	1.83	3.87
	2	0.07	0.51	0.93	0.06	0.26	0.00	0.54	1.43
	3	0.07	0.25	0.18	0.00	0.00	0.00	2.05	9.96
jack pine	1	0.31	2.22	4.99	0.64	2.11	1.46	1.44	9.05
	2	0.12	0.44	1.05	0.66	1.26	0.00	0.81	2.97
	3	0.11	0.89	4.58	4.98	4.76	0.00	0.20	2.09
spruce-fir	1	0.40	0.95	1.79	1.28	4.47	1.46	0.90	64.29
	2	0.19	0.60	1.22	0.52	1.88	0.57	2.36	80.12
	3	0.07	0.49	2.04	0.98	2.61	0.35	1.20	36.70
eastern redcedar	any	0.00	0.00	0.00	0.79	0.00	0.00	0.07	8.28
oak-pine	1	0.12	0.57	1.14	0.62	3.71	0.37	0.81	2.14
	2	0.11	0.95	1.59	0.17	1.89	0.00	0.29	1.28
	3	0.12	0.49	0.60	0.67	0.77	0.00	0.20	4.77
oak-hickory	1	0.18	0.53	1.60	0.78	1.65	0.52	0.91	4.45
	2	0.24	0.59	1.41	0.74	1.61	1.30	0.44	3.02
	3	0.09	0.80	0.16	0.48	0.51	0.00	0.49	3.96
elm-ash-eastern cottonwood	1	0.17	0.87	2.10	0.97	2.17	4.52	1.61	40.33
	2	0.22	0.48	1.78	1.01	3.09	0.89	1.00	156.25
	3	0.13	0.26	0.74	0.49	1.88	0.12	1.17	21.42
maple-beech-birch	1	0.22	0.62	1.74	0.99	1.77	1.41	1.38	7.82
	2	0.29	0.74	2.11	0.96	1.92	3.33	0.90	7.65
	3	0.23	0.69	2.96	1.15	2.81	0.28	0.81	2.37
aspen-birch	1	0.13	0.86	2.10	0.82	2.76	1.10	0.71	14.75
	2	0.12	0.70	2.51	1.04	2.41	2.70	0.53	6.58
	3	0.13	0.52	1.69	0.77	1.80	0.66	1.04	9.55
nonstocked	any	0.07	0.32	0.34	0.19	0.63	0.00	0.00	0.36

4.11.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires. The bark thickness multipliers in Table 4.11.10 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.11.10 - Species-specific constants for determining single bark thickness.

Species	Multiplier (Vsp)	Species used
jack pine	0.04	
Scots pine	0.03	
red pine (natural)	0.043	
red pine (plantation)	0.043	
eastern white pine	0.045	
white spruce	0.025	
Norway spruce	0.029	
balsam fir	0.031	
black spruce	0.032	
tamarack	0.031	
arborvitae	0.025	
eastern hemlock	0.039	
other softwood	0.038	eastern redcedar
eastern redcedar	0.038	
black oak	0.045	
northern pin oak	0.038	
bitternut hickory	0.037	
pignut hickory	0.037	
shagbark hickory	0.04	
bigtooth aspen	0.039	
quaking aspen	0.044	
balsam poplar	0.04	
paper birch	0.027	
butternut	0.041	
black walnut	0.041	
hophornbeam	0.037	
black locust	0.049	
other hardwood[3]	0.034	boxelder

Species	Multiplier (Vsp)	Species used
black ash	0.035	
green ash	0.039	
eastern cottonwood	0.04	
silver maple	0.031	
red maple	0.028	
black cherry	0.03	
American elm	0.031	
slippery elm	0.032	
rock elm	0.033	
yellow birch	0.031	
American basswood	0.038	
sugar maple	0.033	
black maple	0.035	
American beech	0.025	
white ash	0.042	
white oak	0.04	
swamp white oak	0.045	
bur oak	0.042	
chinkapin oak	0.042	
northern red oak	0.042	
boxelder	0.034	
striped maple	0.045	
mountain maple	0.04	
American hornbeam	0.03	
American chestnut	0.04	
common hackberry	0.036	sugarberry
flowering dogwood	0.041	
hawthorn	0.038	
apple	0.043	
blackgum	0.039	
American sycamore	0.033	
pin cherry	0.045	
chokecherry	0.04	
plum	0.04	
willow	0.041	
black willow	0.04	
Missouri River willow	0.04	
sassafras	0.035	
American mountain ash	0.04	

4.11.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.11.11). Default decay rates are based on Abbott and Crossley (1982), Alban and Pastor (1993), Tyrrell and Crow (1994), and Melillo et. al. (1982). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.11.11 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.11	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.06	
6 – 12		
> 12	0.02	
Litter	0.31	
Duff	0.002	0.0

By default, FFE decays all wood species at the rates shown in Table 4.11.12. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.11.12 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword. The decay rate classes were generally determined from the Wood Handbook (1999). When species were classified differently for young or old growth, young growth was assumed. Species not listed in the wood handbook were classed as 4.

Table 4.11.12 - Default wood decay classes used in the LS-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Rate Class	Species	Decay Rate Class
jack pine	4	black oak	2
Scots pine	4	northern pin oak	2
red pine (natural)	4	bitternut hickory	4
red pine (plantation)	4	pignut hickory	4
eastern white pine	4	shagbark hickory	4
white spruce	4	bigtooth aspen	4
Norway spruce	4	quaking aspen	4
balsam fir	4	balsam poplar	4
black spruce	4	paper birch	4
tamarack	3	butternut	4
arborvitae	2	black walnut	4
eastern hemlock	4	hophornbeam	2
other softwood	2	black locust	4
eastern redcedar	2	other hardwood[3]	1
black ash	4	boxelder	4
green ash	4	striped maple	4
eastern cottonwood	4	mountain maple	4
silver maple	4	American hornbeam	4
red maple	4	American chestnut	4
black cherry	2	common hackberry	2
American elm	4	flowering dogwood	4
slippery elm	4	hawthorn	4
rock elm	4	apple	4
yellow birch	4	blackgum	2
American basswood	4	American sycamore	4
sugar maple	4	pin cherry	4
black maple	4	chokecherry	2
American beech	4	plum	2
white ash	4	willow	2
white oak	2	black willow	4
swamp white oak	2	Missouri River willow	4
bur oak	2	sassafras	4
chinkapin oak	2	American mountain ash	2
northern red oak	2	black oak	4

4.11.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.11.13) or they can specify moisture conditions using the MOISTURE keyword. These defaults were set based on input from Jeremy Bennett using local weather station data. Duff moisture values are from FOFEM.

Table 4.11.13 - Moisture values (%), which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1-hr)	5	7	10	19
0.25 – 1.0 in. (10-hr)	8	9	13	29
1.0 – 3.0 in. (100-hr)	12	14	17	22
> 3.0 in. (1000+ -hr)	15	17	21	25
Duff	40	75	100	175
Live woody	89	105	135	140
Live herbaceous	60	82	116	120

4.11.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982, Scott and Burgan 2005) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. Stand management actions such as thinning and harvesting can abruptly increase fuel loads, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the LS-FFE to follow the third of these four options.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.11.5, one or more low fuel fuel models become candidate models. In other regions of the graph, other fuel models may also be candidates. Table 4.11.14 and Table 4.11.15 define which fuel model(s) will become candidates. This logic uses the native plant community in its key. The native plant community codes that are used in LS-FFE are in Table 4.11.16 (Minnesota Department of Natural Resources 2003). Users of LS-FFE should set these codes in their stand list file, input data base, or thru the StdInfo keyword.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.11.5 or Table 4.11.15. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

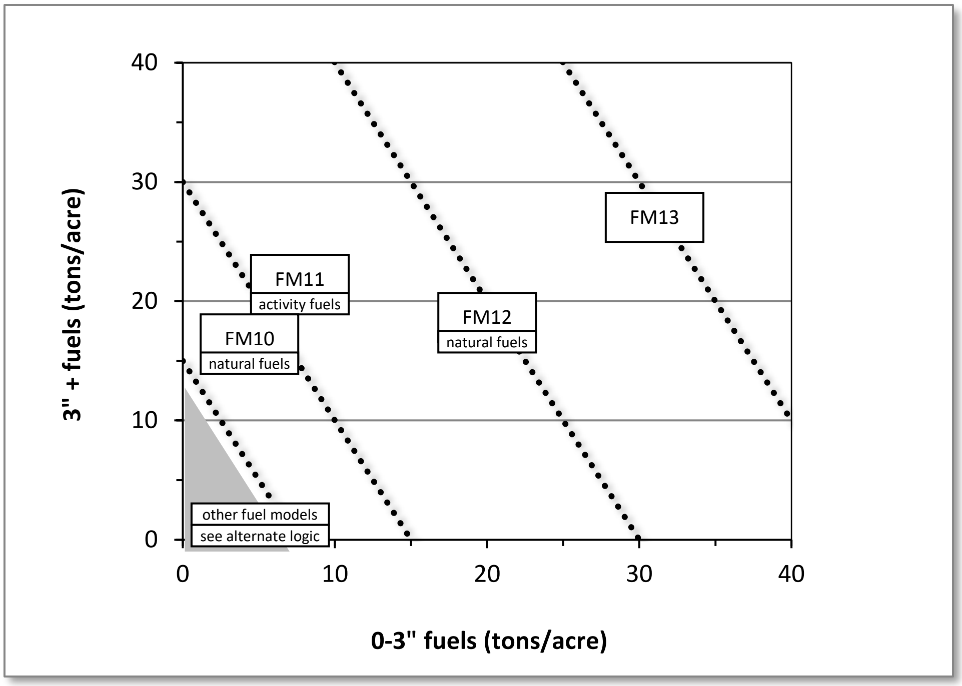


Figure 4.11.5 - Candidate fuel models are determined using the logic shown in Table 4.11.14 and Table 4.11.15. At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. Not all fuel models are candidates under all forest types (see Table 4.11.15).

Table 4.11.14 - In LS-FFE, fire behavior fuel models are determined using forest type. This table shows how forest type is determined. If there are no trees or a forest type cannot be determined, the type from the previous year is used. If this occurs at the beginning of a simulation, the default forest type is red pine.

Forest Type	Definition
Jack Pine	Jack pine composes the most basal area.
Northern Hardwoods	Hemlock, maples, basswood, beech, and red oak compose the most basal area.
Red & Eastern White Pine	Red and eastern white pine compose the most basal area
Mixed Wood	Aspen, birch, and large spruce and fir (5” dbh or larger) compose the most basal area.
Oak	Oaks compose the most basal area.
Aspen / Birch	Aspen, birch, and small spruce and fir (less than 5” dbh) compose the most basal area.
Oak - Pine	If oaks and red and eastern white pine compose the most basal area. In this case, if pines compose more basal area than oaks, the red and eastern white pine forest type is used. If oaks compose more basal area than the pines, the oak forest type is used.

Table 4.11.15 - Relationship between forest type and fuel model selected.

Forest Type		Fuel Model
Jack Pine	surface fuel load is high (see Figure 4.17.5)	10, 11, 12, or 13
	canopy cover ≤ 70% and stand height ≤ 25’	4
	canopy cover ≤ 70% and stand height > 25’ and balsam fir understory (at least 500 BF 1 – 3” per acre)	10 (before greenup) 162 (after greenup)
	canopy cover ≤ 70% and stand height > 25’ and grass understory (native plant community is FDc12 or FDc23)	2
	canopy cover ≤ 70% and stand height > 25’ and not a balsam fir or grass understory	10 (before greenup) 161 (after greenup)

Forest Type		Fuel Model
	canopy cover > 70% and stand height ≤ 15’	4
	canopy cover > 70% and stand height > 15’ and midflame windspeed ≤ 4mph	8
	canopy cover > 70% and stand height > 15’ and midflame windspeed > 4mph	10
Northern Hardwoods	there is activity fuel and surface fuel load is high (see Figure 4.17.5)	11
	else if there is aspen or birch present or at least 30% canopy cover of hemlock	8
	else if maple or basswood is dominant	186
	else if it is a fall burn	9
	else	8
Aspen / Birch	surface fuel load is high (see Figure 4.17.5)	10
	0 – 3” surface fuel is ≥ 5 tons/acre	10
	0 – 3” surface fuel is < 5 tons/acre and less than 500 1 – 3” conifer trees/acre and birch dominant	9
	0 – 3” surface fuel is < 5 tons/acre and less than 500 1 – 3” conifer trees/acre and aspen dominant	8
	0 – 3” surface fuel is < 5 tons/acre and 1 – 3” conifer trees/acre ≥ 500 and midflame windspeed > 4mph	164
	0 – 3” surface fuel is < 5 tons/acre and 1 – 3” conifer trees/acre ≥ 500 and midflame windspeed ≤ 4mph and birch dominant	9
	0 – 3” surface fuel is < 5 tons/acre and 1 – 3” conifer trees/acre ≥ 500 and midflame windspeed ≤ 4mph and aspen dominant	8
Oak	surface fuel load is high (see Figure 4.17.5)	10, 11
	overstory canopy cover (trees 5”+) ≥ 45% and it is an early spring burn and the fine fuel moisture is < 8%	186
	overstory canopy cover (trees 5”+) ≥ 45% and it is an early spring burn and the fine fuel moisture is ≥ 8%	8
	overstory canopy cover (trees 5”+) ≥ 45% and it is not an early spring burn and at least 30% of the basal area is in white oak and black oak	189
	overstory canopy cover (trees 5”+) ≥ 45% and it is not an early spring burn and less than 30% of the basal area in white oak and black oak	9
	overstory canopy cover is between 15 and 45% and the number of 0-2” trees/acre < 500	2
	overstory canopy cover is between 15 and 45% and the number of 0-2” trees/acre ≥ 500	142
	overstory canopy cover is < 15% and the number of 0-2” trees/acre < 500	105
	overstory canopy cover is < 15% and the number of 0-2” trees/acre ≥ 500	142
Mixed Wood (aspen and birch with conifers in the overstory)	surface fuel load is high (see Figure 4.17.5)	10, 11, 12, or 13
	Birch is dominant	9
	else if conifers compose ≥ 30% of the overstory canopy cover	10
	else	8
Red and Eastern white pine	there are activity fuels and slash is 0 – 2 years old	12
	there are activity fuels and slash is 2 - 5 years old	11
	surface fuel load is high (see Figure 4.17.5)	10, 12, 13
	0 – 3” surface fuel is ≥ 5 tons/acre	5
	If pine makes up less than 50% of the canopy cover and there are hardwoods present	8
	else if hazel underbrush is present (native plant community is FDn33 or FDc34) and there is a drought*	146
	else if hazel underbrush is present (native plant community is FDn33 or FDc34) and there is not a drought*	143
	else if there is a balsam fir or balsam fir- eastern white pine understory (at least 500 1 – 3” trees per acre) and the midflame windspeed is ≤ 4 mph	10
	else if there is a balsam fir or balsam fir- eastern white pine understory (at least 500 1 – 3” trees per acre) and the midflame windspeed is > 4 mph	146

Forest Type		Fuel Model
	else if the canopy cover ≥ 50%	9
	else if the canopy cover is ≤ 30% and there is more red pine than eastern white pine	2
	else	9
* No drought is assumed unless one is set thru the FFE keyword Drought		

Table 4.11.16 - LS-FFE native plant community (NPV) codes and descriptions (Minnesota Department of Natural Resources 2003).

NPV Code	NPV description	NPV Code	NPV description
1	FDn12 Northern Dry-Sand Pine Woodland	33	FPn82 Northern Rich Tamarack Swamp (Western Basin)
2	FDn22 Northern Dry-Bedrock Pine (Oak) Woodland	34	FPs63 Southern Rich Conifer Swamp
3	FDn32 Northern Poor Dry-Mesic Mixed Woodland	35	FPw63 Northwestern Rich Conifer Swamp
4	FDn33 Northern Dry-Mesic Mixed Woodland	36	APn80 Northern Spruce Bog
5	FDn43 Northern Mesic Mixed Forest	37	APn81 Northern Poor Conifer Swamp
6	FDc12 Central Poor Dry Pine Woodland	38	APn90 Northern Open Bog
7	FDc23 Central Dry Pine Woodland	39	APn91 Northern Poor Fen
8	FDc24 Central Rich Dry Pine Woodland	40	CTn11 Northern Dry Cliff
9	FDc25 Central Dry Oak-Aspen (Pine) Woodland	41	CTn12 Northern Open Talus
10	FDc34 Central Dry-Mesic Pine-Hardwood Forest	42	CTn24 Northern Scrub Talus
11	MHn35 Northern Mesic Hardwood Forest	43	CTn32 Northern Mesic Cliff
12	MHn44 Northern Wet-Mesic Boreal Hardwood-Conifer Forest	44	CTn42 Northern Wet Cliff
13	MHn45 Northern Mesic Hardwood (Cedar) Forest	45	CTu22 Lake Superior Cliff
14	MHn46 Northern Wet-Mesic Hardwood Forest	46	ROn12 Northern Bedrock Outcrop
15	MHn47 Northern Rich Mesic Hardwood Forest	47	ROn23 Northern Bedrock Shrubland
16	MHc26 Central Dry-Mesic Oak-Aspen Forest	48	LKi32 Inland Lake Sand/Gravel/Cobble Shore
17	MHc36 Central Mesic Hardwood Forest (Eastern)	49	LKi43 Inland Lake Rocky Shore
18	MHc37 Central Mesic Hardwood Forest (Western)	50	LKi54 Inland Lake Clay/Mud Shore
19	MHc47 Central Wet-Mesic Hardwood Forest	51	LKu32 Lake Superior Sand/Gravel/Cobble Shore
20	FFn57 Northern Terrace Forest	52	LKu43 Lake Superior Rocky Shore
21	FFn67 Northern Floodplain Forest	53	RVx32 Sand/Gravel/Cobble River Shore
22	WFn53 Northern Wet Cedar Forest	54	RVx43 Rocky River Shore
23	WFn55 Northern Wet Ash Swamp	55	RVx54 Clay/Mud River Shore
24	WFn64 Northern Very Wet Ash Swamp	56	OPn81 Northern Shrub Shore Fen
25	WFs57 Southern Wet Ash Swamp	57	OPn91 Northern Rich Fen (Water Track)
26	WFw54 Northwestern Wet Aspen Forest	58	OPn92 Northern Rich Fen (Basin)
27	FPn62 Northern Rich Spruce Swamp (Basin)	59	OPn93 Northern Extremely Rich Fen
28	FPn63 Northern Cedar Swamp	60	WMn82 Northern Wet Meadow/Carr
29	FPn71 Northern Rich Spruce Swamp (Water Track)	61	MRn83 Northern Mixed Cattail Marsh
30	FPn72 Northern Rich Tamarack Swamp (Eastern Basin)	62	MRn93 Northern Bulrush-Spikerush Marsh
31	FPn73 Northern Alder Swamp	63	MRu94 Lake Superior Coastal Marsh
32	FPn81 Northern Rich Tamarack Swamp (Water Track)		

4.11.8 Fire-related Mortality

Like most FFE variants, LS-FFE predicts fire-related tree mortality based on species, diameter, and crown scorch (see section 2.5.5 of the FFE documentation). However, some modifications were made to further refine the predictions. The mortality of conifers is reduced by 50% if the burn is simulated before greenup. There is a minimum of 70% mortality for balsam fir that are hit by the flaming front. All maples under 4” dbh die when there is a burn and the flaming front hits them. Hardwoods also receive a reduction in mortality when the burn is before greenup – the mortality of most hardwoods is reduced by 20%, except for oaks above 2.5” dbh, whose mortality is reduced by 50%. All hardwoods less than 1” dbh die if the flaming front hits them.

4.12 Klamath Mountains (NC)

4.12.1 Tree Species

The Klamath Mountains (Northern California) variant models the 10 tree species shown in Table 4.12.1. Two additional categories, ‘other hardwood’ and ‘other softwood’ are modeled using tanoak and Douglas-fir, respectively.

Table 4.12.1 - Tree species simulated by the Klamath Mountains variant.

Common Name	Scientific Name	Notes
sugar pine	*Pinus lambertiana*	
Douglas-fir	*Pseudotsuga menziesii*	
white fir	*Abies concolor*	
Pacific madrone	*Arbutus menziesii*	
incense cedar	*Calocedrus decurrens*	
California black oak	*Querqus keloggii*	
tanoak	*Lithocarpus densiflorus*	
California red fir	*Abies magnifica*	
ponderosa pine	*Pinus ponderosa*	
redwood	*Sequioa sempervirens*	
other hardwood		*= tanoak*
other softwood		*= Douglas-fir*

4.12.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the California variants workshop. A complete description of the Snag Submodel is provided in section 2.3.

Three variables are used to modify the Snag Submodel for the different species in the NC-FFE variant:

- a multiplier to modify the species’ fall rate;
- the maximum number of years that snags will remain standing; and
- a multiplier to modify the species’ height loss rate.

These variables are summarized in Table 4.12.2 and Table 4.12.3.

Unlike the some other FFE variants, snags in the NC-FFE do not decay from a hard to soft state. Users can initialize soft snags using the **SNAGINIT** keyword if they wish, but these initialized soft snags will eventually disappear as they are removed by snag fall. In addition, snags lose height only until they are reduced to half the height of the original live tree. The maximum standing lifetime for many snag species is set to 100 years (Mike Landram, USFS, Vallejo, CA, pers. comm., 2000).

Table 4.12.2 - Default snag fall, snag height loss and soft-snag characteristics for 20” DBH snags in the NC-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.12.3.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - - - Years - - - - - - - - - -			
sugar pine	25	100	20	–
Douglas-fir	35	100	20	–
white fir	35	100	20	–
Pacific madrone	20	50	20	–
incense cedar	45	100	20	–
California black oak	20	50	20	–
tanoak	20	50	20	–
California red fir	35	100	20	–
ponderosa pine	25	100	20	–
redwood	45	150	30	–
other hardwood	20	50	20	–
other softwood	35	100	20	–
All species: soft snags do not normally occur; height loss stops at 50% of original height.				

Table 4.12.3 - Default snag fall, snag height loss and soft-snag multipliers for the NC-FFE. These parameters result in the values shown in Table 4.12.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
sugar pine	1.24	1.49	–
Douglas-fir	0.88	1.49	–
white fir	0.88	1.49	–
Pacific madrone	1.54	1.49	–
incense cedar	0.69	1.49	–
California black oak	1.54	1.49	–
tanoak	1.54	1.49	–
California red fir	0.88	1.49	–
ponderosa pine	1.24	1.49	–
redwood	0.69	1.00	–
other hardwood	1.54	1.49	–
other softwood	0.88	1.49	–
All species: soft snags do not normally occur; height loss stops at 50% of original height.			

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table Table 4.12.4 are used to convert volume to biomass.

4.12.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density calculated from Table 4-3a and Equation 3-5 of The Wood Handbook (Forest Products Laboratory 1999). The coefficients in Table 4.12.4 for madrone are based on tanoak; Douglas-fir is based on 'Douglas-fir Interior west.'

Table 4.12.4 - Wood density (ovendry lb/ft^3) used in the NC-FFE variant.

Species	Density (lb/ft$_3$)
sugar pine	21.2
Douglas-fir	28.7
white fir	23.1
Pacific madrone	36.2
incense cedar	21.8
California black oak	34.9
tanoak	36.2
California red fir	22.5
ponderosa pine	23.7
redwood	21.2
other hardwood	36.2
other softwood	28.7

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the NC-FFE. Some species mappings are used, as shown below in Table 4.12.5. Madrone, California black oak and tanoak crown biomass equations are taken from new sources.

Table 4.12.5 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
sugar pine	western white pine (Brown and Johnston 1976)
Douglas-fir	Brown and Johnston 1976
white fir	grand fir (Brown and Johnston 1976)
Pacific madrone	Snell and Little 1983;
incense cedar	western redcedar (Brown and Johnston 1976)
California black oak	Snell and Little 1983; Snell 1979
tanoak	Snell and Little 1983, Snell 1979
California red fir	grand fir (Brown and Johnston 1976)
ponderosa pine	Brown and Johnston 1976
redwood	western redcedar for biomass, western hemlock for partitioning (Mike Lander, pers. comm.; Brown and Johnston 1976)
other softwood	lodgepole pine (Brown and Johnston 1976)
other hardwood	California black oak (Snell and Little 1983, Snell 1979)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.12.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. These data are from the values provided at the California variants workshop.

Table 4.12.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the NC-FFE variant.

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
sugar pine	3	3	10	15	15
Douglas-fir	5	3	10	15	15
white fir	7	3	10	15	15
Pacific madrone	1	1	10	15	15
incense cedar	5	1	10	15	20
California black oak	1	1	10	15	15
tanoak	1	1	10	15	15
California red fir	7	3	10	15	15
ponderosa pine	3	3	10	10	10
redwood	5	3	10	15	20
other softwood	5	3	10	15	15
other hardwood	1	1	10	15	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.12.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.12.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. When more than one species is present, the final estimate is computed by combining the interpolated estimates from the rows (Table 4.12.7) representing the two dominant species. Those two estimates are themselves weighted by the relative amount of the two dominant species. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Hardwood estimates are from Ottmar and others (2000b).

Table 4.12.7 - Values (dry weight, tons/acre) for live fuels used in the NC-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		**Herbs**	**Shrubs**	**Notes**
sugar pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
Douglas-fir	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
white fir	E	0.15	0.10	Grand fir, NI-FFE
	I	0.30	2.00	
Pacific madrone	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
incense cedar	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
California black oak	E	0.23	0.22	Gambel oak, Ottmar and others 2000b
	I	0.55	0.35	
tanoak	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	
California red fir	E	0.15	0.10	grand fir, NI-FFE
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	NI-FFE
	I	0.25	1.00	
redwood	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
other softwood	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	

Species		Herbs	Shrubs	Notes
other hardwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.12.8). Hardwood estimates are from Ottmar and others (2000b). If tree canopy cover is <10 percent, the DWD pools are assigned an “initiating” value and if cover is >60 percent they are assign the “established” value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. When more than one species is present, the final estimate is computed by combining the interpolated estimates from the rows (Table 4.12.8) representing the two dominant species. Those two estimates are themselves weighted by the relative amount of the two dominant species. All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.12.8 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
sugar pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Pacific madrone	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
incense cedar	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California black oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
tanoak	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
California red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
ponderosa pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
redwood	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
other softwoods	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
other hardwoods	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.12.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.12.9 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.12.9 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
sugar pine	0.072
Douglas-fir	0.063
white fir	0.048
Pacific madrone	0.060
incense cedar	0.060
California black oak	0.030
tanoak	0.052
California red fir	0.039
ponderosa pine	0.063
redwood	0.081
other softwood	0.063
other hardwood	0.052

4.12.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.12.10). Default decay rates are based on Abbott and Crossley (1982).

Table 4.12.10 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.025	0.02
0.25 – 1		
1 – 3		
3 – 6	0.0125	
6 – 12		
> 12		
Litter	0.65	
Duff	0.002	0.0

The default decay rates are modified by incorporating information from the R5 site class. The multipliers shown in Table 4.12.11 modify the default decay rates of Table 4.12.10 to by incorporating a measure of site quality and moisture availability.

Table 4.12.11 - The NC-FFE modifies default decay rate (Table 4.12.10) using R5 Site Code to improve simulated decomposition. Lower R5 Site Classes indicate moister sites.

R5 Site Class	Multiplier
0	1.5
1	1.5
2	1.0
3	1.0
4	1.0
5+	0.5

By default, FFE decays all wood species at the rates shown in Table 4.12.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.12.12 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.12.12 - Default wood decay classes used in the NC-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant). Modified decay classes for madrone, California black oak, tanoak and other hardwoods were adopted at the California variants workshop (Stephanie Rebain, pers. comm., February 2003)

Species	Decay Class
sugar pine	4
Douglas-fir	3
white fir	4
Pacific madrone	3
incense cedar	2
California black oak	2
tanoak	4
California red fir	4
ponderosa pine	4
redwood	1
other softwood	3
other hardwood	4

4.12.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups shown in Table 4.12.13, or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.12.13 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1 hr.)	3	8	12	12
0.25 – 1.0 in. (10 hr.)	4	8	12	12
1.0 – 3.0 in. (100 hr.)	5	10	14	14
> 3.0 in. (1000+ hr.)	10	15	25	25
Duff	15	50	125	125
Live	70	110	150	150

4.12.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are determined in two steps: determination of cover classification and determination of dominant species. The first step uses tree cover attributes classified by the California Wildlife Habitat Relationships (CWHR) system (Mayer and Laudenslayer 1988) shown in Table 4.12.14. The table classifies stands by their canopy cover and the size of the larger trees in the stand, predicting CWHR size class and CWHR density class[2] (the third and fourth columns). Mayer and Laudenslayer's class definitions were modified to reflect the tree size and canopy cover class breakpoints requested at the NC-FFE workshop (Nick Vagle, Rogue River and Siskiyou NF, personal communication). To meet the internal requirements of the CWHR, the largest tree size category provided at the NC-FFE workshop (>32 inches DBH) was merged with the 21–32" category, creating a single >21" category.

Table 4.12.14 - California Wildlife Habitat Relationships, as defined by Mayer and Laudenslayer (1988), with modifications to the tree size and canopy cover class breakpoints for the NC-FFE.

Tree size (DBH in.)	Canopy cover (%)	CWHR Size Class	CWHR Density Class	Stand Description
< 1	< 10	1	–	Seedlings

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[2] A BASIC-language function named 'CWHRSizeDensity' was provided at the WS-FFE workshop. This function is incorporated into the NC-FFE with some minor housekeeping modifications.

Tree size (DBH in.)	Canopy cover (%)	CWHR Size Class	CWHR Density Class	Stand Description
1 – 5	0 – 10	2	S	Sapling – sparse
1 – 5	11 – 40	2	P	Sapling – open cover
1 – 5	41 – 70	2	M	Sapling – moderate cover
1 – 5	> 70	2	D	Sapling – dense cover
5 – 9	0 – 10	3	S	Pole tree – sparse
5 – 9	11 – 40	3	P	Pole tree – open cover
5 – 9	41 – 70	3	M	Pole tree – moderate cover
5 – 9	> 70	3	D	Pole tree – dense cover
9 – 21	0 – 10	4	S	Small tree – sparse
9 – 21	11 – 40	4	P	Small tree – open cover
9 – 21	41 – 70	4	M	Small tree – moderate cover
9 – 21	> 70	4	D	Small tree – dense cover
> 21	0 – 10	5	S	Med/Lg tree – sparse
> 21	11 – 40	5	P	Med/Lg tree – open cover
> 21	41 – 70	5	M	Med/Lg tree – moderate cover
> 21	> 70	5	D	Med/Lg tree – dense cover
> 21	> 70	6	–	Multi-layer canopy, dense cover

*QMD of the 75 percent largest trees based on basal area.

The NC-FFE modifies the internal CWHR logic slightly, making use of two additional measures internal to the CWHR: unadjusted percent canopy cover and overlap-adjusted percent canopy cover, respectively. The two kinds of canopy estimate are used in combination with the CWHR logic to create weights for the predicted CWHR density class. Each stand's CWHR density class becomes a combination of one or two adjacent classes. Figure 4.12.1 shows how the two measures are used to weight the S, P, M or D classes at each timestep of the simulation. When a point (defined by the two kinds of canopy cover estimate) lies on a dashed line in the figure, that CWHR density class is given a 100% weight. Otherwise, the distance from the point to the nearest dashed lines is used to create weights for the nearest CWHR density classes.

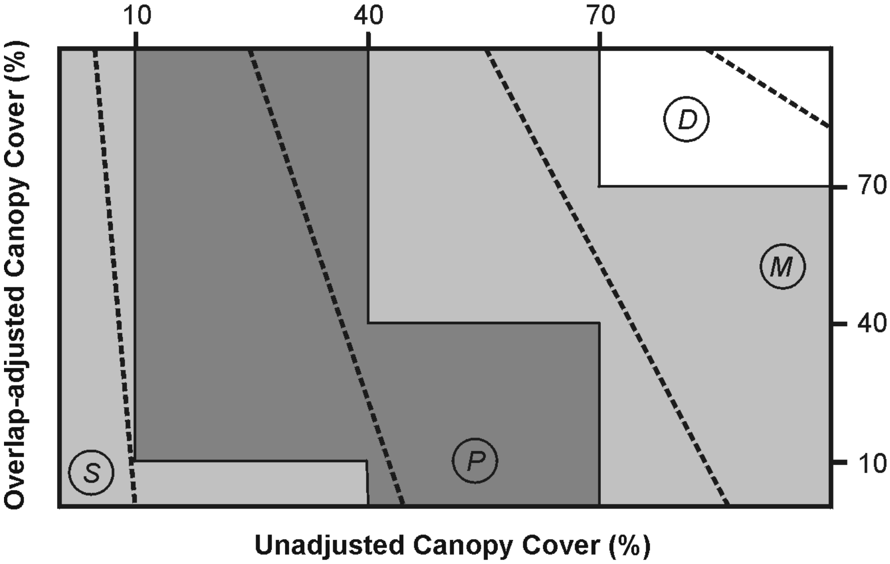


Figure 4.12.1 - Two measures of canopy cover, unadjusted and overlap-adjusted percent canopy cover, are used to derive weighted estimates of the four CWHR density classes. (S = sparse, P = open, M = moderate and D = dense)

The second step determines the dominant species. A species is considered dominant if it comprises more than 80 percent of the stand basal area. The search starts with pine and moves down the column of forest types listed in the leftmost column of Table 4.12.15. If no species is dominant, then fir-mixed conifer is the default cover type.

The rules governing Table 4.12.15 select one or two candidate (usually low) fuel models. These are used along with the high fuels models to select the final set of weighted fuel models. The table has been modified from Landram's original table so that with the exception of the right-most column (mature Size Class 6 stands), cells with fuel model 10 or 12 in the original table have been replaced with fuel model 8. This change was made so that when appropriate, the default FFE fuel model logic (described in section 2.4.8) is not constrained in its selection of a candidate high fuel models: combinations of fuel models 10, 11,12 and 13 may still be selected when fuel loads are high. Finally, in order to give Table 4.12.15 priority, FM10 is removed from the list of candidate models when FM11 has been selected from the table.

In some situations a thinning or disturbance may cause one of the selected fuel models to switch from FM8 or FM9 to FM5. When this happens, the transition to these brush fuel models is modified to simulate a delay in brush ingrowth. In the case where an FM8 or FM9 fuel model is predicted to change to FM5, the change is made over five years, gradually shifting from FM8 or FM9 to FM5.

Finally, flame length is calculated using the weights from above the appropriate fuel models. The **FLAMEADJ** keyword allows users to scale the calculated flame length or override the calculated flame length with a value they choose.

Table 4.12.15 - Fire behavior fuels models for the NC-FFE are determined using forest type and CWHR class, as described in the text. The modeling logic allows one or more fuel models to be selected.

Size Class	**1**	**2**				**3**				**4**				**5**				**6**
Density Class		**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	
Forest Type																		
Pine	5	6	6	6	6	2	2	9	9	2	2	2	9	2	2	9	9	10
Red fir	5	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
White fir – east side	5	5	5	8	8	11	11	11	8	8	8	8	8	8	8	8	8	10
White fir – west side	5	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
Douglas-fir	5	5	5	6	6	6	6	8	8	11	11	9	8	11	11	9	8	10
Hardwoods	5	5	5	6	6	11	11	11	9	9	9	9	9	9	9	9	9	10
Pine mixed – conifer	5	5	5	6	6	6	6	6	9	9	9	8	8	8	8	8	8	10
Fir mixed – conifer	5	5	5	6	6	6	6	6	8	6	6	8	8	6	6	8	8	10
Other softwood	5	5	5	6	6	6	6	6	8	6	6	8	8	6	6	8	8	10

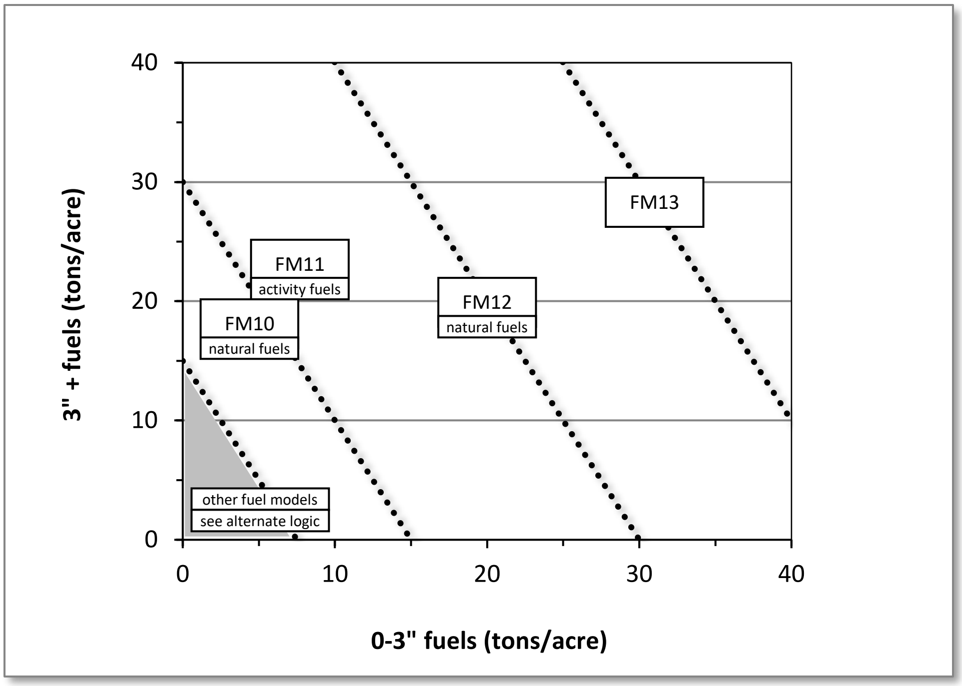


Figure 4.12.2 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.12.15. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

4.13 Northeast (NE)

4.13.1 Tree Species

The Northeast variant models the 105 tree species, plus two other composite species categories shown in Table 4.13.1.

Table 4.13.1 - Tree species simulated by the Northeast variant.

Common name	Scientific name
balsam fir	*Abies balsamea*
tamarack	*Larix laricina*
white spruce	*Picea glauca*
red spruce	*Picea rubens*
Norway spruce	*Picea abies*
black spruce	*Picea mariana*
spruce	*Picea*
red pine	*Pinus resinosa*
eastern white pine	*Pinus strobus*
loblolly pine	*Pinus taeda*
Virginia pine	*Pinus viginiana*
arborvitae	*Thuja occidentalis*
Atlantic white cedar	*Chamaecyparis thyoides*
eastern redcedar	*Juniperus virginiana*
juniper	*Juniperus*
eastern hemlock	*Tsuga canadensis*
hemlock	*Tsuga*
pine	*Pinus*
jack pine	*Pinus banksiana*
shortleaf pine	*Pinus echinata*
Table Mountain pine	*Pinus pungens*
pitch pine	*Pinus rigida*
pond pine	*Pinus serotina*
Scots pine	*Pinus sylvestris*
other softwood	
red maple	*Acer rubrum*
sugar maple	*Acer saccharum*
black maple	*Acer nigrum*
silver maple	*Acer saccharinum*
yellow birch	*Betula alleghaniensis*
sweet birch	*Betula lenta*
river birch	*Betula nigra*
paper birch	*Betula papyrifera*
gray birch	*Betula populifolia*
hybrid hickory	*Carya*
pignut hickory	*Carya glabra*
shellbark hickory	*Carya laciniosa*
shagbark hickory	*Carya ovata*
mockernut hickory	*Carya alba*
American beech	*Fagus grandifolia*
ash	*Fraxinus*
white ash	*Fraxinus americana*
black ash	*Fraxinus nigra*
green ash	*Fraxinus pennsylvanica*
pumpkin ash	*Fraxinus profunda*
tuliptree	*Liriodendron tulipifera*
sweetgum	*Liquidamber styraciflua*
cucumber tree	*Magnolia acuminata*
quaking aspen	*Populus tremuloides*
white oak	*Quercus alba*
bur oak	*Quercus macrocarpa*
chinkapin oak	*Quercus muehlenbergii*
post oak	*Quercus stellata*
oak	*Quercus*
scarlet oak	*Quercus coccinea*
shingle oak	*Quercus imbricaria*
water oak	*Quercus nigra*
pin oak	*Quercus palustris*
chestnut oak	*Quercus prinus*
swamp white oak	*Quercus bicolor*
swamp chestnut oak	*Quercus michauxii*
northern red oak	*Quercus rubra*
southern red oak	*Quercus falcata*
black oak	*Quercus velutina*
cherrybark oak	*Quercus pagoda*
buckeye	*Aesculus*
yellow buckeye	*Aesculus flava*
water birch	*Betula occidentalis*
common hackberry	*Celtis occidentalis*
common persimmon	*Diospyros virginiana*
American holly	*Ilex opaca*
butternut	*Juglans cinerea*
black walnut	*Juglans nigra*
Osage-orange	*Maclura pomifera*
magnolia	*Magnolia*
sweetbay	*Magnolia virginiana*
apple	*Malus*
water tupelo	*Nyssa aquatica*
blackgum	*Nyssa sylvatica*
sourwood	*Oxydendrum arboreum*
princesstree	*Paulownia tomentosa*
American sycamore	*Platanus occidentalis*
willow oak	*Quercus phellos*
black locust	*Robinia pseudoacacia*
black willow	*Salix nigra*
sassafras	*Sassafras albidum*
American basswood	*Tilia americana*
white basswood	*Tilia americana* var. *heterophylla*
elm	*Ulmus*
American elm	*Ulmus americana*
slippery elm	*Ulmus rubra*
other hardwood	
boxelder	*Acer negundo*
striped maple	*Acer pensylvanicum*
tree of heaven	*Ailanthus altissima*
serviceberry	*Amelanchier*
American hornbeam	*Carpinus caroliniana*
flowering dogwood	*Cornus florida*

Common name	Scientific name	Common name	Scientific name
balsam poplar	*Populus balsamifera*	hawthorn	*Crataegus*
eastern cottonwood	*Populus deltoides*	hophornbeam	*Ostrya virginiana*
bigtooth aspen	*Populus grandidentata*	plum	*Prunus*
swamp cottonwood	*Populus heterophylla*	pin cherry	*Prunus pensylvanica*
black cherry	*Prunus serotina*		

4.13.2 Snags

The snag model logic is based on input given by researchers at the Northeast research station. Parts of it were taken from the SN-FFE and LS-FFE, where reasonable. A complete description of the Snag Submodel is provided in section 2.3.

Initially, each species was put into a snag class (1 - 3), as listed in Table 4.13.2. The snag class is defined as follows:

1 – fastest in terms of decay

2 – average in terms of decay

3 – slowest in terms of decay

Table 4.13.2 - Snag class for each species in NE-FFE.

Species	Snag class	Species	Snag class
balsam fir	1	white oak	3
tamarack	3	bur oak	3
white spruce	1	chinkapin oak	3
red spruce	1	post oak	3
Norway spruce	1	oak	3
black spruce	1	scarlet oak	2
spruce	1	shingle oak	2
red pine	1	water oak	2
eastern white pine	2	pin oak	2
loblolly pine	1	chestnut oak	3
Virginia pine	1	swamp white oak	3
arborvitae	3	swamp chestnut oak	3
Atlantic white cedar	3	northern red oak	2
eastern redcedar	3	southern red oak	2
juniper	3	black oak	2
eastern hemlock	3	cherrybark oak	2
hemlock	3	buckeye	2
pine	1	yellow buckeye	2
jack pine	1	water birch	1
shortleaf pine	1	common hackberry	2
Table Mountain pine	1	common persimmon	3
pitch pine	1	American holly	2
pond pine	1	butternut	2
Scots pine	1	black walnut	2
other softwood	1	Osage-orange	2
red maple	2	magnolia	2
sugar maple	2	sweetbay	2
black maple	2	apple	2
silver maple	2	water tupelo	3
yellow birch	1	blackgum	3
sweet birch	1	sourwood	2
river birch	1	princesstree	2
paper birch	1	American sycamore	2
gray birch	1	willow oak	2
hybrid hickory	3	black locust	3
pignut hickory	3	black willow	1

Species	Snag class
shellbark hickory	3
shagbark hickory	3
mockernut hickory	3
American beech	2
ash	2
white ash	2
black ash	2
green ash	2
pumpkin ash	2
tuliptree	2
sweetgum	2
cucumber tree	2
quaking aspen	1
balsam poplar	1
eastern cottonwood	1
bigtooth aspen	1
swamp cottonwood	1
black cherry	2
sassafras	2
American basswood	1
white basswood	1
elm	1
American elm	1
slippery elm	1
other hardwood	2
boxelder	2
striped maple	2
tree of heaven	2
serviceberry	2
American hornbeam	2
flowering dogwood	2
hawthorn	2
hophornbeam	2
plum	2
pin cherry	2

The snag class is used to modify the Snag Submodel for the different species in the NE-FFE variant thru a multiplier to modify the time required for snags to decay from a “hard” to a “soft” state. The basic equation used to predict the amount of time until a snag is soft can be found in section 2.3.5.

Table 4.13.3 - Default soft-snag multipliers for the NE-FFE. This multiplier is the default value used by the SNAGDCAY keyword.

Snag Class	Hard-to-Soft multiplier	Year til soft for hard 12” snags
1	0.07	2
2	0.21	6
3	0.35	10

Other model parameters that are set for all species in general include:

- the snag fall rate;
- the maximum number of years that snags will remain standing; and
- the snag height loss rate.

Unlike most FFE variants, the NE-FFE base snag fall rate was modified from the one used in the NI-FFE model. The base snag fall rate is linearly interpolated based on dbh. The assumed annual fall rates are in Table 4.13.4. They were based on discussions with Coeli Hoover and Linda Heath (FS Northern Research Station) and Yamasaki and Leak (2006).

Table 4.13.4 - Default snag fall rates for the NE-FFE.

DBH (inches)	Years until all snags have fallen (yrs)	Associated snag fall rate (proportion each year)
1	5	0.20
5	15	0.0667
12	25	0.04

The last 5 percent of snags over 20 inches fall at a slower rate and some remain standing up to 50 years.

The base height loss rate for snags is 1.5% a year. The corresponding number of years until a snag reaches 50% of its original height is 45 years. The base height loss rate after 50% of a snag's height is lost is 1%. Soft snags lose height twice as fast as hard snags.

Because the snag fall rates and height loss rates do not vary between species, the default snag fall and snag height loss multipliers (used by the SNAGFALL and SNAGBRK keywords) are 1.0.

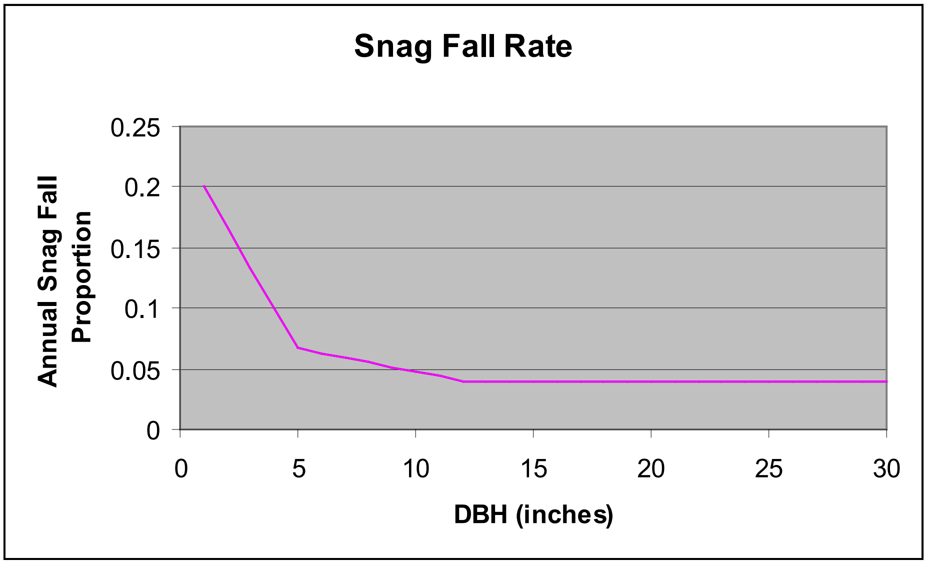


Figure 4.13.1 - The rate of fall of small snags and the first 95% of large snags.

Figure 4.13.2 and Figure 4.13.3 show the proportion of 5", 12", and larger trees still standing after various amounts of time. From Figure 4.13.3, you can see how the last 5% of these large snags fall at a slower rate and that some persist for as long as 50 years.

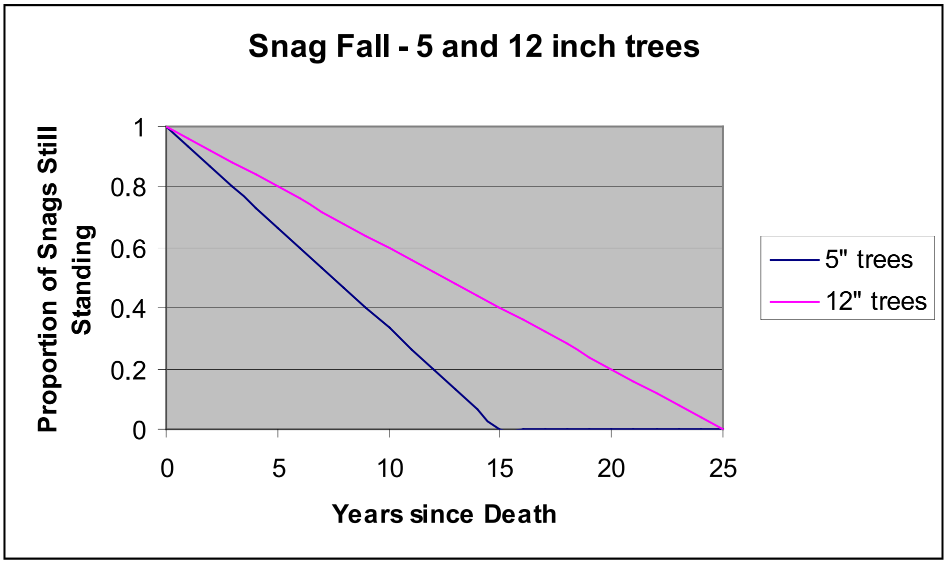


Figure 4.13.2 - Snag fall rates for 5 and 12 inch trees.

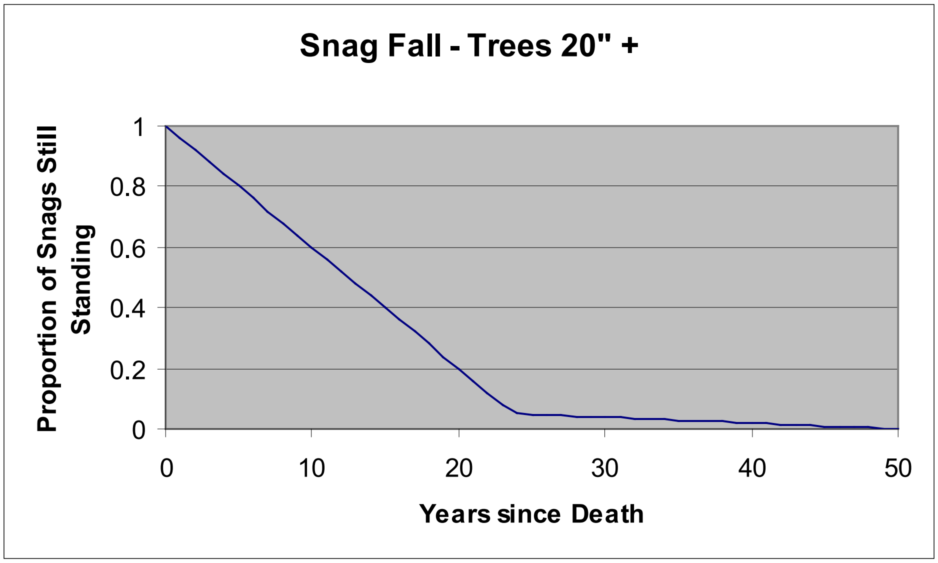


Figure 4.13.3 - Snag fall rates for trees larger than 20 inches dbh.

Figure 4.18.4 shows the number of years it takes a hard snag to become soft for different diameter snags.

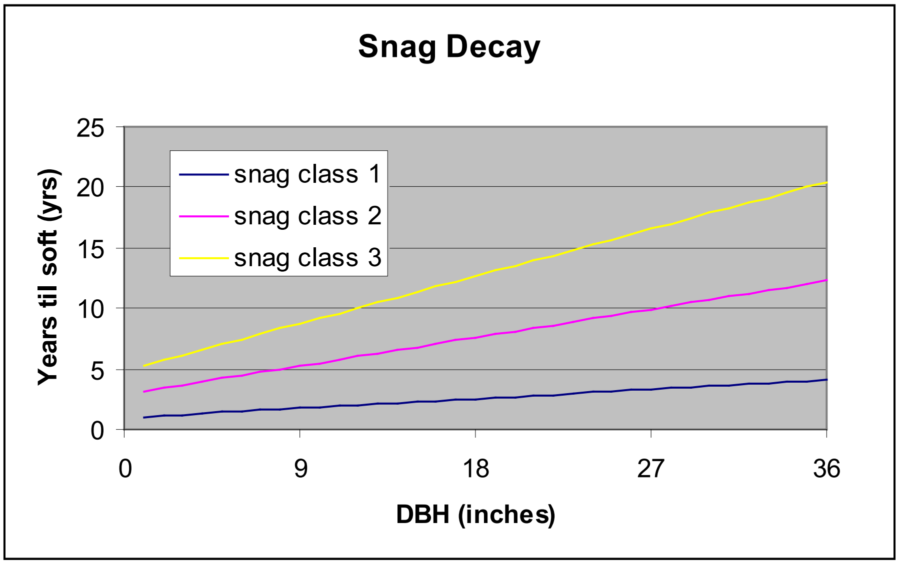


Figure 4.13.4 - The number of years until soft for various diameter snags.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.13.5 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

4.13.3 Fuels

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and dead surface fuels. Live herb and shrub fuel load and the initial dead surface fuel load are assigned based on the Forest Type code, as reported in the Summary Statistics Table.

One difference between the implementation of FFE in the Northeast variant, relative to its implementation in all of the western variants, is the distinction between crown material and stemwood. In the western variants, stemwood biomass is calculated by converting total cubic foot volume to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood and foliage alone. In the Northeast variant, total cubic foot volume equations are not in use. As a result, stemwood biomass is calculated by converting merchantable cubic foot volume (to a 4 inch top diameter inside bark) to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood and foliage plus the unmerchantable portion of the main stem (stemwood above a 4 inch diameter). This has some effects that users should be aware of.

1) The default assumption in the western variants when harvesting is that the stems are taken and the crown material (branchwood) is left. In the Northeast variant this corresponds to a default assumption that the merchantable material is taken and the unmerchantable material (branchwood, small trees, unmerchantable topwood) is left.
2) Surface fuel accumulation is predicted from a variety of processes including crown breakage and crown lift. Based on a default percentage and the change in crown ratio for each tree record, a certain amount of material is predicted to fall to the ground each year. This assumption changes slightly when using the Northeast variant. Rather than predicting a certain percentage of the branchwood will fall each year, essentially the model is predicting a certain percentage of the unmerchantable material (branchwood, small trees, unmerchantable topwood) will fall each year.
3) Other changes were made to handle this situation and are described in the section on Tree Crowns.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using wood density calculated from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). Generally, species not listed were given a default value of 28.7 lbs/cuft.

Table 4.13.5 - Wood density (ovendry lbs/green ft3) used in the NE-FFE variant.

Species	lbs/cuft	Species used	Species	lbs/cuft	Species used
balsam fir	20.6		white oak	37.4	
tamarack	30.6		bur oak	36.2	
white spruce	23.1		chinkapin oak	37.4	white oak
red spruce	23.1		post oak	37.4	
Norway spruce	23.1	red / white spruce	oak	37.4	white oak
black spruce	23.7		scarlet oak	37.4	
spruce	23.1	red / white spruce	shingle oak	34.9	northern red oak
red pine	25.6		water oak	34.9	
eastern white pine	21.2		pin oak	36.2	
loblolly pine	29.3		chestnut oak	35.6	
Virginia pine	28.1		swamp white oak	39.9	
arborvitae	18.1		swamp chestnut oak	37.4	
Atlantic white cedar	19.3		northern red oak	34.9	

Species	lbs/cuft	Species used
eastern redcedar	27.4	
juniper	27.4	eastern redcedar
eastern hemlock	23.7	
hemlock	26.2	mountain / western hemlock
pine	25.6	red pine
jack pine	24.9	
shortleaf pine	29.3	
Table Mountain pine	28.1	Virginia pine
pitch pine	29.3	
pond pine	31.8	
Scots pine	25.6	red pine
other softwood	25.6	red pine
red maple	30.6	
sugar maple	34.9	
black maple	32.4	
silver maple	27.4	
yellow birch	34.3	
sweet birch	37.4	
river birch	29.9	paper birch
paper birch	29.9	
gray birch	29.9	paper birch
hybrid hickory	39.9	mockernut / shagbark hickory
pignut hickory	41.2	
shellbark hickory	38.7	
shagbark hickory	39.9	
mockernut hickory	39.9	
American beech	34.9	
ash	33.1	green ash
white ash	34.3	
black ash	28.1	
green ash	33.1	
pumpkin ash	33.1	green ash
tuliptree	24.9	
sweetgum	28.7	
cucumber tree	27.4	
quaking aspen	21.8	
balsam poplar	19.3	
eastern cottonwood	23.1	
bigtooth aspen	22.5	
swamp cottonwood	23.1	eastern cottonwood
black cherry	29.3	

Species	lbs/cuft	Species used
southern red oak	32.4	
black oak	34.9	
cherrybark oak	38.0	
buckeye	28.7	default
yellow buckeye	28.7	default
water birch	29.9	paper birch
common hackberry	30.6	
common persimmon	28.7	default
American holly	28.7	default
butternut	22.5	
black walnut	31.8	
Osage-orange	28.7	default
magnolia	28.7	southern magnolia
sweetbay	28.7	southern magnolia
apple	29.3	black cherry
water tupelo	28.7	
blackgum	28.7	
sourwood	28.7	default
princesstree	28.7	default
American sycamore	28.7	
willow oak	34.9	
black locust	41.2	
black willow	22.5	
sassafras	26.2	
American basswood	20.0	
white basswood	20.0	American basswood
elm	28.7	American elm
American elm	28.7	
slippery elm	29.9	
other hardwood	28.7	default
boxelder	30.6	red maple
striped maple	30.6	red maple
tree of heaven	28.7	default
serviceberry	28.7	default
American hornbeam	28.7	default
flowering dogwood	28.7	default
hawthorn	28.7	default
hophornbeam	28.7	default
plum	29.3	black cherry
pin cherry	29.3	black cherry

Tree Crown: For merchantable trees, estimates of crown material, including foliage, branchwood and bolewood above a 4 inch top (DOB), are from Jenkins and others (2003). These equations do not provide information on how the crown material is distributed by size class. Information on partitioning canopy fuel loads by size class was taken from several sources (Snell and Little (1983), Loomis and Blank (1981), Loomis and Roussopoulos (1978), Loomis et. al. (1966)). Species were mapped when necessary. Because information on how crown material is partitioned for different species is often based on different definitions of "crown" (branchwood only, branchwood plus stemwood above a 0.25 inch diameter, branchwood plus stemwood above a 1 inch diameter), the equations to predict the proportion of crown biomass in various size classes are adjusted. The basic assumption is that the biomass of the unmerchantable tip can be calculated from the volume of a cone, where the height of the cone is the difference between total height and height at a 4 inch top diameter and the bottom diameter of the cone is 4 inches. There are some additions made to these estimates of crown biomass. Jenkin's equations include branchwood and stem material above a 4 inch DOB top, while the Northeast volume equations go up to a 4 inch DIB top. As a result, there is a small portion of biomass that is missing. This is estimated and added to the crown material estimates.

For unmerchantable trees, total above ground biomass is predicted by summing the estimate of crown biomass with an estimate of the bole biomass. This is done by estimating the volume of the breakpoint diameter tree with both the standard National Volume Estimator Library volume equation, as well as a simplified equation (Vol = 0.0015*D*D*H) to compute an adjustment factor that is used along with the simplified volume equation to estimate the volume and biomass of the unmerchantable tree bole. This was done to ensure smooth, non-erratic biomass estimates for trees as they grow and pass the merchantable dbh breakpoint. A similar method (to that for large trees) is used to adjust how the crown material is distributed by size class. In this case the main stem is assumed to be cone-shaped above breast height and cylinder-shaped below breast height.

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are primarily from Hardin et. al. (2001). Exceptions include eastern redcedar and northern white-cedar, which are from Barnes and Wagner (2002).

Dead foliage and branch materials also contribute to litter fall. Each species was categorized into 1 of 6 crown fall rate categories and the life span of dead foliage and branches was determined for each category. The categorization and rates are based on those developed for SN-FFE and LS-FFE, as well as general input from the NE development meeting.

Table 4.13.6 - Life span of live foliage and crown fall class (1 to 6) for species modeled in the NE-FFE variant.

Species	Leaf Life (years)	Crown Fall Class	Species	Leaf Life (years)	Crown Fall Class
balsam fir	8	6	white oak	1	3
tamarack	1	1	bur oak	1	3
white spruce	8	6	chinkapin oak	1	3
red spruce	8	6	post oak	1	3
Norway spruce	8	6	oak	1	3
black spruce	8	6	scarlet oak	1	4
spruce	8	6	shingle oak	1	4
red pine	4	6	water oak	1	4
eastern white pine	2	6	pin oak	1	4
loblolly pine	3	6	chestnut oak	1	3
Virginia pine	3	6	swamp white oak	1	3
arborvitae	2	1	swamp chestnut oak	1	3
Atlantic white cedar	3	1	northern red oak	1	4
eastern redcedar	5	1	southern red oak	1	4
juniper	5	1	black oak	1	4
eastern hemlock	3	3	cherrybark oak	1	4
hemlock	3	3	buckeye	1	5
pine	2	6	yellow buckeye	1	5
jack pine	2	6	water birch	1	6
shortleaf pine	4	6	common hackberry	1	4
Table Mountain pine	3	6	common persimmon	1	4
pitch pine	2	6	American holly	3	4
pond pine	2	6	butternut	1	4
Scots pine	3	6	black walnut	1	4
other softwood	2	6	Osage-orange	1	5

Species	Leaf Life (years)	Crown Fall Class	Species	Leaf Life (years)	Crown Fall Class
red maple	1	5	magnolia	1	4
sugar maple	1	5	sweetbay	1	4
black maple	1	5	apple	1	4
silver maple	1	5	water tupelo	1	3
yellow birch	1	6	blackgum	1	3
sweet birch	1	6	sourwood	1	5
river birch	1	6	princesstree	1	5
paper birch	1	6	American sycamore	1	5
gray birch	1	6	willow oak	1	4
hybrid hickory	1	2	black locust	1	2
pignut hickory	1	2	black willow	1	6
shellbark hickory	1	2	sassafras	1	4
shagbark hickory	1	2	American basswood	1	6
mockernut hickory	1	2	white basswood	1	6
American beech	1	4	elm	1	5
ash	1	5	American elm	1	5
white ash	1	5	slippery elm	1	5
black ash	1	5	other hardwood	1	5
green ash	1	5	boxelder	1	5
pumpkin ash	1	5	striped maple	1	5
tuliptree	1	4	tree of heaven	1	5
sweetgum	1	5	serviceberry	1	5
cucumber tree	1	4	American hornbeam	1	4
quaking aspen	1	6	flowering dogwood	1	5
balsam poplar	1	6	hawthorn	1	5
eastern cottonwood	1	6	hophornbeam	1	4
bigtooth aspen	1	6	plum	1	4
swamp cottonwood	1	6	pin cherry	1	4
black cherry	1	4			

Table 4.13.7 - Years until all snag crown material of certain sizes has fallen by crown fall class

Crown fall class	Snag Crown Material Time to 100% Fallen (years)					
	Foliage	<0.25”	0.25–1”	1-3”	3-6”	6-12”
1	1 (cedars = 3)	5	5	10	25	25
2	1	3	3	6	12	12
3	1	2	2	5	10	10
4	1	1	1	4	8	8
5	1	1	1	3	6	6
6	1	1	1	2	4	4

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very crudely within NE-FFE. Shrubs and herbs are assigned a constant biomass value based on Chojnacky et. al. (2004).

Table 4.13.8 - Values (dry weight, tons/acre) for live fuels used in the NE-FFE.

Forest Type	Herbs	Shrubs
All stand types	0.31	0.31

Dead Fuels: Initial default fuel pools are based on FIA forest type and size class. Default fuel loadings are based on FIA fuels data collected in the Northeast and were provided by Randy Morin and Chris Woodall. All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.13.9 - FIA forest type and size class are used to assign default surface fuel values (tons/acre) by size class. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

FIA Forest type	FIA size class	Size class (inches)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
white / red / jack pine	all	0.81	1.19	1.66	0.73	2.24	2.01	3.06	11.20

	FIA size	Size class (inches)							
FIA Forest type	**class**	**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
spruce –fir	1	0.37	0.59	1.85	0.82	2.47	5.40	3.36	48.56
spruce –fir	2	0.50	0.68	1.77	1.52	3.17	1.64	1.91	22.14
spruce –fir	3	0.31	0.65	1.55	1.45	2.82	1.08	1.57	25.87
loblolly-shortleaf pine	all	0.21	1.08	7.32	0.53	0.57	0.00	4.21	13.94
exotic softwoods	all	0.34	0.50	0.56	0.08	0.00	0.00	0.60	8.11
oak-pine	1	0.23	0.82	2.55	0.83	2.11	1.20	4.06	22.63
oak-pine	2 or 3	0.26	0.84	1.15	0.49	0.50	4.64	3.12	17.56
oak-hickory	1	0.31	0.72	2.09	0.86	1.49	2.34	2.01	7.64
oak-hickory	2	0.32	1.13	2.51	0.53	0.98	0.52	1.75	7.31
oak-hickory	3	0.17	0.77	1.43	0.45	0.54	0.06	1.35	3.43
oak-gum-cypress	all	0.32	0.75	1.31	0.64	2.10	0.98	1.07	15.21
elm-ash-cottonwood	1 or 2	0.17	0.68	1.65	0.57	1.20	1.66	0.70	5.83
elm-ash-cottonwood	3	0.22	2.15	0.85	0.03	0.05	0.21	0.36	1.38
maple-beech-birch	1	0.39	0.90	2.88	0.95	2.25	1.96	2.39	13.75
maple-beech-birch	2	0.37	1.03	2.61	0.91	1.46	1.57	2.28	16.74
maple-beech-birch	3	0.33	0.73	1.25	0.54	0.92	1.99	1.71	8.27
aspen-birch	1 or 2	0.48	1.66	2.80	0.87	1.70	2.97	2.72	19.61
aspen-birch	3	0.52	0.76	2.57	1.15	0.94	0.34	1.34	10.36
nonstocked	5	0.33	1.08	1.47	0.24	0.49	0.53	1.01	1.07

4.13.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.13.10 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.13.10 - Species-specific constants for determining single bark thickness.

Species	Multiplier (Vsp)	Species used	Species	Multiplier (Vsp)	Species used
balsam fir	0.031		white oak	0.04	
tamarack	0.031		bur oak	0.042	
white spruce	0.025		chinkapin oak	0.042	
red spruce	0.034		post oak	0.044	
Norway spruce	0.029		oak	0.045	quercus sp.
black spruce	0.032		scarlet oak	0.04	
spruce	0.034		shingle oak	0.041	
red pine	0.043		water oak	0.036	
eastern white pine	0.045		pin oak	0.041	
loblolly pine	0.052		chestnut oak	0.049	
Virginia pine	0.033		swamp white oak	0.045	
arborvitae	0.025		swamp chestnut oak	0.046	
Atlantic white cedar	0.025		northern red oak	0.042	
eastern redcedar	0.038		southern red oak	0.044	
juniper	0.033	juniperus sp.	black oak	0.045	
eastern hemlock	0.039		cherrybark oak	0.044	
hemlock	0.04	western / mountain hemlock	buckeye	0.036	Ohio buckeye
pine	0.03	Pinus sp.	yellow buckeye	0.05	
jack pine	0.04		water birch	0.05	
shortleaf pine	0.037		common hackberry	0.036	sugarberry
Table Mountain pine	0.04		common persimmon	0.041	
pitch pine	0.045		American holly	0.042	
pond pine	0.62		butternut	0.041	
Scots pine	0.03		black walnut	0.041	
other softwood	0.03	pinus sp.	Osage-orange	0.037	

Species	Multiplier (Vsp)	Species used
red maple	0.028	
sugar maple	0.033	
black maple	0.035	
silver maple	0.031	
yellow birch	0.031	
sweet birch	0.03	
river birch	0.029	
paper birch	0.027	
gray birch	0.033	betula sp.
hybrid hickory	0.044	carya sp.
pignut hickory	0.037	
shellbark hickory	0.043	
shagbark hickory	0.04	
mockernut hickory	0.043	
American beech	0.025	
ash	0.042	fraxinus sp.
white ash	0.042	
black ash	0.035	
green ash	0.039	
pumpkin ash	0.037	
tuliptree	0.041	
sweetgum	0.036	
cucumber tree	0.036	
quaking aspen	0.044	
balsam poplar	0.04	
eastern cottonwood	0.04	
bigtooth aspen	0.039	
swamp cottonwood	0.05	
black cherry	0.03	
magnolia	0.039	magnolia sp.
sweetbay	0.04	
apple	0.043	
water tupelo	0.03	
blackgum	0.039	
sourwood	0.036	
princesstree	0.05	
American sycamore	0.033	
willow oak	0.041	
black locust	0.049	
black willow	0.04	
sassafras	0.035	
American basswood	0.04	
white basswood	0.05	
elm	0.039	ulmus sp.
American elm	0.031	
slippery elm	0.032	
other hardwood	0.045	middle of this group
boxelder	0.034	
striped maple	0.045	
tree of heaven	0.05	
serviceberry	0.05	
American hornbeam	0.03	
flowering dogwood	0.041	
hawthorn	0.038	
hophornbeam	0.037	
plum	0.05	prunus sp.
pin cherry	0.045	

4.13.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.13.11). Default decay rates are based on Foster and Lang (1982), Arthur et. al. (1993), Fahey et. al. (1988), and Melillo et. al. (1982). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.13.11 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.19	0.02
0.25 – 1		
1 – 3	0.11	
3 – 6	0.07	
6 – 12	0.03	
> 12		
Litter	0.40	
Duff	0.002	0.0

By default, FFE decays all wood species at the rates shown in Table 4.13.11. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.13.12 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword. The decay rate classes were generally determined from the Wood Handbook (1999). When species were classified differently for young or old growth, young growth was assumed. Species not listed in the wood handbook were classed as 4.

Table 4.13.12 - Default wood decay classes used in the NE-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Rate Class
balsam fir	4
tamarack	3
white spruce	4
red spruce	4
Norway spruce	4
black spruce	4
spruce	4
red pine	4
eastern white pine	4
loblolly pine	4
Virginia pine	4
arborvitae	2
Atlantic white cedar	2
eastern redcedar	2
juniper	2
eastern hemlock	4
hemlock	4
pine	4
jack pine	4
shortleaf pine	4
Table Mountain pine	4
pitch pine	4
pond pine	4
Scots pine	4
other softwood	4
red maple	4
sugar maple	4
black maple	4
silver maple	4
yellow birch	4
sweet birch	4
river birch	4
paper birch	4
gray birch	4
hybrid hickory	4
pignut hickory	4
shellbark hickory	4
shagbark hickory	4
mockernut hickory	4
American beech	4
ash	4
white ash	4
black ash	4
green ash	4
pumpkin ash	4
tuliptree	4
sweetgum	4
cucumber tree	4
quaking aspen	4
balsam poplar	4
eastern cottonwood	4
bigtooth aspen	4
swamp cottonwood	4
black cherry	2
white oak	2
bur oak	2
chinkapin oak	2
post oak	2
oak	2
scarlet oak	2
shingle oak	2
water oak	2
pin oak	2
chestnut oak	2
swamp white oak	2
swamp chestnut oak	2
northern red oak	2
southern red oak	2
black oak	2
cherrybark oak	2
buckeye	4
yellow buckeye	4
water birch	4
common hackberry	4
common persimmon	4
American holly	4
butternut	4
black walnut	2
Osage-orange	1
magnolia	4
sweetbay	4
apple	2
water tupelo	4
blackgum	4
sourwood	4
princesstree	4
American sycamore	4
willow oak	2
black locust	1
black willow	4
sassafras	2
American basswood	4
white basswood	4
elm	4
American elm	4
slippery elm	4
other hardwood	4
boxelder	4
striped maple	4
tree of heaven	4
serviceberry	4
American hornbeam	4
flowering dogwood	4
hawthorn	4
hophornbeam	4
plum	2
pin cherry	2

4.13.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.13.13) or they can specify moisture conditions using the **MOISTURE** keyword. These defaults were set based on the values used in LS-FFE.

Table 4.13.13 - Moisture values (%), which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	5	7	10	19
0.25 – 1.0 in. (10-hr)	8	9	13	29
1.0 – 3.0 in. (100-hr)	12	14	17	22
> 3.0 in. (1000+ -hr)	15	17	21	25
Duff	40	75	100	175
Live woody	89	105	135	140
Live herbaceous	60	82	116	120

4.13.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. Stand management actions such as thinning and harvesting can abruptly increase fuel loads, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the NE-FFE to follow the third of these four options.

NOTE: Currently NE-FFE does not have a detailed fuel model selection logic. As a result, fuel models are selected based on fuel loading only (Figure 4.13.5). When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.13.5, fuel model 9 becomes a candidate model. When fuel loads are higher, other fuel models (fm 10 – 13) may also become candidates.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by the logic described above. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

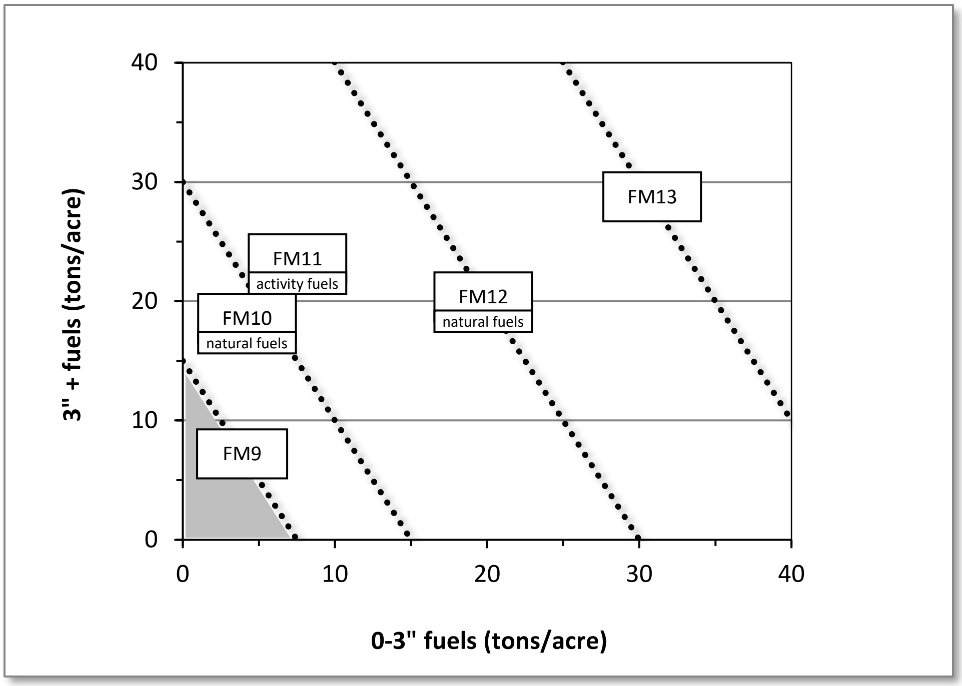


Figure 4.13.5 - At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. At low fuel loads, fuel model 9 is selected.

4.13.8 Fire-related Mortality

Like most FFE variants, NE-FFE predicts fire-related tree mortality based on species, diameter, and crown scorch (see section 2.5.5 of the FFE documentation). However, some modifications were made to further refine the predictions. The mortality of conifers is reduced by 50% if the burn is simulated before greenup. There is a minimum of 70% mortality for balsam fir that are hit by the flaming front. All maples under 4” dbh die when there is a burn and the flaming front hits them. Hardwoods also receive a reduction in mortality when the burn is before greenup – the mortality of most hardwoods is reduced by 20%, except for oaks above 2.5” dbh, whose mortality is reduced by 50%. All hardwoods less than 1” dbh die if the flaming front hits them.

4.14 Pacific Northwest Coast (PN)

4.14.1 Tree Species

The Pacific Northwest coast variant models the 37 tree species shown in Table 4.14.1. One additional category, ‘other’, is modeled using quaking aspen.

Table 4.14.1 - Tree species simulated by the Pacific Northwest Coast variant.

Common Name	Scientific Name	Notes
Pacific silver fir	*Abies amabilis*	
white fir	*Abies concolor*	
grand fir	*Abies grandis*	
subalpine fir	*Abies lasiocarpa*	
California red fir	*Abies magnifica*	
Sitka spruce	*Picea sitchensis*	
noble fir	*Abies procera*	
Alaska cedar	*Callitropsis nootkatensis*	
incense cedar	*Calocedrus decurrens*	
Engelmann spruce	*Picea engelmannii*	
lodgepole pine	*Pinus contorta*	
Jeffrey pine	*Pinus jeffreyi*	
sugar pine	*Pinus lambertiana*	
western white pine	*Pinus monticola*	
ponderosa pine	*Pinus ponderosa*	
Douglas-fir	*Pseudotsuga menziesii*	
redwood	*Sequoia sempervirens*	
western redcedar	*Thuja plicata*	
western hemlock	*Tsuga heterophylla*	
mountain hemlock	*Tsuga mertensiana*	
bigleaf maple	*Acer macrophyllum*	
red alder	*Alnus rubra*	
white alder	*Alnus rhombifolia*	
paper birch	*Betula papyrifera*	
giant chinquapin	*Chrysolepis chrysophylla* var. *chrysophylla*	
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	
Oregon white oak	*Quercus garryana*	
western juniper	*Juniperus occidentalis*	
subalpine larch	*Larix lyallii*	
whitebark pine	*Pinus albicaulis*	
knobcone pine	*Pinus attenuata*	
Pacific yew	*Taxus brevifolia*	
Pacific dogwood	*Cornus nuttallii*	
hawthorn	*Crataegus*	
bitter cherry	*Prunus emarginata*	
willow	*Salix*	
other		= *quaking aspen*

4.14.2 Snags

In the PN variant, the snag dynamics were modified based on the work of Kim Mellen-McLean, region 6 wildlife ecologist. These relationships are described in the following document: http://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/R6snags.pdf

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.14.2 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

4.14.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and dead surface fuel. Live herb and shrub fuel load and the initial dead surface fuel load are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a 'bare ground' stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using wood density calculated from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.14.2 for Douglas-fir is based on 'Douglas-fir coast'. The value for juniper is from Chojnacky and Moisen (1993).

Table 4.14.2 - Wood density (overdry lbs/green ft^3) used in the PN-FFE variant.

Species	Density (lbs/ft^3)	Species	Density (lbs/ft^3)
Pacific silver fir	24.9	mountain hemlock	26.2
white fir	23.1	bigleaf maple	27.4
grand fir	21.8	red alder	23.1
subalpine fir	19.3	white alder	36.2
California red fir	22.5	paper birch	29.9
Sitka spruce	20.6	giant chinquapin	36.2
noble fir	23.1	quaking aspen	21.8
Alaska cedar	26.2	black cottonwood	19.3
incense cedar	21.8	Oregon white oak	37.4
Engelmann spruce	20.6	western juniper	34.9
lodgepole pine	23.7	subalpine larch	29.9
Jeffrey pine	21.2	whitebark pine	22.5
sugar pine	21.2	knobcone pine	23.7
western white pine	22.5	Pacific yew	26.2
ponderosa pine	23.7	Pacific dogwood	27.4
Douglas-fir	28.1	hawthorn	27.4
redwood	21.2	bitter cherry	29.3
western redcedar	19.3	willow	22.5
western hemlock	26.2	other	21.8

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for many species in the PN-FFE (Table 4.14.3).

Table 4.14.3 - The crown biomass equations used in the PN-FFE. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
Pacific silver fir	grand fir; Brown and Johnston (1976)
white fir	grand fir; Brown and Johnston (1976)

Species	Species Mapping and Equation Source
grand fir	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
California red fir	subalpine fir; Brown and Johnston (1976)
Sitka spruce	Engelmann spruce; Brown and Johnston (1976)
noble fir	grand fir; Brown and Johnston (1976)
Alaska cedar	western larch; Brown and Johnston (1976)
incense cedar	based on western redcedar; Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
lodgepole pine	Brown and Johnston (1976)
Jeffrey pine	western white pine; Brown and Johnston (1976)
sugar pine	western white pine; Brown and Johnston (1976)
western white pine	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
redwood	western redcedar for biomass, western hemlock for partitioning (Mike Lander, pers. comm.; Brown and Johnston 1976)
western redcedar	Brown and Johnston (1976)
western hemlock	Brown and Johnston (1976)
mountain hemlock	Gholz and others (1979); western hemlock (Brown and Johnston 1976)
bigleaf maple	Snell and Little (1983)
red alder	Snell and Little (1983)
white alder	madrone; Snell and Little (1983)
paper birch	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
giant chinquapin	tanoak; Snell and Little (1983), Snell (1979)
quaking aspen	Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
black cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Oregon white oak	tanoak; Snell and Little (1983), Snell (1979)
western juniper	oneseed juniper; Grier and others (1992)
subalpine larch	subalpine fir; Brown and Johnston (1976)
whitebark pine	Johnston (1976)
knobcone pine	lodgepole pine; Brown and Johnston (1976)
Pacific yew	western redcedar; Brown and Johnston (1976)
Pacific dogwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
hawthorn	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
bitter cherry	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
willow	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other	aspen; Jenkins et. al. (2003); Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.14.4. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are based on Keane and others (1989) and in some cases were adapted at the model design workshop. Lifespans are taken from the FFE workshop, with western white pine and mountain hemlock mapped using ponderosa pine, and western hemlock and western redcedar based on Douglas-fir.

Table 4.14.4 - Life span of live and dead foliage (yr) and dead branches for species modeled in the PN-FFE variant.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
Pacific silver fir	7	2	5	5	15
white fir	7	2	5	5	15
grand fir	7	2	5	5	15
subalpine fir	7	2	5	5	15
California red fir	7	2	5	5	15
Sitka spruce	5	2	5	5	15
noble fir	7	2	5	5	15
Alaska cedar	5	2	5	5	20

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
incense cedar	5	1	5	5	20
Engelmann spruce	6	2	5	5	10
lodgepole pine	3	2	5	5	15
Jeffrey pine	3	2	3	10	15
sugar pine	3	2	5	5	15
western white pine	4	2	5	5	15
ponderosa pine	4	2	5	5	15
Douglas-fir	5	2	5	5	15
redwood	5	3	10	15	20
western redcedar	5	2	5	5	20
western hemlock	5	3	10	15	15
mountain hemlock	4	2	5	5	15
bigleaf maple	1	1	10	15	15
red alder	1	1	10	15	15
white alder	1	1	10	15	15
paper birch	1	1	10	15	15
giant chinquapin	1	1	10	15	15
quaking aspen	1	1	10	15	15
black cottonwood	1	1	10	15	15
Oregon white oak	1	1	10	15	15
western juniper	4	2	5	5	15
subalpine larch	1	1	5	5	15
whitebark pine	3	3	10	15	15
knobcone pine	4	3	10	15	15
Pacific yew	7	3	10	15	20
Pacific dogwood	1	1	10	15	15
hawthorn	1	1	10	15	15
bitter cherry	1	1	10	15	15
willow	1	1	10	15	15
other	1	1	10	15	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.14.5). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.14.5). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Values for quaking aspen are from Ottmar and others (2000b). Values for western juniper are from Ottmar and others (1998).

Table 4.14.5 - Values (dry weight, tons/acre) for live fuels used in the PN-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
Pacific silver fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
white fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
subalpine fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
California red fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
Sitka spruce	E	0.30	0.20	Use Engelmann spruce

Species		Herbs	Shrubs	Notes
	I	0.30	2.00	
noble fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
Alaska cedar	E	0.20	0.20	Use western redcedar
	I	0.40	2.00	
incense cedar	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
Engelmann spruce	E	0.30	0.20	
	I	0.30	2.00	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Jeffrey pine	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
sugar pine	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
western white pine	E	0.15	0.10	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	
	I	0.25	0.10	
Douglas-fir	E	0.20	0.20	
	I	0.40	2.00	
redwood	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
western redcedar	E	0.20	0.20	
	I	0.40	2.00	
western hemlock	E	0.20	0.20	
	I	0.40	2.00	
mountain hemlock	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
bigleaf maple	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
red alder	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
white alder	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
paper birch	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
giant chinquapin	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	
quaking aspen	E	0.25	0.25	Ottmar and others 2000b
	I	0.18	1.32	
black cottonwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
Oregon white oak	E	0.23	0.22	Gambel oak – Ottmar and others 2000b
	I	0.55	0.35	
western juniper	E	0.14	0.35	Ottmar and others (1998)
	I	0.10	2.06	
subalpine larch	E	0.20	0.20	Use western larch
	I	0.40	2.00	
whitebark pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
knobcone pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
Pacific yew	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
Pacific dogwood	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	

Species		Herbs	Shrubs	Notes
hawthorn	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
bitter cherry	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
willow	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) and were reviewed and in some cases modified at the model workshop (Table 4.14.6). Values for quaking aspen are from Ottmar and others (2000b). Values for western juniper are from Ottmar and others (1998). If tree canopy cover is <10 percent, the DWD pools are assigned an "initiating" value and if cover is >60 percent they are assign the "established" value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.14.6 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
Pacific silver fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
California red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Sitka spruce	E	0.7	0.7	3.0	7.0	7.0	10.0	1.0	35.0
	I	0.5	0.5	2.0	2.8	2.8	6.0	0.5	12.0
noble fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Alaska cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
incense cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
Engelmann spruce	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	12.0	0.6	30.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	12.0
Jeffrey pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
sugar pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Douglas-fir	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
redwood	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western redcedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western hemlock	E	0.7	0.7	3.0	7.0	7.0	10.0	1.0	35.0
	I	0.5	0.5	2.0	2.8	2.8	6.0	0.5	12.0
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
bigleaf maple	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
red alder	E	0.7	0.7	1.6	2.5	2.5	5.0	0.8	30.0
	I	0.1	0.1	0.2	0.5	1.4	3.0	0.4	12.0
white alder	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
paper birch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
giant chinquapin	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
Oregon white oak	E	0.7	0.7	0.8	1.2	1.2	0.5	1.4	0.0
	I	0.1	0.1	0.1	0.2	0.2	0.0	0.5	0.0
western juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0
subalpine larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
whitebark pine	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
knobcone pine	E	0.9	0.9	1.2	7.0	8.0	12.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	12.0
Pacific yew	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
Pacific dogwood	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
hawthorn	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
bitter cherry	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
willow	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.14.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.14.7 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.14.7 - Species-specific constants for determining single bark thickness.

Species	**Multiplier (V_{sp})**	**Species**	**Multiplier (V_{sp})**
Pacific silver fir	0.047	mountain hemlock	0.040
white fir	0.048	bigleaf maple	0.024
grand fir	0.046	red alder	0.026
subalpine fir	0.041	white alder	0.060
California red fir	0.039	paper birch	0.027
Sitka spruce	0.027	giant chinquapin	0.045
noble fir	0.045	quaking aspen	0.044
Alaska cedar	0.022	black cottonwood	0.044
incense cedar	0.081	Oregon white oak	0.029
Engelmann spruce	0.036	subalpine larch	0.050
lodgepole pine	0.028	whitebark pine	0.030
Jeffrey pine	0.068	knobcone pine	0.030
sugar pine	0.072	Pacific yew	0.025
western white pine	0.035	Pacific dogwood	0.062
ponderosa pine	0.063	hawthorn	0.038
Douglas-fir	0.063	bitter cherry	0.062
redwood	0.081	willow	0.041
western redcedar	0.035	other	0.044
western hemlock	0.040		

4.14.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5. Default decay rates (Table 4.14.8) are based on values provided by Kim Mellen-McLean, Pacific Northwest Regional wildlife ecologist, for the Pacific Northwest area. They are from published literature with adjustment factors based on temperature and moisture as determined by an expert panel at the Dead Wood Decay Calibration workshop in July 2003. The habitat code set by the **STDINFO** keyword or read in from an input database determines the temperature and moisture class for a stand, as shown in Table 4.14.9.

A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster. The decay rates for individual species vary based on the decay rate class of that species (Table 4.14.10). The decay rates may be modified for each decay class using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.14.8 - Default annual loss rates are applied based on size class, temperature and moisture class, and decay rate class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

	Size Class (inches)	Annual Loss Rate				Proportion of Loss Becoming Duff
		decay class 1	decay class 2	decay class 3	decay class 4	
moderate, wet	< 0.25	0.057	0.067	0.080	0.108	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.033	0.053	0.100	
	6 – 12					
	> 12	0.010	0.021	0.034	0.064	
moderate, mesic	< 0.25	0.069	0.081	0.097	0.154	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.024	0.050	0.082	0.154	
	6 – 12					
	> 12	0.012	0.025	0.041	0.077	
moderate, dry	< 0.25	0.093	0.109	0.131	0.177	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.024	0.050	0.082	0.154	
	6 – 12					
	> 12	0.016	0.034	0.055	0.104	
cold, wet	< 0.25	0.052	0.061	0.073	0.098	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.012	0.025	0.041	0.077	
	6 – 12					
	> 12	0.009	0.019	0.031	0.058	
cold, mesic	< 0.25	0.052	0.061	0.073	0.098	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.012	0.025	0.041	0.077	
	6 – 12					
	> 12	0.009	0.019	0.031	0.058	
cold, dry	< 0.25	0.064	0.075	0.090	0.131	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.020	0.043	0.070	0.131	
	6 – 12					
	> 12	0.011	0.023	0.038	0.071	
All	Litter	0. 5	0.5	0.5	0.5	0.02
	Duff	0.002	0.002	0.002	0.002	0.0

Table 4.14.9 - Habitat type - moisture and temperature regime relationships for the PN-FFE variant. The moisture and temperature classes affect the default decay rates. The original class is an older classification still used in the fuel model selection logic of this variant and was provided by Tom DeMeo and Kim Mellen-McLean, USFS, Portland, OR (pers. comm. 2003).

Habitat Type Code	Orig. Class	Temperature	Moisture	Habitat Type Code	Orig. Class	Temperature	Moisture
CDS221	Dry	moderate	dry	CHS132	Dry	moderate	dry
CDS255	Dry	moderate	dry	CHS133	Dry	moderate	mesic
CDS651	Dry	moderate	dry	CHS134	Dry	moderate	dry

Habitat Type Code	Orig. Class	Temperature	Moisture	Habitat Type Code	Orig. Class	Temperature	Moisture
CEF321	Dry	cold	dry	CHS136	Wet	moderate	mesic
CES212	Dry	cold	dry	CHS137	Mesic	moderate	mesic
CES321	Dry	cold	dry	CHS138	Mesic	moderate	mesic
CES621	Dry	cold	dry	CHS139	Mesic	moderate	mesic
CFF111	Wet	cold	wet	CHS221	Mesic	moderate	mesic
CFF211	Dry	moderate	dry	CHS222	Wet	moderate	wet
CFF311	Dry	cold	mesic	CHS321	Dry	moderate	dry
CFF611	Mesic	cold	wet	CHS322	Dry	moderate	dry
CFF612	Wet	cold	wet	CHS323	Wet	moderate	wet
CFF911	Mesic	cold	mesic	CHS324	Dry	moderate	dry
CFS156	Mesic	cold	mesic	CHS331	Mesic	moderate	mesic
CFS211	Dry	cold	mesic	CHS332	Dry	moderate	mesic
CFS212	Mesic	cold	mesic	CHS333	Dry	moderate	mesic
CFS213	Mesic	cold	mesic	CHS334	Dry	moderate	mesic
CFS214	Dry	cold	mesic	CHS335	Wet	moderate	mesic
CFS215	Mesic	cold	mesic	CHS421	Mesic	moderate	mesic
CFS217	Wet	cold	mesic	CHS422	Wet	moderate	wet
CFS218	Mesic	cold	mesic	CHS423	Mesic	moderate	mesic
CFS219	Mesic	cold	mesic	CHS512	Wet	moderate	wet
CFS311	Wet	cold	wet	CHS521	Wet	moderate	wet
CFS611	Dry	cold	mesic	CHS610	Mesic	moderate	mesic
CFS612	Mesic	cold	mesic	CHS621	Mesic	moderate	mesic
CHF112	Wet	moderate	wet	CHS622	Dry	moderate	mesic
CHF121	Wet	moderate	wet	CHS623	Wet	moderate	mesic
CHF122	Mesic	moderate	mesic	CHS624	Wet	moderate	mesic
CHF131	Wet	moderate	wet	CMS242	Wet	cold	mesic
CHF132	Wet	moderate	wet	CSF111	Wet	moderate	wet
CHF211	Wet	moderate	mesic	CSF121	Wet	moderate	wet
CHF511	Dry	moderate	dry	CSF321	Wet	moderate	wet
CHF911	Mesic	moderate	mesic	CSS221	Wet	moderate	wet
CHM111	Wet	moderate	wet	CSS321	Wet	moderate	wet
CHS121	Mesic	moderate	mesic	CSS521	Wet	moderate	wet
CHS122	Mesic	moderate	mesic	CSS522	Wet	moderate	wet
CHS123	Dry	moderate	dry	CSS621	Wet	moderate	wet
CHS131	Mesic	moderate	mesic				

Table 4.14.10 - Default wood decay classes used in the PN-FFE variant. Classes are based on the advice of an expert panel at the Dead Wood Decay Calibration workshop organized by Kim Mellen-McLean in July 2003.

Species	Decay Rate Class	Species	Decay Rate Class
Pacific silver fir	3	mountain hemlock	2
white fir	3	bigleaf maple	4
grand fir	3	red alder	4
subalpine fir	3	white alder	4
California red fir	3	paper birch	4
Sitka spruce	2	giant chinquapin	3
noble fir	3	quaking aspen	4
Alaska cedar	1	black cottonwood	4
incense cedar	1	Oregon white oak	3
Engelmann spruce	2	western juniper	1
lodgepole pine	2	subalpine larch	1
Jeffrey pine	3	whitebark pine	1
sugar pine	1	knobcone pine	2
western white pine	1	Pacific yew	1
ponderosa pine	3	Pacific dogwood	4
Douglas-fir	1	hawthorn	4

Species	Decay Rate Class	Species	Decay Rate Class
redwood	1	bitter cherry	4
western redcedar	1	willow	4
western hemlock	2	other	4

4.14.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.14.11) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.14.11 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1-hr)	4	8	12	16
0.25 – 1.0 in. (10-hr)	4	8	12	16
1.0 – 3.0 in. (100-hr)	5	10	14	18
> 3.0 in. (1000+ -hr)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.14.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger ‘Activity Fuels’ conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models; or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the PN-FFE to follow the third of these four options. The fuel model selection logic is based on information provided at the PN-FFE design workshop. The appropriate fuel model is determined using measures of cover type, canopy cover (CC) and average size (QMD). Fuel model selection begins by summing the basal area for six species groups:

- Pacific silver fir, western hemlock, Sitka spruce, western redcedar (SF or WH or SS or RC in Figure 4.14.2);
- Douglas-fir, grand fir, western white pine (DF or GF or WP);
- mountain hemlock, subalpine fir, whitebark pine (MH or AF or WB);
- red alder (RA);
- lodgepole pine (LP); and
- Oregon white oak, tanoak (WO or TA).

Species not included in the list are pooled with the Douglas-fir group. The two highest basal area groups are then selected and assigned weights in proportion to their basal area. For example, if a stand is 25% alder and 75% Douglas-fir, then the logic of the red alder rules will account for one quarter of the fuel selection and the logic for the Douglas-fir rules will account for the remainder.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.14.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The two dominant cover types described above, along with the flow diagrams in Figure 4.14.2, define which low fuel model(s) will become candidates. According to the logic of each of the figures, only a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover and QMD), as well as by the blended contribution of the two dominant cover types.

Some of the rules shown in Figure 4.14.2 include information about site-specific moisture regime or site-specific ground cover type. Moisture regime is based on the habitat code provided by the **STDINFO** keyword, using the classification shown in Table 4.14.9. Ground cover type is also based on habitat code, as shown in Table 4.14.12.

Table 4.14.12 - Habitat type – ground cover mapping for the PN-FFE variant. Ground cover classes modify default fuel model selection, as described in the text. Unclassified habitat groups default to 'Grass'.

Habitat Type Code	Ground Cover	Habitat Type Code	Ground Cover	Habitat Type Code	Ground Cover	Habitat Type Code	Ground Cover
CDS221	Shrub	CFS217	Shrub	CHS132	Shrub	CHS422	Shrub
CDS255	Shrub	CFS218	Shrub	CHS133	Shrub	CHS423	Shrub
CDS651	Shrub	CFS219	Shrub	CHS134	Shrub	CHS512	Shrub
CEF321	Shrub	CFS311	Shrub	CHS136	Shrub	CHS521	Shrub
CES212	Shrub	CFS611	Shrub	CHS137	Shrub	CHS610	Shrub
CES321	Shrub	CFS612	Shrub	CHS138	Shrub	CHS621	Shrub
CES621	Shrub	CHF112	Forb	CHS139	Shrub	CHS622	Shrub
CFF111	Forb	CHF121	Forb	CHS221	Shrub	CHS623	Shrub
CFF211	Forb	CHF122	Forb	CHS222	Shrub	CHS624	Shrub
CFF311	Forb	CHF131	Forb	CHS321	Shrub	CMS242	Shrub
CFF611	Forb	CHF132	Forb	CHS322	Shrub	CSF111	Forb
CFF612	Forb	CHF211	Shrub	CHS323	Forb	CSF121	Forb
CFF911	–	CHF511	Forb	CHS324	Shrub	CSF321	Forb
CFS156	Shrub	CHF911	–	CHS331	Shrub	CSS221	Shrub
CFS211	Shrub	CHM111	Forb	CHS332	Shrub	CSS321	Shrub
CFS212	Shrub	CHS121	Shrub	CHS333	Shrub	CSS521	Shrub
CFS213	Shrub	CHS122	Shrub	CHS334	Shrub	CSS522	Shrub
CFS214	Shrub	CHS123	Shrub	CHS335	Shrub	CSS621	Shrub
CFS215	Shrub	CHS131	Shrub	CHS421	Shrub		

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.14.1 or Figure 4.14.2 The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

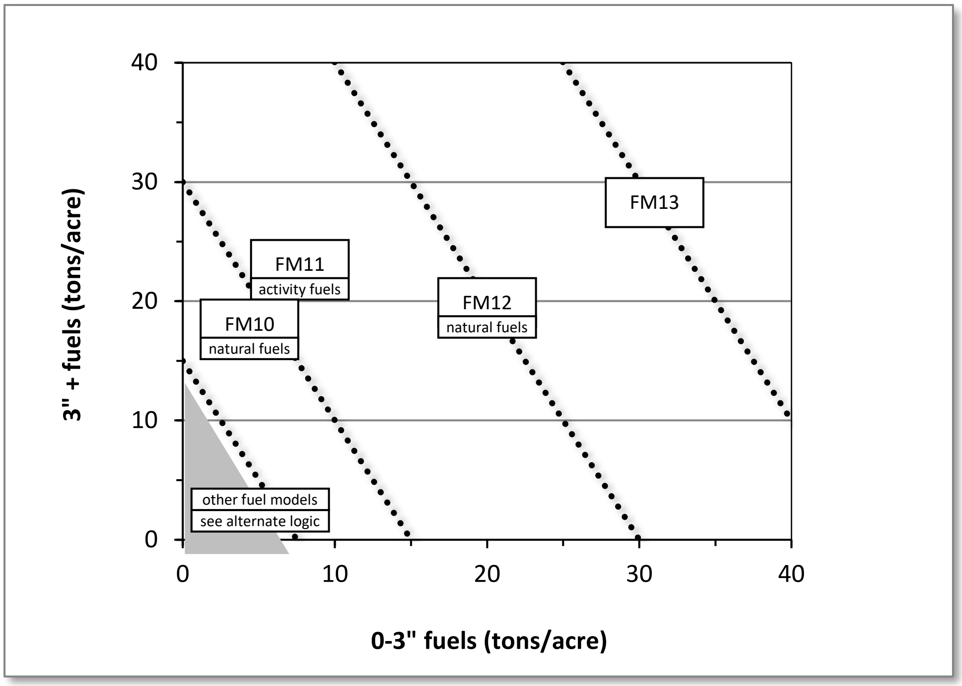


Figure 4.14.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.14.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

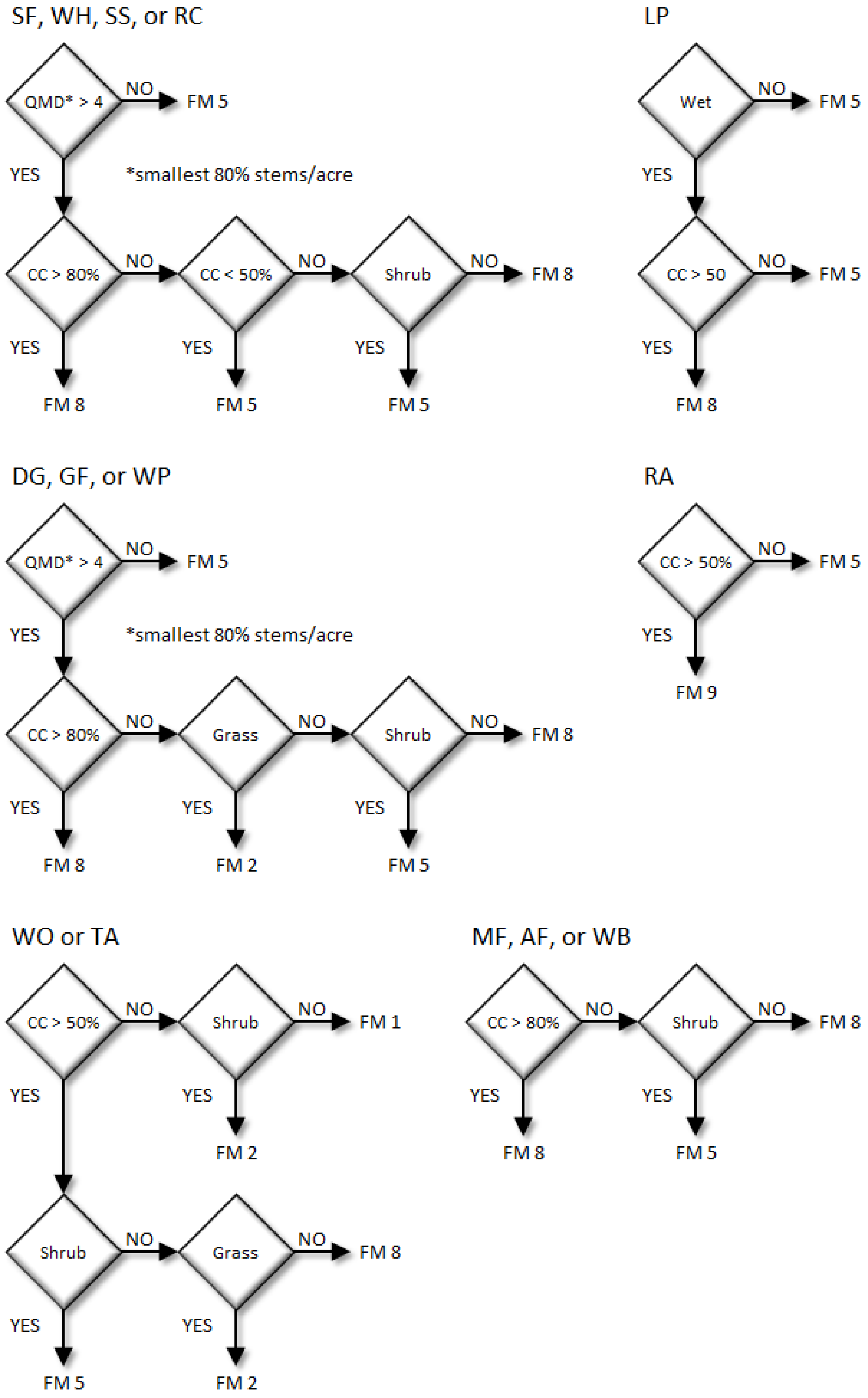


Figure 4.14.2 - Fuel models for the PN-FFE variant.

4.15 South Central Oregon/Northeast California (SO)

4.15.1 Tree Species

The expanded South Central Oregon/Northeast California (SORNEC) variant models the 31 tree species shown in Table 4.15.1. Two additional categories, ‘other softwood’ and ‘other hardwood’, are modeled using Douglas-fir and quaking aspen.

Table 4.15.1 - Tree species imulated by the Southern Oregon/Northern California variant.

Common Name	Scientific Name	Notes
western white pine	*Pinus monticola*	
sugar pine	*Pinus lambertiana*	
Douglas-fir	*Pseudotsuga menziesii*	
white fir	*Abies concolor*	
mountain hemlock	*Tsuga mertensiana*	
incense cedar	*Calocedrus decurrens*	
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
Shasta red fir	*Abies shastensis*	
ponderosa pine	*Pinus ponderosa*	
western juniper	*Juniperus occidentalis*	
grand fir	*Abies grandis*	
subalpine fir	*Abies lasiocarpa*	
Pacific silver fir	*Abies amabilis*	
noble fir	*Abies procera*	
whitebark pine	*Pinus albicaulis*	
western larch	*Larix occidentalis*	
western redcedar	*Thuja plicata*	
western hemlock	*Tsuga heterophylla*	
Pacific yew	*Taxus brevifolia*	
white alder	*Alnus rhombifolia*	
red alder	*Alnus rubra*	
bigleaf maple	*Acer macrophyllum*	
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	
bitter cherry	*Prunus emarginata*	
Oregon white oak	*Quercus garryana*	
willow	*Salix*	
giant chinquapin	*Chrysolepis chrysophylla* var. *chrysophylla*	
curl-leaf mountain mahogany	*Cercocarpus ledifolius*	
birchleaf mountain mahogany	*Cercocarpus montanus* var *glaber*	
other softwood		*= Douglas-fir*
other hardwood		*= quaking aspen*

4.15.2 Snags

Oregon

In the SO variant, the snag dynamics were modified based on the work of Kim Mellen-McLean, region 6 wildlife ecologist. These relationships are described in the following document: http://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/R6snags.pdf

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.15.4 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

California

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were originally developed at the SO-FFE workshop. Parameters for California stands were revised at a California variants workshop (Stephanie Rebain, pers. comm., February 2003) A complete description of the Snag Submodel is provided in section 2.3.

Four variables are used to modify the Snag Submodel for the different species in the SO-FFE variant:

1) a multiplier to modify the species' fall rate
2) a multiplier to modify the time required for snags to decay from a "hard" to "soft" state
3) the maximum number of years that snags will remain standing
4) a multiplier to modify the species' height loss rate

These variables are summarized in Table 4.15.2 and Table 4.15.3.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.15.4 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Table 4.15.2 - Default snag fall, snag height loss and soft-snag characteristics for 20" DBH snags in the California portion of the SO-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.16.3. Snags from California stands never become soft, and height loss in snags from California stands stops at 50% of the original height.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - -	- Years -	- - - - - - - - - -	
California				
western white pine	25	100	20	–
sugar pine	25	100	20	–
Douglas-fir	35	100	20	–
white fir	35	100	20	–
mountain hemlock	25	100	20	–
incense cedar	45	100	20	–
lodgepole pine	25	100	20	–
Engelmann spruce	35	100	20	–
Shasta red fir	35	100	20	–
ponderosa pine	25	100	20	–
western juniper	45	150	20	–
grand fir	35	100	20	–
subalpine fir	35	100	20	–
Pacific silver fir	35	100	20	–
noble fir	35	100	20	–
whitebark pine	25	100	20	–
western larch	35	100	20	–
western redcedar	45	100	20	–
western hemlock	25	100	20	–
Pacific yew	45	100	20	–
white alder	25	100	20	–
red alder	25	100	20	–
bigleaf maple	25	100	20	–
quaking aspen	25	100	20	–

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - - - Years - - - - - - - - - -			
black cottonwood	25	100	20	–
bitter cherry	25	100	20	–
Oregon white oak	25	100	20	–
willow	25	100	20	–
giant chinquapin	25	100	20	–
curl-leaf mountain mahogany	25	100	20	–
birchleaf mountain mahogany	25	100	20	–
other softwood	35	100	20	–
other hardwood	25	100	20	–

Table 4.15.3 - Default snag fall, snag height loss and soft-snag multipliers for the California portion of the SO-FFE. These parameters result in the values shown in Table 4.15.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
California			
western white pine	1.24	1.49	–
sugar pine	1.24	1.49	–
Douglas-fir	0.88	1.49	–
white fir	0.88	1.49	–
mountain hemlock	1.24	1.49	–
incense cedar	0.69	1.49	–
lodgepole pine	1.24	1.49	–
Engelmann spruce	0.88	1.49	–
Shasta red fir	0.88	1.49	–
ponderosa pine	1.24	1.49	–
western juniper	0.69	1.49	–
grand fir	0.88	1.49	–
subalpine fir	0.88	1.49	–
Pacific silver fir	0.88	1.49	–
noble fir	0.88	1.49	–
whitebark pine	1.24	1.49	–
western larch	0.88	1.49	–
western redcedar	0.69	1.49	–
western hemlock	1.24	1.49	–
Pacific yew	0.69	1.49	–
white alder	1.24	1.49	–
red alder	1.24	1.49	–
bigleaf maple	1.24	1.49	–
quaking aspen	1.24	1.49	–
black cottonwood	1.24	1.49	–
bitter cherry	1.24	1.49	–
Oregon white oak	1.24	1.49	–
willow	1.24	1.49	–
giant chinquapin	1.24	1.49	–
curl-leaf mountain mahogany	1.24	1.49	–
birchleaf mountain mahogany	1.24	1.49	–
other softwood	0.88	1.49	–
other hardwood	1.24	1.49	–

4.15.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and dead surface fuel. Live herb and shrub fuel load and the initial dead surface fuel load are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a 'bare ground' stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using wood density calculated from table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.15.4 for Douglas-fir is based on 'Douglas-fir Interior west.' The value for juniper is from Chojnacky and Moisen (1993).

Table 4.15.4 - Wood density (ovendry lbs/green ft^3) used in the SO-FFE variant.

Species	Density (lbs/ft^3)
western white pine	22.5
sugar pine	21.2
Douglas-fir	28.7
white fir	23.1
mountain hemlock	26.2
incense cedar	21.8
lodgepole pine	23.7
Engelmann spruce	20.6
Shasta red fir	22.5
ponderosa pine	23.7
western juniper	34.9
grand fir	21.8
subalpine fir	19.3
Pacific silver fir	24.9
noble fir	23.1
whitebark pine	22.5
western larch	29.9
western redcedar	19.3
western hemlock	26.2
Pacific yew	26.2
white alder	23.1
red alder	23.1
bigleaf maple	27.4
quaking aspen	21.8
black cottonwood	19.3
bitter cherry	29.3
Oregon white oak	37.4
willow	22.5
giant chinquapin	36.2
curl-leaf mountain mahogany	21.8
birchleaf mountain mahogany	21.8
other softwood	28.7
other hardwood	21.8

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the SO-FFE. Some species mappings are used, as shown below in Table 4.15.5. Mountain hemlock biomass is based on Gholz and others (1979), using western hemlock equations from Brown and Johnston to partition the biomass and also to provide estimates for trees under one inch diameter. Juniper equations are based on a single-stem form.

Table 4.15.5 - The crown biomass equations used in the SO-FFE. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
western white pine	Brown and Johnston (1976)
sugar pine	western white pine; Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
white fir	grand fir; Brown and Johnston (1976)
mountain hemlock	Gholz and others (1979); western hemlock (Brown and Johnston 1976)
incense cedar	based on western redcedar; Brown and Johnston (1976)
lodgepole pine	Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
Shasta red fir	subalpine fir; Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
western juniper	oneseed juniper; Grier and others (1992)
grand fir	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
Pacific silver fir	grand fir; Brown and Johnston (1976)
noble fir	grand fir; Brown and Johnston (1976)
whitebark pine	Brown (1978)
western larch	Brown and Johnston (1976)
western redcedar	Brown and Johnston (1976)
western hemlock	Brown and Johnston (1976)
Pacific yew	western redcedar; Brown and Johnston (1976)
white alder	red alder; Snell and Little (1983)
red alder	Snell and Little (1983)
bigleaf maple	Snell and Little (1983)
quaking aspen	Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
black cottonwood	Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
bitter cherry	Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
Oregon white oak	tanoak; Snell and Little (1983), Snell (1979)
willow	Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
giant chinquapin	tanoak; Snell and Little (1983), Snell (1979)
curl-leaf mountain mahogany	aspen; Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
birchleaf mountain mahogany	aspen; Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
other softwood	Douglas-fir; Brown and Johnston (1976)
other hardwood	aspen; Jenkins et. al. (2003), Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.15.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. These data are from the values provided at the SO-FFE workshop and California variants model verification workshop (Stephanie Rebain, USFS, pers. comm. February 2003).

Table 4.15.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the SO-FFE variant.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
Oregon					
western white pine	4	2	5	5	15
sugar pine	3	2	5	5	15
Douglas-fir	5	2	5	5	15
white fir	7	2	5	5	15
mountain hemlock	4	2	5	5	15

	Live	**Dead**			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
incense cedar	5	1	5	5	20
lodgepole pine	3	2	5	5	15
Engelmann spruce	6	2	5	5	10
Shasta red fir	7	2	5	5	15
ponderosa pine	4	2	5	5	10
western juniper	4	2	5	5	15
grand fir	7	2	5	5	15
subalpine fir	7	2	5	5	15
Pacific silver fir	7	2	5	5	15
noble fir	7	2	5	5	15
whitebark pine	3	2	5	5	15
western larch	1	1	5	5	15
western redcedar	5	2	5	5	20
western hemlock	5	2	5	5	15
Pacific yew	7	2	5	5	20
white alder	1	1	5	5	15
red alder	1	1	5	5	15
bigleaf maple	1	1	5	5	15
quaking aspen	1	1	5	5	15
black cottonwood	1	1	5	5	15
bitter cherry	1	1	5	5	15
Oregon white oak	1	1	5	5	15
willow	1	1	5	5	15
giant chinquapin	1	1	5	5	15
curl-leaf mountain mahogany	1	1	5	5	15
birchleaf mountain mahogany	1	1	5	5	15
other softwood	5	2	5	5	15
other hardwood	1	1	5	5	15
California					
western white pine	4	3	10	15	15
sugar pine	3	3	10	15	15
Douglas-fir	5	3	10	15	15
white fir	7	3	10	15	15
mountain hemlock	4	3	10	15	15
incense cedar	5	1	10	15	20
lodgepole pine	3	3	10	15	15
Engelmann spruce	6	3	10	10	10
Shasta red fir	7	3	10	15	15
ponderosa pine	4	3	10	10	10
western juniper	4	3	10	15	15
grand fir	7	3	10	15	15
subalpine fir	7	3	10	15	15
Pacific silver fir	7	3	10	15	15
noble fir	7	3	10	15	15
whitebark pine	3	3	10	15	15
western larch	1	1	10	15	15
western redcedar	5	3	10	15	20
western hemlock	5	3	10	15	15
Pacific yew	7	3	10	15	20
white alder	1	1	10	15	15
red alder	1	1	10	15	15
bigleaf maple	1	1	10	15	15
quaking aspen	1	1	10	15	15
black cottonwood	1	1	10	15	15
bitter cherry	1	1	10	15	15
Oregon white oak	1	1	10	15	15
willow	1	1	10	15	15
giant chinquapin	1	1	10	15	15
curl-leaf mountain mahogany	1	1	10	15	15
birchleaf mountain mahogany	1	1	10	15	15

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
other softwood	5	3	10	15	15
other hardwood	1	1	10	15	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on structural stage and cover type, using Fuel Characterization Classes (FCCs, Ottmar and others 1996). In each timestep, selection of the FCC begins with the stand structure logic of Crookston and Stage (1999), embedded in FVS. The resulting Crookston and Stage classification is then converted to Ottmar’s classification system, using Table 4.15.7. Cover type is then defined by the species with the greatest basal area. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. The FCC is then assigned using Table 4.15.8. Finally, shrub and herb loads are assigned using Table 4.15.9, and are set to zero if the structural stage is undefined. The structural class rules used in the SO-FFE variant were first developed for the Interior Columbia River Basin Assessment (Hessburg and others 1999).

Table 4.15.7 - Stand structure classification is converted from the Crookston and Stage to Ottmar system using these mappings and assumptions.

Stand Classification System		
Crookston and Stage (1999)	**Ottmar and others (1996)**	**Notes**
0	1	Regenerating from bare ground
1	1	Stand initiation
2	2	Stem exclusion, open canopy: <60% canopy cover
2	3	Stem exclusion, closed canopy: >=60% canopy cover
3	4	Understory reinitiation
4	5	Young forest, single stratum
5	6	Old forest, single stratum
6	7	Old forest, multistrata

Table 4.15.8 - Cover type and structural stage class are used to determine the appropriate FCC, in order to estimate herb and shrub load and the initial default down woody debris load. FCCs for sugar pine are mapped using western white pine. When a ponderosa pine stand is classed as regenerating from bare ground, it is assumed that it has been recently logged and is assigned FCC-1 instead of FCC-4. Species 12 –33 are assumed the same as Douglas-fir.

	Structural Stage §					
Species	**1**	**2**	**3**	**4, 5**	**6**	**7**
western white pine	52	53	56	58	57	61
sugar pine	52	53	56	58	57	61
Douglas-fir	52	53	56	58	62	62
white fir	52	53	56	58	62	62
mountain hemlock	52	53	56	58	62	62
incense cedar	52	53	56	58	62	62
lodgepole pine	103	106	107	110	112	113
Engelmann spruce	52	53	56	59	61	62
Shasta red fir	52	53	56	59	62	62
ponderosa pine	4, 1	4	4	8	11	10
western juniper	–	–	–	160	–	–
grand fir	52	53	56	58	62	62
subalpine fir	52	53	56	58	62	62
Pacific silver fir	52	53	56	58	62	62
noble fir	52	53	56	58	62	62
whitebark pine	52	53	56	58	62	62
western larch	52	53	56	58	62	62
western redcedar	52	53	56	58	62	62
western hemlock	52	53	56	58	62	62
Pacific yew	52	53	56	58	62	62

	Structural Stage §					
Species	**1**	**2**	**3**	**4, 5**	**6**	**7**
white alder	52	53	56	58	62	62
red alder	52	53	56	58	62	62
bigleaf maple	52	53	56	58	62	62
quaking aspen	52	53	56	58	62	62
black cottonwood	52	53	56	58	62	62
bitter cherry	52	53	56	58	62	62
Oregon white oak	52	53	56	58	62	62
willow	52	53	56	58	62	62
giant chinquapin	52	53	56	58	62	62
curl-leaf mountain mahogany	52	53	56	58	62	62
birchleaf mountain mahogany	52	53	56	58	62	62
other softwood	52	53	56	58	62	62
other hardwood	52	53	56	58	62	62

§ 1 = stand initiation (si); 2 = stem exclusion, open canopy (cover <60%) (seoc); 3 = stem exclusion, closed canopy (canopy cover>60%) (secc); 4 = understory re-initiation (ur); 5 = young forest, multi-story (yfms); 6 = old forest single-story (ofss); 7 = old forest, multi-story (ofms).

Table 4.15.9 - Default live fuel loads (tons/acre) are determined for each FCC. The appropriate FCC is assigned using Table 4.15.8.

FCC	Herb	Shrub	FCC	Herb	Shrub
1	0.3	0.4	59	0.7	0.7
4	0.5	0.5	61	0.3	0.4
8	0.0	0.0	62	0.8	0.5
10	0.5	2.5	103	0.3	0.4
11	0.5	0.5	106	0.5	0.5
52	0.5	0.5	107	0.5	0.5
53	0.5	0.5	110	0.5	0.5
56	0.5	0.5	112	0.3	0.4
57	0.3	0.4	113	0.5	0.5
58	0.3	0.4	160	0.7	3.3

Dead Fuels: Initial default values for the dead fuel components are determined using Fuel Characterization Classes (FCCs; Ottmar and others 1996) using Table 4.15.7 and Table 4.15.8 and following the process just described in the section on live herbs and shrubs. The FCC diameter breakpoints shown in Table 4.15.10 are different from those used by FFE. Linear interpolation is used to partition the FCC fuel loads into the FFE size classes. Currently, the > 20” class in the table below is put into the 12 – 20” class within FFE so that users with older databases (before the new down wood size classes were introduced) will not have large down fuel double-counted. This may change in the future when the new database structure is fully implemented within FSVEG. The SO-FFE initial loads for litter are set to zero, since these data are absent from the FCC system. Default initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.15.10 - Default dead fuel loads (tons/acre) are determined for each FCC used in the SO-FFE variant. The appropriate FCC for each modeled stand is assigned using Table 4.15.7 and Table 4.15.8. Litter estimates are absent in the FCC, and set to zero. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

	Size Class (in)							
FCC	**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 9**	**9 – 20**	**> 20**	**Litter**	**Duff**
1	0.5	0.8	1.7	1.9	3.0	0.0	–	2.3
4	0.1	1.5	2.2	1.1	1.8	3.3	–	6.0
8	0.1	1.6	4.2	2.1	2.9	4.7	–	9.8

	Size Class (in)							
FCC	**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 9**	**9 – 20**	**> 20**	**Litter**	**Duff**
10	0.2	1.2	2.3	2.3	2.4	2.0	–	12.8
11	0.0	1.5	4.9	10.1	6.2	4.0	–	12.8
52	0.6	2.3	1.9	2.0	0.0	0.0	–	2.3
53	0.5	1.3	3.0	4.5	1.5	0.0	–	2.3
56	0.5	1.3	3.0	4.5	1.5	0.0	–	9.1
57	0.4	0.6	1.1	8.8	7.2	5.0	–	9.1
58	0.7	1.1	1.5	3.1	4.7	0.0	–	15.9
59	0.5	1.8	3.5	12.3	2.3	0.0	–	15.9
61	0.5	1.2	1.2	2.5	5.2	2.0	–	20.4
62	0.5	2.6	4.3	7.0	10.5	3.0	–	20.4
103	0.5	0.8	1.7	0.9	0.0	0.0	–	2.3
106	0.3	0.7	4.0	0.8	0.0	0.0	–	3.8
107	0.4	1.2	7.4	2.1	0.0	0.0	–	3.8
110	0.7	2.3	5.9	5.1	2.0	0.0	–	4.5
112	0.2	0.9	1.7	1.3	3.0	0.0	–	6.0
113	0.2	1.1	3.4	14.8	3.5	0.0	–	6.0
160	0.2	0.4	0.8	0.0	0.0	0.0	–	2.3

4.15.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.15.11 are used to calculate single bark and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.15.11 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
western white pine	0.035
sugar pine	0.072
Douglas-fir	0.063
white fir	0.048
mountain hemlock	0.040
incense cedar	0.060
lodgepole pine	0.028
Engelmann spruce	0.036
Shasta red fir	0.039
ponderosa pine	0.063
western juniper	0.025
grand fir	0.046
subalpine fir	0.041
Pacific silver fir	0.047
noble fir	0.045
whitebark pine	0.03
western larch	0.063
western redcedar	0.035
western hemlock	0.04
Pacific yew	0.025
white alder	0.062
red alder	0.026
bigleaf maple	0.024
quaking aspen	0.044
black cottonwood	0.044
bitter cherry	0.062
Oregon white oak	0.029
willow	0.041
giant chinquapin	0.045
curl-leaf mountain mahogany	0.044
birchleaf mountain mahogany	0.044

Species	Multiplier (V_{sp})
other softwood	0.063
other hardwood	0.044

4.15.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5. Default decay rates differ for the Region 5 (California, Table 4.15.12) and Region 6 (Oregon, Table 4.15.13) portions of SO-FFE. Decay rates for California stands were revised at a California variants workshop (Stephanie Rebain, pers. comm, February 2003), based on the decay rates used in the Sierra Nevada Framework. Decay rates for Oregon stands are based on values provided by Kim Mellen-McLean, Pacific Northwest Regional wildlife ecologist, for the Pacific Northwest area. They are from published literature with adjustment factors based on temperature and moisture as determined by an expert panel at the Dead Wood Decay Calibration workshop in July 2003. The habitat code set by the **STDINFO** keyword or read in from an input database determines the temperature and moisture class for a stand, as shown in Table 4.15.14.

A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster. The decay rates for individual species vary based on the decay rate class of that species (Table 4.15.15) in the R6 portion of this variant. The decay rates may be modified for each decay class using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.15.12 - Default annual loss rates are applied based on size class for the Region 5 (California) portion of the SO-FFE. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster

Size Class	Annual Loss Rate	Proportion of Loss Becoming Duff
0 – 0.25 in.	0.025	0.02
0.25 – 1.0 in.		
1.0 – 3.0 in.		
3.0 – 6.0 in.	0.0125	
6.0 – 12.0 in.		
> 12.0 in.		
Litter	0.5	
Duff	0.002	0.0

Table 4.15.13 - Default annual loss rates are applied based on size class, temperature and moisture class, and decay rate class for the Region 6 (Oregon) portion of SO-FFE. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster

	Size Class (inches)	**Annual Loss Rate**				**Proportion of Loss Becoming Duff**
		decay class 1	**decay class 2**	**decay class 3**	**decay class 4**	
hot, mesic	< 0.25	0.113	0.121	0.134	0.168	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.036	0.048	0.063	0.111	
	6 – 12					
	> 12	0.028	0.037	0.049	0.086	
hot, dry	< 0.25	0.057	0.061	0.068	0.085	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.021	0.028	0.049	
	6 – 12					
	> 12	0.014	0.019	0.025	0.044	
moderate, wet	< 0.25	0.103	0.109	0.122	0.153	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.035	0.046	0.061	0.107	
	6 – 12					
	> 12	0.026	0.034	0.045	0.078	
moderate, mesic	< 0.25	0.076	0.081	0.090	0.113	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.032	0.043	0.056	0.099	
	6 – 12					
	> 12	0.019	0.025	0.033	0.058	
moderate, dry	< 0.25	0.067	0.071	0.079	0.099	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.023	0.030	0.040	0.070	
	6 – 12					
	> 12	0.017	0.022	0.029	0.051	
cold, wet	< 0.25	0.092	0.098	0.109	0.137	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.034	0.045	0.059	0.104	
	6 – 12					
	> 12	0.023	0.030	0.040	0.070	
cold, mesic	< 0.25	0.087	0.092	0.103	0.129	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.033	0.044	0.058	0.102	
	6 – 12					
	> 12	0.022	0.029	0.038	0.066	
cold, dry	< 0.25	0.057	0.061	0.068	0.085	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.021	0.028	0.049	
	6 – 12					
	> 12	0.014	0.019	0.025	0.044	
All	Litter	0.50	0.50	0.50	0.50	0.02
	Duff	0.002	0.002	0.002	0.002	0.0

Table 4.15.14 - Habitat type - moisture and temperature regime relationships for the SO-FFE variant. The moisture and temperature classes affect the default decay rates for the Region 6 (Oregon) portion of this variant.

Habitat Type Code	Temperature	Moisture	Habitat Type Code	Temperature	Moisture
CDS612	moderate	mesic	CPG212	moderate	dry
CDS613	moderate	mesic	CPH311	moderate	mesic
CDS614	moderate	mesic	CPS111	hot	dry
CEM111	cold	wet	CPS112	hot	dry
CEM221	cold	wet	CPS121	hot	dry
CEM222	cold	mesic	CPS211	hot	dry
CEM311	cold	wet	CPS212	hot	dry
CEM312	cold	wet	CPS213	hot	dry
CLC111	cold	dry	CPS214	moderate	dry
CLC112	cold	dry	CPS215	moderate	dry
CLF111	moderate	dry	CPS216	hot	dry
CLG311	moderate	dry	CPS217	moderate	dry
CLG313	moderate	dry	CPS218	moderate	dry
CLG314	moderate	dry	CPS311	moderate	dry
CLG315	moderate	dry	CPS312	moderate	dry
CLG411	moderate	dry	CPS314	moderate	dry
CLG412	moderate	dry	CPS511	moderate	mesic
CLG413	moderate	dry	CRG111	moderate	dry
CLG415	moderate	dry	CRS111	moderate	dry
CLH111	moderate	mesic	CRS112	moderate	dry
CLM111	moderate	wet	CRS311	moderate	mesic
CLM112	moderate	mesic	CWC111	moderate	dry
CLM113	moderate	wet	CWC211	moderate	mesic
CLM114	moderate	wet	CWC212	moderate	mesic
CLM211	moderate	mesic	CWC213	moderate	mesic
CLM311	moderate	wet	CWC215	moderate	mesic
CLM312	moderate	wet	CWC311	moderate	dry
CLM313	moderate	mesic	CWC411	moderate	mesic
CLM314	moderate	wet	CWC412	hot	dry
CLM411	cold	dry	CWC911	cold	wet
CLM911	cold	wet	CWF431	moderate	mesic
CLS112	hot	dry	CWH111	moderate	mesic
CLS211	moderate	dry	CWH112	moderate	mesic
CLS212	moderate	dry	CWH211	hot	dry
CLS213	moderate	dry	CWM111	moderate	wet
CLS214	moderate	dry	CWS112	moderate	dry
CLS215	moderate	dry	CWS113	moderate	dry
CLS216	moderate	dry	CWS114	moderate	dry
CLS311	moderate	dry	CWS115	moderate	dry
CLS412	cold	dry	CWS116	moderate	mesic
CLS413	cold	dry	CWS117	moderate	dry
CLS414	cold	dry	CWS312	moderate	mesic
CLS911	warm	dry	CWS313	moderate	mesic
CMS111	cold	dry	HQM121	moderate	mesic
CPC211	hot	dry	HQM411	moderate	wet
CPF111	moderate	dry	HQS221	moderate	mesic

Table 4.15.15 - Default wood decay classes used in the SO-FFE variant. Classes are based on the advice of an expert panel at the Dead Wood Decay Calibration workshop organized by Kim Mellen-McLean in July 2003.

Species	Decay Class
western white pine	1
sugar pine	1
Douglas-fir	1
white fir	3
mountain hemlock	2
incense cedar	1
lodgepole pine	2
Engelmann spruce	2
Shasta red fir	3
ponderosa pine	3
western juniper	1
grand fir	3
subalpine fir	3
Pacific silver fir	3
noble fir	3
whitebark pine	1
western larch	1
western redcedar	1
western hemlock	2
Pacific yew	1
white alder	4
red alder	4
bigleaf maple	4
quaking aspen	4
black cottonwood	4
bitter cherry	4
Oregon white oak	3
willow	4
giant chinquapin	3
curl-leaf mountain mahogany	4
birchleaf mountain mahogany	4
other softwood	1
other hardwood	4

4.15.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups shown in Table 4.15.16, or they can specify moisture conditions for each class using the **MOISTURE** keyword. The predefined moisture groups are the same as those defined for the NI-FFE.

Table 4.15.16 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1 hr.)	4	8	12	16
0.25 – 1.0 in. (10 hr.)	4	8	12	16
1.0 – 3.0 in. (100 hr.)	5	10	14	18
> 3.0 in. (1000+ hr.)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.15.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger ‘Activity Fuels’ conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the SO-FFE to follow the third of these four options.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.15.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The logical flow shown in Figure 4.15.2 defines which low fuel model(s) will become candidates. According to the logic of Figure 4.15.2, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, snag density, etc.). In addition, a fuzzy logic approach is used to incorporate weights based on the dominant cover type.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.15.1 or Figure 4.15.2. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

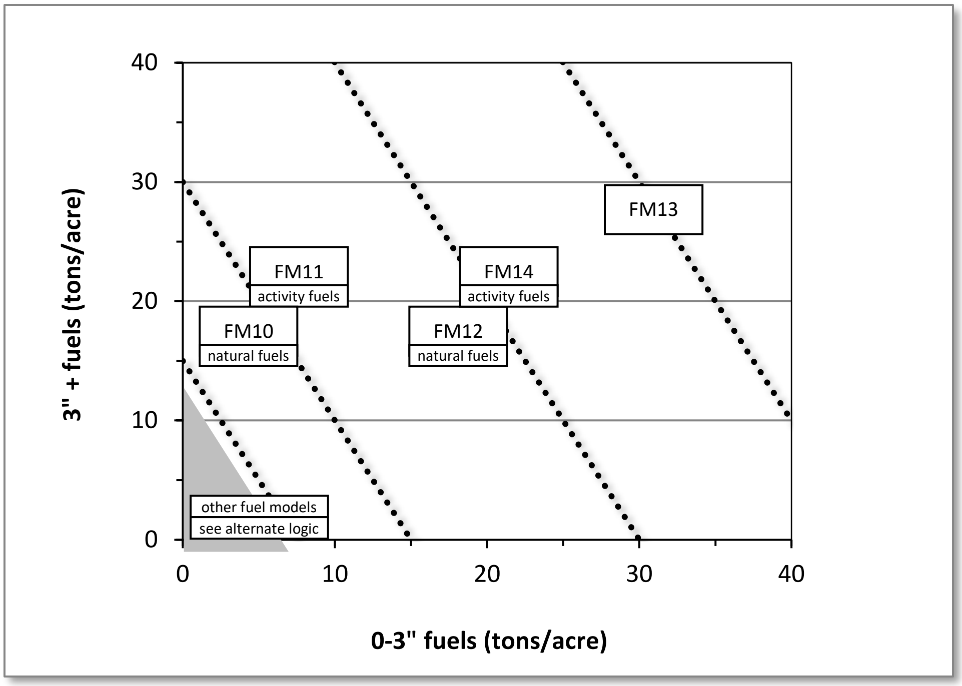


Figure 4.15.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.15.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description section 2.4.8 for further details).

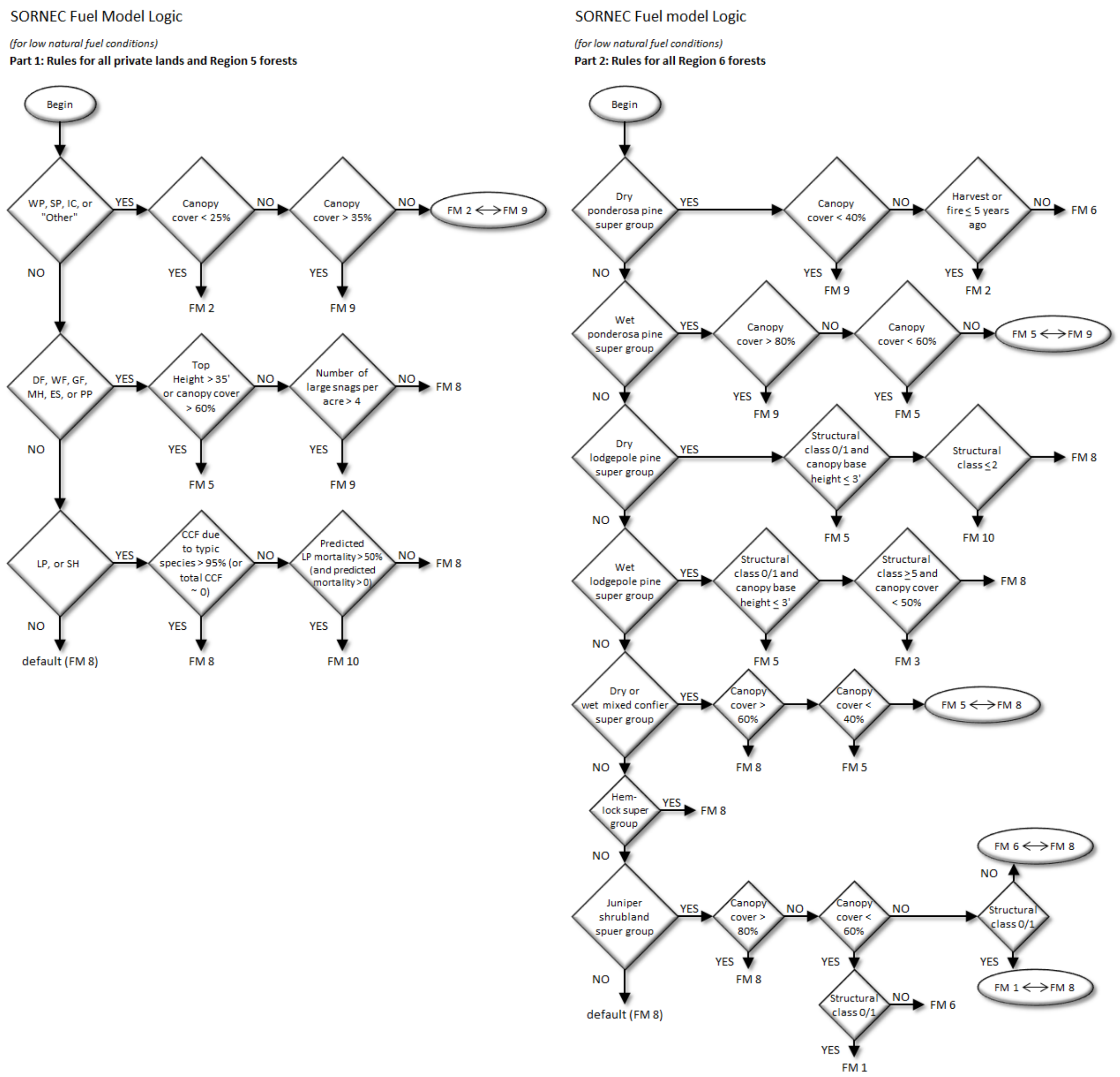


Figure 4.15.2 - Fuel model logic for Region 5 (a) and Region 6 (b) forests modeled in the SO-FFE.

4.15.8 Consumption

Consumption of natural fuels is modeled in the same way as in the NI-FFE (section 2.5.5). Activity fuels, material created from a stand entry in the previous five years, are modeled using equations from Consume 1.0 (Ottmar and other 1993) with some modifications based on new information.

1-hr and 10-hr fuels

100 percent consumption.

100-hr fuels

$$C = 0.9 - 0.0535\left[M_{10} - 0.03\left(\frac{\ln\left(0.5F\left(1+\frac{Slope-20}{60}+\frac{Wind}{4}\right)\right)}{\ln(2)}\right)-12\right]$$

where:

C = percent consumption
F = amount of 100-hr fuel present before the burn (in tons/acre)
M_{10} = percent fuel moisture of the 10-hr fuels
$Slope$ = site slope (in percent)
$Wind$ = wind speed at the time of the fire (in miles per hour)

1000-hr+ fuels

The consumption of larger fuels depends on their moisture as well as the moisture level of the 10-hr fuels, 1000-hr fuels, and the amount of consumption of the 100-hr fuels.

First, a diameter reduction variable (DRED) is calculated based on fuel moisture (M):

Condition	Equation
M > 60%	1: DRED = –0.005 × M + 0.731
M > 44% and M ≤ 60%	2: DRED = –0.0178 × M + 1.489
M ≥ 44% and Consumption of 100hr ≤ 75%	3: DRED = –0.096 × M + 4.6495
M < 44% and Consumption of 100hr ≥ 85%	4: DRED = –0.125 × M + 6.27
M < 44% and Consumption of 100hr 75% – 85%	Interpolate between eq. 3 and 4

Then, if the 10-hr fuel moisture is less than 15 percent, the DRED value is further modified:

1000-hr Fuel Moisture	Equation
M ≤ 40%	DRED = DRED × (1 - 0.22)
M 40%-50%	DRED = DRED × (1 - 0.11)

Finally, the percent consumption can be calculated as:

$$C = 1 - \left(\frac{a - DRED}{5.2}\right)^2$$

where:

C = percent consumption
$DRED$ = diameter reduction factor calculated above
a = 5.2 for 1000-hr fuels and 13.7 for 10000-hr fuels

Duff: The consumption of duff depends on the moisture level of the duff and consumption in some of the other fuel classes. Assumptions were made about the duff moisture values at which each of the equations was used, the quadratic mean diameter of the 100-hr fuels, the number of dry months prior to the fire, and the bulk density.

Duff Moisture	Equation
≥ 200%	R = 0.537 + (C1000 + C10000)
125% – 200%	R = 0.323 + 1.034 + $\sqrt{DRED}$
50% – 125%	R = 1.323 + 1.034 + $\sqrt{DRED}$
< 50%	R = 2.323 + 1.034 + $\sqrt{DRED}$

where:

C_i = consumption value of the i-th hour fuels
$DRED$ = diameter reduction factor of large fuels, calculated above
R = reduction factor of the duff

Consumption, in tons/acre rather than percent, is then calculated as:

$$C = 12.1 \times R \times b$$

where:

C = maximum tons/acre of duff consumed
R = reduction factor of the duff, calculated above
b = 0.5 when duff depth is less than 1 inch; 0.75 when duff depth is 2 or more inches; and interpolated when duff depth is 1-2 inches

4.16 Southern (SN)

4.16.1 Tree Species

The Southern variant models the 87 tree species, plus three other composite species categories shown in Table 4.16.1.

Table 4.16.1 - Tree species simulated by the Southern variant.

Common name	Scientific name
fir	*Abies*
juniper	*Juniperus*
spruce	*Picea*
sand pine	*Pinus clausa*
shortleaf pine	*Pinus echinata*
slash pine	*Pinus elliottii*
spruce pine	*Pinus glabra*
longleaf pine	*Pinus palustris*
Table Mountain pine	*Pinus pungens*
pitch pine	*Pinus rigida*
pond pine	*Pinus serotina*
eastern white pine	*Pinus strobus*
loblolly pine	*Pinus taeda*
Virginia pine	*Pinus viginiana*
bald cypress	*Taxodium distichum*
pond cypress	*Taxodium ascendens*
hemlock	*Tsuga*
southern sugar maple	*Acer barbatum*
boxelder	*Acer negundo*
red maple	*Acer rubrum*
silver maple	*Acer saccharinum*
sugar maple	*Acer saccharum*
buckeye	*Aesculus*
birch	*Betula*
sweet birch	*Betula lenta*
American hornbeam	*Carpinus caroliniana*
hybrid hickory	*Carya*
catalpa	*Catalpa*
hackberry	*Celtis*
eastern redbud	*Cercis canadensis*
flowering dogwood	*Cornus florida*
common persimmon	*Diospyros virginiana*
American beech	*Fagus grandifolia*
ash	*Fraxinus*
white ash	*Fraxinus americana*
black ash	*Fraxinus nigra*
green ash	*Fraxinus pennsylvanica*
honeylocust	*Gleditsia triacanthos*
loblolly bay	*Gordonia lasianthus*
silverbell	*Halesia*
American holly	*Ilex opaca*
butternut	*Juglans cinerea*
black walnut	*Juglans nigra*
sweetgum	*Liquidamber styraciflua*
tuliptree	*Liriodendron tulipifera*
magnolia	*Magnolia*
cucumber tree	*Magnolia acuminata*
southern magnolia	*Magnolia grandiflora*
sweetbay	*Magnolia virginiana*
bigleaf magnolia	*Magnolia macrophylla*
apple	*Malus*
mulberry	*Morus*
water tupelo	*Nyssa aquatica*
blackgum	*Nyssa sylvatica*
swamp tupelo	*Nyssa biflora*
hophornbeam	*Ostrya virginiana*
sourwood	*Oxydendrum arboreum*
redbay	*Persea borbonia*
American sycamore	*Platanus occidentalis*
cottonwood	*Populus*
bigtooth aspen	*Populus grandidentata*
black cherry	*Prunus serotina*
white oak	*Quercus alba*
scarlet oak	*Quercus coccinea*
southern red oak	*Quercus falcata*
cherrybark oak	*Quercus pagoda*
turkey oak	*Quercus laevis*
laurel oak	*Quercus laurifolia*
overcup oak	*Quercus lyrata*
blackjack oak	*Quercus marilandica*
swamp chestnut oak	*Quercus michauxii*
chinkapin oak	*Quercus muehlenbergii*
water oak	*Quercus nigra*
chestnut oak	*Quercus prinus*
northern red oak	*Quercus rubra*
Shumard's oak	*Quercus shumardii*
post oak	*Quercus stellata*
black oak	*Quercus velutina*
live oak	*Quercus virginiana*
black locust	*Robinia pseudoacacia*
willow	*Salix*
sassafras	*Sassafras albidum*
basswood	*Tilia*
elm	*Ulmus*
winged elm	*Ulmus alata*
American elm	*Ulmus americana*
slippery elm	*Ulmus rubra*
other softwood	
other hardwood	
other	

4.16.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the FFE design workshop. A complete description of the Snag Submodel is provided in section 2.3.

Four variables are used to modify the Snag Submodel for the different species in the SN-FFE variant:

- a multiplier to modify the species' fall rate;
- a multiplier to modify the time required for snags to decay from a "hard" to "soft" state;
- the maximum number of years that snags will remain standing; and
- a multiplier to modify the species' height loss rate.

Initially, each species was put into a snag class (1, 2, or 3), as listed in Table 4.16.2. Then the above variables were determined for each snag class. Snag class 1 generally represents pines, snag class 2 generally represents black oak and similar species, and snag class 3 generally represents white oak species and redcedar. These variables are summarized in Table 4.16.3 and Table 4.16.4.

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.16.5 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

Table 4.16.2 - Snag class for each species in SN-FFE.

Species	Snag class	Species	Snag class
fir	2	magnolia	2
juniper	3	cucumber tree	2
spruce	2	southern magnolia	2
sand pine	1	sweetbay	2
shortleaf pine	1	bigleaf magnolia	2
slash pine	1	apple	2
spruce pine	1	mulberry	2
longleaf pine	1	water tupelo	3
Table Mountain pine	1	blackgum	3
pitch pine	1	swamp tupelo	3
pond pine	1	hophornbeam	2
eastern white pine	1	sourwood	2
loblolly pine	1	redbay	2
Virginia pine	1	American sycamore	2
bald cypress	3	cottonwood	1
pond cypress	3	bigtooth aspen	1
hemlock	2	black cherry	2
southern sugar maple	2	white oak	3
boxelder	2	scarlet oak	2
red maple	2	southern red oak	2
silver maple	2	cherrybark oak	2
sugar maple	2	turkey oak	2
buckeye	2	laurel oak	2
birch	1	overcup oak	2
sweet birch	1	blackjack oak	3
American hornbeam	2	swamp chestnut oak	2

Species	Snag class
hybrid hickory	3
catalpa	2
hackberry	2
eastern redbud	2
flowering dogwood	2
common persimmon	3
American beech	2
ash	2
white ash	2
black ash	2
green ash	2
honeylocust	3
loblolly bay	2
silverbell	2
American holly	2
butternut	2
black walnut	2
sweetgum	2
tuliptree	2

Species	Snag class
chinkapin oak	3
water oak	3
chestnut oak	2
northern red oak	2
Shumard's oak	2
post oak	3
black oak	2
live oak	2
black locust	3
willow	1
sassafras	2
basswood	1
elm	1
winged elm	1
American elm	1
slippery elm	1
other softwood	1
other hardwood	2
other	2

Table 4.16.3 - Snag fall, snag height loss and soft-snag characteristics for 12” DBH snags in the SN-FFE variant. These characteristics directly coincide with the parameter values shown in Table 4.16.4.

Snag Class	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - - - Years - - - - - - - - - - -			
1	3	6 (pines are 50)	0	2
2	7	15	0	6
3	11	25 (RC is 100)	0	10

Table 4.16.4 - Default snag fall, snag height loss and soft-snag multipliers for the SN-FFE. These parameters result in the values shown in Table 4.16.3. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Snag Class	Snag Fall	Height loss	Hard-to-Soft
1	7.71	0	0.07
2	3.07	0	0.21
3	1.96	0	0.35

Additionally, the base fall rate diameter cutoff (diameter at which 5 percent of snags are assigned a slower fall rate) was changed from 18 in. to 12 in. DBH. Due to the dynamics of eastern redcedar, for redcedar snags, even those less than 12 inches, 5 percent are assigned a slower fall rate.

Figure 4.16.1, Figure 4.16.2, and Figure 4.16.3 show how these values translate for 10 and 20 inch snags of varying species.

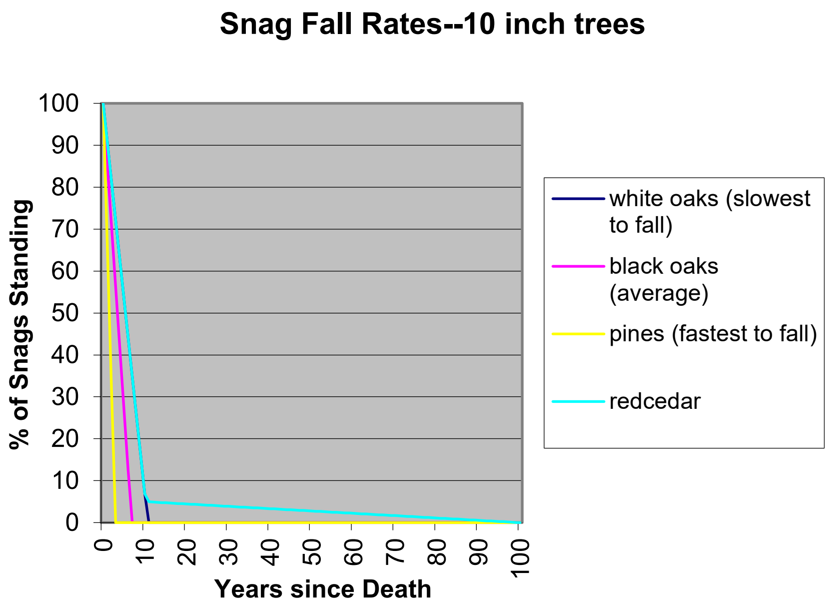


Figure 4.16.1 - Snag fall rates for 10 inch trees.

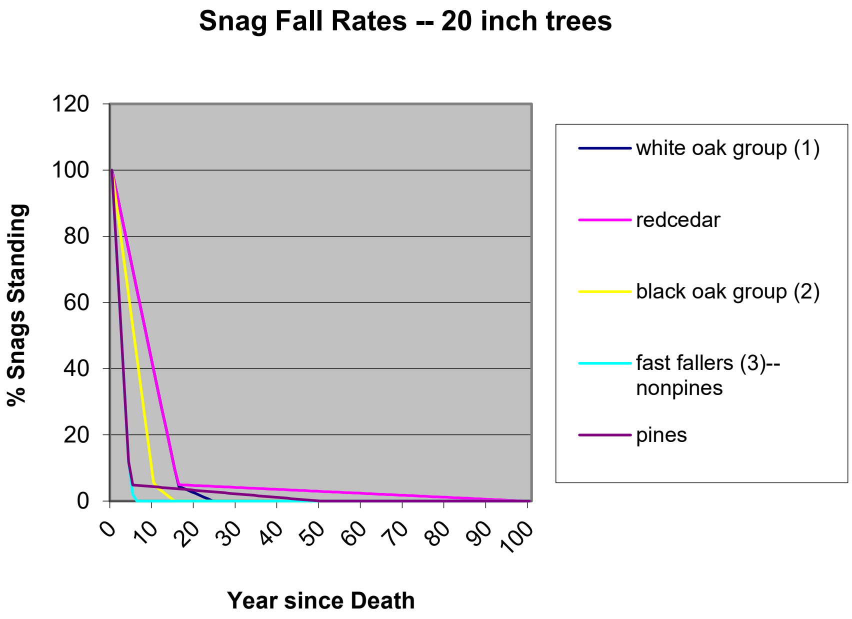


Figure 4.16.2 - Snag fall rates for 20 inch trees.

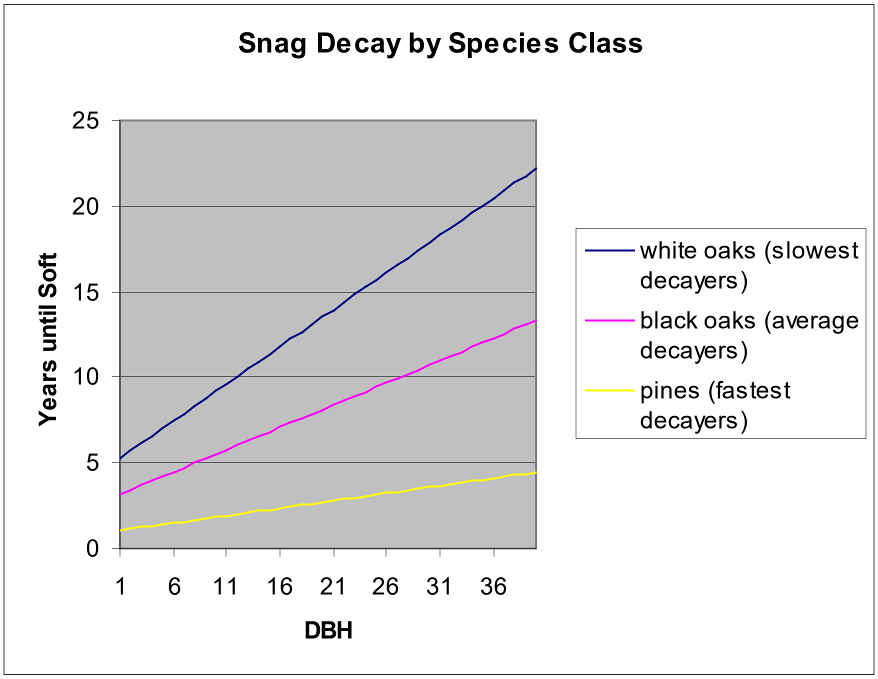


Figure 4.16.3 - The number of years until soft for various diameter snags.

4.16.3 Fuels

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the Forest Type code, as reported in the Summary Statistics Table.

One difference between the implementation of FFE in the southern variant, relative to its implementation in all of the western variants, is the distinction between crown material and stemwood. In the western variants, stemwood biomass is calculated by converting total cubic foot volume to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood and foliage alone. In the southern variant, total cubic foot volume equations are not in use. As a result, stemwood biomass is calculated by converting merchantable cubic foot volume (to a 4 inch top diameter inside bark) to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood and foliage plus the unmerchantable portion of the main stem (stemwood above a 4 inch diameter). This has some effects that users should be aware of.

1) The default assumption in the western variants when harvesting is that the stems are taken and the crown material (branchwood) is left. In the southern variants this corresponds to a default assumption that the merchantable material is taken and the unmerchantable material (branchwood, small trees, unmerchantable topwood) is left.
2) Surface fuel accumulation is predicted from a variety of processes including crown breakage and crown lift. Based on a default percentage and the change in crown ratio for each tree record, a certain amount of material is predicted to fall to the ground each year. This assumption changes slightly when using the southern variant. Rather than predicting a certain percentage of the branchwood will fall each year, essentially the model is predicting a certain percentage of the unmerchantable material (branchwood, small trees, unmerchantable

topwood) will fall each year. These percentages may need to be altered in the future, as a result.

3) Other changes were made to handle this situation and are described in the section on Tree Crowns.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density calculated from Table 4-3a and Equation 3-5 of The Wood Handbook (Forest Products Laboratory 1999). Generally, for species not listed, softwoods were mapped to redcedar and hardwoods were mapped to black oak.

Table 4.16.5 - Wood density (ovendry lb/ft^3) used in the SN-FFE variant.

Species	lbs/cuft	Species used	Species	lbs/cuft	Species used
fir	20.6	balsam fir	magnolia	27.4	cucumbertree
juniper	27.4		cucumber tree	27.4	
spruce	23.1	red spruce	southern magnolia	28.7	
sand pine	28.7		sweetbay	27.4	cucumbertree
shortleaf pine	29.3		bigleaf magnolia	27.4	cucumbertree
slash pine	33.7		apple	34.9	black oak
spruce pine	25.6		mulberry	34.9	black oak
longleaf pine	33.7		water tupelo	28.7	
Table Mountain pine	28.1	Virginia pine	blackgum	28.7	
pitch pine	29.3		swamp tupelo	28.7	
pond pine	31.8		hophornbeam	34.9	black oak
eastern white pine	21.2		sourwood	34.9	black oak
loblolly pine	29.3		redbay	34.9	black oak
Virginia pine	28.1		American sycamore	28.7	
bald cypress	26.2		cottonwood	23.1	
pond cypress	26.2	baldcypress	bigtooth aspen	22.5	
hemlock	23.7		black cherry	29.3	
southern sugar maple	34.9	sugar maple	white oak	37.4	
boxelder	30.6	red maple	scarlet oak	37.4	
red maple	30.6		southern red oak	32.4	
silver maple	27.4		cherrybark oak	38.0	
sugar maple	34.9		turkey oak	34.9	black oak
buckeye	34.9	blackoak	laurel oak	34.9	
birch	34.3	yellow birch	overcup oak	35.6	
sweet birch	37.4		blackjack oak	34.9	black oak
American hornbeam	34.9	black oak	swamp chestnut oak	37.4	
hybrid hickory	39.9	shagbark/mockernut	chinkapin oak	37.4	white oak
catalpa	34.9	black oak	water oak	34.9	
hackberry	30.6		chestnut oak	35.6	
eastern redbud	34.9	black oak	northern red oak	34.9	
flowering dogwood	34.9	black oak	Shumard's oak	34.9	black oak
common persimmon	34.9	black oak	post oak	37.4	
American beech	34.9		black oak	34.9	
ash	33.1	green ash	live oak	49.9	
white ash	34.3		black locust	41.2	
black ash	28.1		willow	22.5	
green ash	33.1		sassafras	26.2	
honeylocust	37.4		basswood	20.0	
loblolly bay	34.9	black oak	elm	28.7	American elm
silverbell	34.9	black oak	winged elm	28.7	American elm
American holly	34.9	black oak	American elm	28.7	
butternut	22.5		slippery elm	29.9	
black walnut	31.8		other softwood	27.4	redcedar
sweetgum	28.7		other hardwood	34.9	black oak
tuliptree	24.9		other	34.9	black oak

Tree Crown: For merchantable trees, estimates of crown material, including foliage, branchwood and bolewood above a 4 inch top (DOB), are from Jenkins and others (2003). These equations do not provide information on how the crown material is distributed by size class. Information on partitioning canopy fuel loads by size class was taken from several sources (Snell and Little (1983), Loomis and Blank (1981), Loomis and Roussopoulos (1978), Loomis et. al. (1966)). Species were mapped when necessary. Because information on how crown material is partitioned for different species is often based on different definitions of "crown" (branchwood only, branchwood plus stemwood above a 0.25 inch diameter, branchwood plus stemwood above a 1 inch diameter), the equations to predict the proportion of crown biomass in various size classes are adjusted. The basic assumption is that the biomass of the unmerchantable tip can be calculated from the volume of a cone, where the height of the cone is the difference between total height and height at a 4 inch top diameter and the bottom diameter of the cone is 4 inches. There are some additions made to these estimates of crown biomass. Jenkin's equations include branchwood and stem material above a 4 inch DOB top, while the Northeast volume equations go up to a 4 inch DIB top. As a result, there is a small portion of biomass that is missing. This is estimated and added to the crown material estimates.

For unmerchantable trees, total above ground biomass is predicted by summing the estimate of crown biomass with an estimate of the bole biomass. This is done by estimating the volume of the breakpoint diameter tree with both the standard National Volume Estimator Library volume equation, as well as a simplified equation (Vol = 0.0015*D*D*H) to compute an adjustment factor that is used along with the simplified volume equation to estimate the volume and biomass of the unmerchantable tree bole. This was done to ensure smooth, non-erratic biomass estimates for trees as they grow and pass the merchantable dbh breakpoint. A similar method (to that for large trees) is used to adjust how the crown material is distributed by size class. In this case the main stem is assumed to be cone-shaped above breast height and cylinder-shaped below breast height.

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are primarily from Hardin et. al. (2001). Exceptions include eastern redcedar (Barnes and Wagner (2002)), holly (www.americanforests.org/productsandpubs/magazine/archives/2002winter/inprofile.php) and loblolly bay (www.fl-dof.com/pubs/trees_of_florida/loblollybay.html)

Dead foliage and branch materials also contribute to litter fall. Each species was categorized into 1 of 6 crown fall rate categories and the life span of dead foliage and branches was determined for each category. Species not in the Ozarks/Ouachita region were classed as 5.

Table 4.16.6 - Life span of live foliage and crown fall class (1 to 6) for species modeled in the SN-FFE variant.

Species	Leaf Life (years)	Crown Fall Class	Species	Leaf Life (years)	Crown Fall Class
fir	8	5	magnolia	1	4
juniper	5	1	cucumber tree	1	4
spruce	8	5	southern magnolia	2	4
sand pine	2	6	sweetbay	1	4
shortleaf pine	4	6	bigleaf magnolia	1	4
slash pine	2	6	apple	1	4
spruce pine	2	6	mulberry	1	5
longleaf pine	2	6	water tupelo	1	3
Table Mountain pine	3	6	blackgum	1	3

Species	Leaf Life (years)	Crown Fall Class	Species	Leaf Life (years)	Crown Fall Class
pitch pine	2	6	swamp tupelo	1	3
pond pine	2	6	hophornbeam	1	4
eastern white pine	2	6	sourwood	1	5
loblolly pine	3	6	redbay	1	5
Virginia pine	3	6	American sycamore	1	5
bald cypress	1	1	cottonwood	1	5
pond cypress	1	1	bigtooth aspen	1	5
hemlock	4	5	black cherry	1	4
southern sugar maple	1	5	white oak	1	3
boxelder	1	5	scarlet oak	1	4
red maple	1	5	southern red oak	1	4
silver maple	1	5	cherrybark oak	1	4
sugar maple	1	5	turkey oak	1	4
buckeye	1	5	laurel oak	1	4
birch	1	5	overcup oak	1	3
sweet birch	1	5	blackjack oak	1	2
American hornbeam	1	4	swamp chestnut oak	1	3
hybrid hickory	1	2	chinkapin oak	1	3
catalpa	1	4	water oak	1	3
hackberry	1	4	chestnut oak	1	3
eastern redbud	1	5	northern red oak	1	4
flowering dogwood	1	5	Shumard’s oak	1	4
common persimmon	1	4	post oak	1	3
American beech	1	4	black oak	1	4
ash	1	5	live oak	1	5
white ash	1	5	black locust	1	2
black ash	1	5	willow	1	6
green ash	1	5	sassafras	1	4
honeylocust	1	2	basswood	1	5
loblolly bay	1	5	elm	1	5
silverbell	1	5	winged elm	1	5
American holly	3	4	American elm	1	5
butternut	1	4	slippery elm	1	5
black walnut	1	4	other softwood	2	5
sweetgum	1	5	other hardwood	1	5
tuliptree	1	4	other	1	5

Table 4.16.7 - Years until all snag crown material of certain sizes has fallen by crown fall class

Crown fall class	Snag Crown Material Time to 100% Fallen (years)					
	Foliage	<0.25”	0.25–1”	1-3”	3-6”	6-12”
1	1 (RC is 3)	5	5	10	25	25
2	1	3	3	6	12	12
3	1	2	2	5	10	10
4	1	1	1	4	8	8
5	1	1	1	3	6	6
6	1	1	1	2	4	4

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. For most stands, shrubs and herbs are assigned a biomass value based on forest type (Table 4.16.8). Data for pines and redcedar are based on information from the Reference database for fuel loadings for the continental U.S. and Alaska (Scott Mincemoyer, on file at the Missoula Fire Lab). Data for hardwoods and oak-savannah are from Nelson and Graney (1996).

Table 4.16.8 - Values (dry weight, tons/acre) for live fuels used in the SN-FFE for most stands.

Forest Type	Herbs	Shrubs
Pines	0.10	0.25
Hardwoods	0.01	0.03
Redcedar	1.0	5.0
Oak-Savannah	0.02	0.13

Table 4.16.9 - Values (dry weight, tons/acre) for live fuels used in the SN-FFE for coastal plain stands; piedmont and mountain pyric stands will get 40% of the values shown in this table.

Site Index	Age of Rough (years)							
	1	2	3	5	7	10	15	20
< 50	0.4	0.4	0.5	0.6	0.9	1.4	2.6	4.2
50 – 65	1.2	1.3	1.3	1.5	1.7	2.2	3.4	5.1
65 – 80	2.6	2.6	2.7	2.8	3.1	3.5	4.7	6.4
80 -95	4.5	4.5	4.6	4.7	5.0	5.5	6.6	8.3
95 – 110	7.0	7.0	7.0	7.2	7.4	7.9	9.1	10.8
110+	10.0	10.0	10.0	10.2	10.4	10.9	12.1	13.8

For stands with certain ecological unit codes, a different set of herb and shrub values are assumed (Table 4.16.9). For coastal plain (EUC starts with 232), piedmont (EUC starts with 231), and mountain (EUC starts with M221) sites, the values are taken from the Southern Forestry Smoke Management Guidebook, table VI-F-9 (Southern Forest Fire Laboratory Staff 1976). Since the understory height is not known, site index is used as a surrogate. Coastal plain sites will get the values shown above, while piedmont and mountain pyric sites will get 40% of the values shown above. All of the biomass is assumed to be in the shrub category and none is in the herb category. The age of rough is determined from the time since the last fire, if any are included in the FVS run. Until a fire is simulated, it is assumed that the last fire was 5 years before the inventory date. For years not represented in the table, interpolation is used.

Dead Fuels: Initial default CWD pools are based on forest type, using FIA data collected in the southern region. Initial fuel loads can be modified using the FUELINIT keyword. All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.16.10 - Forest type is used to assign default down woody debris (tons/acre) by size class. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

Forest Type	FIA Forest Type Codes	Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
White Pine	101-105	0.10	0.50	1.68	0.55	0.64	0.07	4.02	12.52
Longleaf – slash pine	141, 142	0.10	0.66	0.98	0.12	0.29	0.26	6.38	8.66
Loblolly – shortleaf pine	160s	0.14	0.72	1.54	0.25	0.44	0.33	4.90	6.03
Eastern redcedar	181, 402	0.24	1.24	2.72	0.36	0.97	0.33	3.82	3.80
Pine-hardwood	400s (not 402)	0.18	0.77	2.17	0.31	0.86	0.78	4.07	6.15

Oak-hickory	500s	0.13	0.68	1.93	0.43	1.01	1.01	4.28	5.91
Oak-gum-cypress	600s	0.13	0.67	1.83	0.18	0.57	0.77	2.49	5.68
Elm-ash-cottonwood	700s	0.22	1.09	2.68	0.26	0.76	0.43	2.33	1.60
Maple-beech-birch	800s	0.09	0.64	2.03	0.43	1.18	3.38	3.75	4.10

4.16.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.16.11 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003). For some species, (red oak, black oak, scarlet oak, white oak, chestnut oak, black and swamp tupelo, red maple, and hickories), fire-related mortality is predicted using height of stem-bark char, rather than bark thickness, based on equations in Regelbrugge and Smith (1994). It is assumed that height of stem-bark char is 70% of flame length (expert communication with Elizabeth Reinhardt, Cain (1984)).

Table 4.16.11 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species used	Species	Multiplier (V_{sp})	Species used
fir	0.052		magnolia	0.039	
juniper	0.038		cucumber tree	0.036	
spruce	0.034		southern magnolia	0.033	
sand pine	0.035		sweetbay	0.04	
shortleaf pine	***		bigleaf magnolia	0.033	
slash pine	0.055		apple	0.043	
spruce pine	0.035		mulberry	0.038	red mulberry
longleaf pine	0.049		water tupelo	0.03	
Table Mountain pine	0.04		blackgum	0.039	
pitch pine	0.045		swamp tupelo	0.037	
pond pine	0.062		hophornbeam	0.037	
eastern white pine	0.045		sourwood	0.036	
loblolly pine	0.052		redbay	0.038	
Virginia pine	0.033		American sycamore	0.033	
bald cypress	0.025		cottonwood	0.04	
pond cypress	0.042		bigtooth aspen	0.039	
hemlock	0.039		black cherry	0.03	
southern sugar maple	0.029		white oak	0.04	
boxelder	0.034		scarlet oak	0.04	
red maple	0.028		southern red oak	0.044	
silver maple	0.031		cherrybark oak	0.044	southern red oak
sugar maple	0.033		turkey oak	0.037	
buckeye	0.036	Ohio buckeye	laurel oak	0.036	
birch	0.033		overcup oak	0.039	
sweet birch	0.03		blackjack oak	0.037	
American hornbeam	0.03		swamp chestnut oak	0.046	
hybrid hickory	0.04	shagbark hickory	chinkapin oak	0.042	
catalpa	0.037		water oak	0.036	
hackberry	0.036	sugarberry	chestnut oak	0.049	
eastern redbud	0.035		northern red oak	0.042	

Species	Multiplier (V_{sp})	Species used
flowering dogwood	0.041	
common persimmon	0.041	
American beech	0.025	
ash	0.042	
white ash	0.042	
black ash	0.035	
green ash	0.039	
honeylocust	0.038	
loblolly bay	0.038	
silverbell	0.038	
American holly	0.042	
butternut	0.041	
black walnut	0.041	
sweetgum	0.036	
tuliptree	0.041	
Shumard's oak	0.037	
post oak	0.044	
black oak	0.045	
live oak	0.043	
black locust	0.049	
willow	0.04	black willow
sassafras	0.035	
basswood	0.038	American basswood
elm	0.039	
winged elm	0.031	
American elm	0.031	
slippery elm	0.032	
other softwood	0.038	redcedar
other hardwood	0.045	black oak
other	0.045	black oak

4.16.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.16.12). Default wood decay rates are based on Abbott and Crossley (1982) and Barber and VanLear (1984). The litter decay rate is based on Sharpe et. al. (1980) and Witkamp (1966). For decay class 1 (pines and other softwoods, see Table 4.16.13, Table 4.16.12), these rates were adjusted based on a decay study by Dr. Philip Radtke. A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.16.12 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate: decay class 1	Annual Loss Rate: decay classes 2 – 4	Proportion of Loss Becoming Duff
< 0.25	0.11	0.11	0.02
0.25 – 1			
1 – 3	0.11	0.09	
3 – 6	0.11	0.07	
6 – 12			
> 12			
Litter	0.65	0.65	
Duff	0.002	0.002	0.0

By default, FFE decays all wood species at the rates shown in Table 4.16.12. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.16.13 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword. The decay rate classes were generally determined from the Wood Handbook (1999). When species were classified differently for young or old growth, young growth was assumed. Some species, such as many oaks, were assigned a decay rate class based on information provided at the development workshop. Species not present in the Ozarks/Ouachita region were classed as 4 if not in the wood handbook.

Table 4.16.13 - Default wood decay classes used in the SN-FFE variant. Classes are from the Wood Handbook (1999), with pines separated out. (1 = pines; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Rate Class	Species	Decay Rate Class
fir	4	magnolia	4
juniper	2	cucumber tree	4
spruce	4	southern magnolia	4
sand pine	1	sweetbay	4
shortleaf pine	1	bigleaf magnolia	4
slash pine	1	apple	3
spruce pine	1	mulberry	2
longleaf pine	1	water tupelo	2
Table Mountain pine	1	blackgum	2
pitch pine	1	swamp tupelo	2
pond pine	1	hophornbeam	3
eastern white pine	1	sourwood	4
loblolly pine	1	redbay	4
Virginia pine	1	American sycamore	4
bald cypress	3	cottonwood	4
pond cypress	3	bigtooth aspen	4
hemlock	4	black cherry	2
southern sugar maple	4	white oak	2
boxelder	4	scarlet oak	3
red maple	4	southern red oak	3
silver maple	4	cherrybark oak	3
sugar maple	4	turkey oak	3
buckeye	4	laurel oak	3
birch	4	overcup oak	3
sweet birch	4	blackjack oak	2
American hornbeam	3	swamp chestnut oak	3
hybrid hickory	4	chinkapin oak	2
catalpa	2	water oak	2
hackberry	4	chestnut oak	3
eastern redbud	3	northern red oak	3
flowering dogwood	3	Shumard's oak	3
common persimmon	2	post oak	2
American beech	4	black oak	3
ash	4	live oak	2
white ash	4	black locust	2
black ash	4	willow	4
green ash	4	sassafras	2
honeylocust	2	basswood	4
loblolly bay	4	elm	4
silverbell	4	winged elm	4
American holly	3	American elm	4
butternut	4	slippery elm	4
black walnut	2	other softwood	1
sweetgum	4	other hardwood	4

Species	Decay Rate Class	Species	Decay Rate Class
tuliptree	4	other	4

4.16.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.16.14) or they can specify moisture conditions using the **MOISTURE** keyword. These defaults were altered based on input from Gregg Vickers and Bennie Terrell. Duff moisture values are from FOFEM.

Table 4.16.14 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Extremely Dry	Very Dry	Dry	Wet
0 – 0.25 in. (1-hr)	5	6	7	16
0.25 – 1.0 in. (10-hr)	7	8	9	16
1.0 – 3.0 in. (100-hr)	12	13	14	18
> 3.0 in. (1000+ -hr)	17	18	20	50
Duff	40	75	100	175
Live	55	80	100	150

4.16.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. Stand management actions such as thinning and harvesting can abruptly increase fuel loads, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models, or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the SN-FFE to follow the third of these four options.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.16.4, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. Table 4.16.15 and Table 4.16.16 define which low fuel model(s) will become candidates. According to the logic of this table, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, moisture levels, etc.).

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.16.4 or Table 4.16.15. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

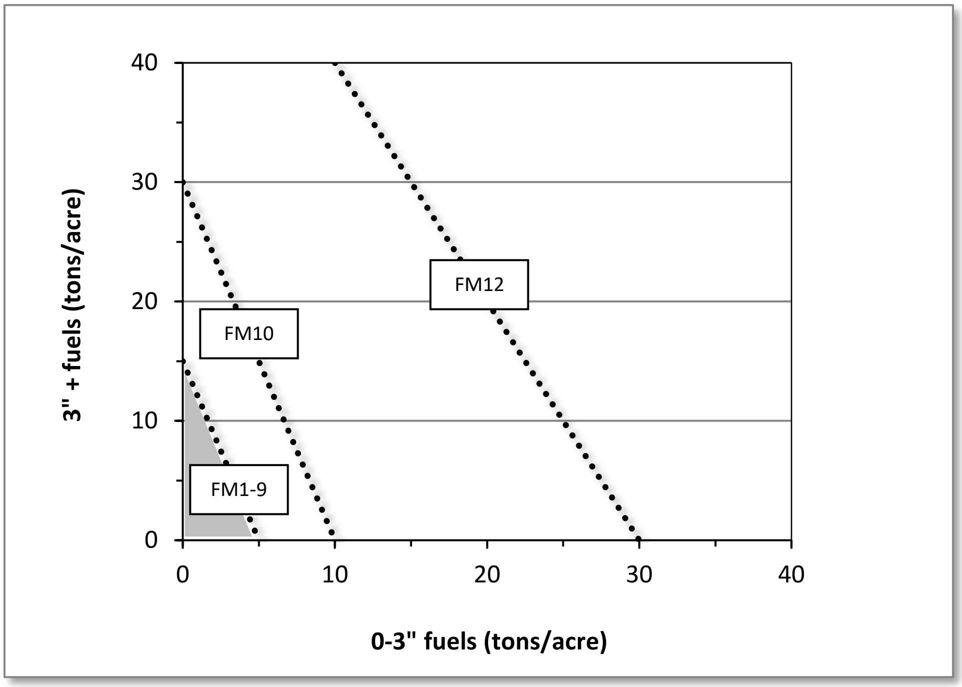


Figure 4.16.4 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in section 2.4.8. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines.

Table 4.16.15 - When low fuel loads are present in the SN-FFE, fire behavior fuel models are determined using forest type. This table shows how forest type is determined. A default of Hardwood is used when the forest type code does not key to any of the listed forest types.

Forest Type	Definition
Hardwood	Forest type code of 504, 505, 510, 512, 515, 519, 520 or 997; Forest type code 501 or 503 and not Oak Savannah;
Hardwood-Pine	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, 401, 403, 404, 405, 406, 407, 409, or 996, 50% or less BA in pine, and not Pine-Bluestem
Pine-Hardwood	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, 401, 403, 404, 405, 406, 407, 409, or 996, 50 - 70% BA in pine, and not Pine-Bluestem
Pine	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, 401, 403, 404, 405, 406, 407, 409, or 996, more than 70% BA in pine, and not Pine-Bluestem
Pine-Bluestem	Forest type code of 162, less than fully stocked and average top height > 50 ft.
Oak Savannah	Forest type code of 501 or 503, less than fully stocked and average top height > 30 ft.
Eastern Redcedar	Forest type code of 181 or 402
Bottomland Hardwoods	Forest type code of 602, 605, 701, 706, 708, or 807
Non-stocked	Forest type code of 999

Table 4.16.16 - Relationship between forest type and fuel model selected.

Forest type		**Fuel model**
Hardwood, Hardwood-Pine, and Pine-Hardwood	0-3” fuel > 5 tons	5
	0-3” fuel <=5 tons and 3”+ moisture >20%	8
	0-3” fuel <= 5 tons and 3”+ moisture <= 20%	9
Pine and Bottomland Hardwoods	3”+ moisture >20%	8
	3”+ moisture <= 20%	9
Pine-Bluestem		2
Oak Savannah		2
Eastern Redcedar	Avg. ht. of redcedar > 6 ft.	4
	Avg. ht. of redcedar <= 6 ft.	6
Non-stocked		6

4.16.8 Other

Crown fire is not modeled in the SN-FFE. As a result, every fire is seen as a surface fire, and crown fire hazard indices, such as the torching index and crowning index, are not reported. Canopy base height and canopy bulk density are reported, but keep in mind that these calculations do not include hardwoods. Also, when using the FlameAdj keyword to alter predicted fire behavior, users can override the flame length only. No matter what users enter for percent crowning (zero, blank, positive value, this will be overwritten internally with zero. If users would like to simulate additional mortality due to crowning, the **FixMort** keyword can be used to do so.

4.17 Tetons (TT)

4.17.1 Tree Species

The Tetons variant models the 16 individual tree species shown in Table 4.17.1. Two additional categories, 'other softwood' and 'other hardwood' are modeled using whitebark pine to simulate other softwoods and narrowleaf cottonwood to simulate other hardwoods.

Table 4.17.1 - Tree species simulated by the Tetons variant.

Common Name	Scientific Name	Notes
whitebark pine	*Pinus albicaulis*	
limber pine	*Pinus flexilis*	
Douglas-fir	*Pseudotsuga menziesii*	
singleleaf pinyon	*Pinus monophylla*	= UT singleleaf pinyon
blue spruce	*Picea pungens*	= TT Engelmann spruce
quaking aspen	*Populus tremuloides*	
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
subalpine fir	*Abies lasiocarpa*	
ponderosa pine	*Pinus ponderosa*	= CI ponderosa pine
Utah juniper	*Juniperus osteosperma*	= UT Utah juniper
Rocky Mountain juniper	*Juniperus scopulorum*	= UT Rocky Mtn juniper
bigtooth maple	*Acer grandidentatum*	= SO bigleaf maple
Rocky Mountain maple	*Acer glabrum*	= UT quaking aspen
narrowleaf cottonwood	*Populus angustifolia*	= UT narrowleaf cottonwood
curl-leaf mountain mahogany	*Cercocarpus ledifolius*	= UT curlleaf mtn mahogany
other softwood		= TT whitebark pine
other hardwood		= TT narrowleaf cottonwood

4.17.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the FFE design workshop. A complete description of the Snag Submodel is provided in section 2.3.

Four variables are used to modify the Snag Submodel for the different species in the TT-FFE variant:

- A multiplier to modify the species' fall rate;
- A multiplier to modify the time required for snags to decay from a "hard" to "soft" state;
- The maximum number of years that snags will remain standing; and
- A multiplier to modify the species' height loss rate.

These variables are summarized in Table 4.17.2 and Table 4.17.3. Height loss is only significant for Douglas-fir and is set to zero for all other species. After Douglas-fir snags have lost half their original height, the rate of height loss increases markedly, as shown in Table 4.17.2. In the case of Douglas-fir and spruce snags >18" DBH, the fall rate is reduced to 32% of the rate predicted by Marcot's equation. Finally, the fall rate of aspen is also halved in the ten years following a burn.

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.17.4 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

Table 4.17.2 - Default snag fall, snag height loss and oft-snag characteristics for 15” DBH snags in the TT-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.17.3.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - - - Years - - - - - - - - - - -			
whitebark pine	59	90	–	29
limber pine	59	90	–	29
Douglas-fir	34¶	100	30	40
singleleaf pinyon	24	150	310	29
blue spruce	46¶	100	–	29
quaking aspen	10	15	–	29
lodgepole pine	15	50	–	29
Engelmann spruce	46¶	100	–	29
subalpine fir	30	40	–	29
ponderosa pine	24	90	–	32
Utah juniper	24	150	310	29
Rocky Mountain juniper	24	150	310	29
bigtooth maple	24	90	30	32
Rocky Mountain maple	24	100	30	32
narrowleaf cottonwood	6	5	–	29
curl-leaf mountain mahogany	24	90	30	32
other softwood	59	90	–	29
other hardwood	6	5	–	29

¶ This value apples to snags 18” DBH; see text for details.

Table 4.17.3 - Default snag fall, snag height loss and soft-snag multipliers for the TT-FFE. These parameters result in the values shown in Table 4.17.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
whitebark pine	0.41	–	0.9
limber pine	0.41	–	0.9
Douglas-fir	0.81¶	1.01§	1.1
singleleaf pinyon	1.00	0.0978	0.9
blue spruce	0.61¶	–	0.9
quaking aspen	2.40	–	0.9
lodgepole pine	1.60	–	0.9
Engelmann spruce	0.61¶	–	0.9
subalpine fir	0.81	–	0.9
ponderosa pine	1.00	–	1.0
Utah juniper	1.00	0.0978	0.9
Rocky Mountain juniper	1.00	0.0978	0.9
bigtooth maple	1.00	1.00	1.0
Rocky Mountain maple	1.00	1.00	1.0
narrowleaf cottonwood	4.00	–	0.9
curl-leaf mountain mahogany	1.00	1.00	1.0
other softwood	0.41	–	0.9
other hardwood	4.00	–	0.9

¶ This value apples to Douglas-fir and spruce snags <18” DBH; see text for details.

§ height loss coefficient = 4.61 after 50% height loss

4.17.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a lodgepole cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density values calculated from the green specific gravity values from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.17.4 for Douglas-fir is based on ‘Douglas-fir north’.

Table 4.17.4 - Wood density (ovendry lb/ft3) used in the TT-FFE variant.

Species	Density (lb/ft^3)
whitebark pine	22.5
limber pine	22.5
Douglas-fir	28.1
singleleaf pinyon	31.8
blue spruce	20.6
quaking aspen	21.8
lodgepole pine	23.7
Engelmann spruce	20.6
subalpine fir	19.3
ponderosa pine	23.7
Utah juniper	34.9
Rocky Mountain juniper	34.9
bigtooth maple	27.4
Rocky Mountain maple	30.6
narrowleaf cottonwood	19.3
curl-leaf mountain mahogany	21.8
other softwood	22.5
other hardwood	19.3

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the TT-FFE (Table 4.17.5).

Table 4.17.5 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
whitebark pine	Brown (1978)
limber pine	lodgepole pine: Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
singleleaf pinyon	common pinyon; Grier and others (1992)
blue spruce	Engelmann spruce; Brown and Johnston (1976)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
lodgepole pine	Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)

Species	Species Mapping and Equation Source
subalpine fir	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
Utah juniper	oneseed juniper; Grier and others (1992)
Rocky Mountain juniper	oneseed juniper; Grier and others (1992)
bigtooth maple	Snell and Little (1983)
Rocky Mountain maple	bigtooth maple; Snell and Little (1983)
narrowleaf cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
curl-leaf mountain mahogany	aspen; Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other softwood	whitebark pine; Brown (1978)
other hardwood	cottonwood; Jenkins et. al. (2003); Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.17.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are from Keane and others (1989).

Table 4.17.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the TT-FFE variant.

Species	Live	Dead			
	Foliage	Foliage	<0.25”	0.25–1”	> 1”
whitebark pine	3	2	5	5	15
limber pine	3	2	5	5	15
Douglas-fir	5	2	5	5	15
singleleaf pinyon	3	2	10	15	15
blue spruce	6	2	5	5	10
quaking aspen	1	1	5	5	10
lodgepole pine	3	2	5	5	15
Engelmann spruce	6	2	5	5	10
subalpine fir	7	2	5	5	15
ponderosa pine	4	2	5	5	10
Utah juniper	4	2	10	15	20
Rocky Mountain juniper	4	2	10	15	20
bigtooth maple	1	1	5	5	15
Rocky Mountain maple	1	1	5	5	15
narrowleaf cottonwood	1	1	10	15	10
curl-leaf mountain mahogany	1	1	5	5	15
other softwood	3	2	5	5	15
other hardwood	1	1	10	15	10

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.17.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.17.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Data on pinyon, juniper, and quaking aspen were developed after examining live fuels reported in the Stereo Photo Guides for Quantifying Natural Fuels (Ottmar and others 2000a, Ottmar and others 2000b).

Table 4.17.7 - Values (dry weight, tons/acre) for live fuels used in the TT-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
whitebark pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	

Species		Herbs	Shrubs	Notes
limber pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
Douglas-fir	E	0.20	0.20	
	I	0.40	2.00	
singleleaf pinyon	E	0.04	0.05	Ottmar and others 2000a
	I	0.13	1.63	
blue spruce	E	0.15	0.20	Use Engelmann spruce
	I	0.30	2.00	
quaking aspen	E	0.25	0.25	Ottmar and others 2000b
	I	0.18	1.32	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Engelmann spruce	E	0.15	0.20	
	I	0.30	2.00	
subalpine fir	E	0.15	0.20	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	Use CI ponderosa pine
	I	0.25	0.10	
Utah juniper	E	0.04	0.05	Ottmar and others 2000a
	I	0.13	1.63	
Rocky Mountain juniper	E	0.04	0.05	Ottmar and others 2000a
	I	0.13	1.63	
bigtooth maple	E	0.20	0.20	from SO BM, use CR DF
	I	0.40	2.00	
Rocky Mountain maple	E	0.20	0.20	Use IE mountain maple
	I	0.40	2.00	
narrowleaf cottonwood	E	0.25	0.25	Use quaking aspen, Ottmar and others 2000b
	I	0.18	1.32	
curl-leaf mtn mahogany	E	0.25	0.25	Use quaking aspen, Ottmar and others 2000b
	I	0.18	1.32	
other softwood	E	0.20	0.10	Use whitebark pine
	I	0.40	1.00	
other hardwood	E	0.25	0.25	Use quaking aspen, Ottmar and others 2000b
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.17.8). Data on pinyon, juniper, and quaking aspen were developed based on fuel loadings reported in the Stereo Photo Guides for Quantifying Natural Fuels (Ottmar and others 2000a, Ottmar and others 2000b). (Litter values for pinyon and juniper were lowered because the photo series values seemed too high.) If tree canopy cover is <10 percent, the DWD pools are assigned an “initiating” value and if cover is >60 percent they are assign the “established” value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.17.8 - Canopy cover and cover type are used to assign default dead fuel loads (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
whitebark pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
limber pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
singleleaf pinyon	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
blue spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Utah juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Rocky Mtn juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
bigtooth maple	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Rocky Mtn maple	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
narrowleaf cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
curl-leaf mtn mahogany	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other softwood	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
other hardwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.17.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.17.9 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.17.9 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
whitebark pine	0.030
limber pine	0.030
Douglas-fir	0.063
singleleaf pinyon	0.030
blue spruce	0.036
quaking aspen	0.044
lodgepole pine	0.028
Engelmann spruce	0.036
subalpine fir	0.041

Species	Multiplier (V_{sp})
ponderosa pine	0.063
Utah juniper	0.025
Rocky Mountain juniper	0.025
bigtooth maple	0.024
Rocky Mountain maple	0.040
narrowleaf cottonwood	0.038
curl-leaf mountain mahogany	0.044
other softwood	0.030
other hardwood	0.038

4.17.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.17.10). By default, down material decays at the rate used by the UT-FFE: 55 percent lower than the default decay rates based on Abbott and Crossley (1982). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.17.10 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. The rates for woody material are the same as those used by the UT-FFE. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.054	0.02
0.25 – 1		
1 – 3	0.041	
3 – 6	0.0068	
6 – 12		
> 12		
Litter	0.50	
Duff	0.002	0.0

By default, FFE decays all wood species at the rates shown in Table 4.17.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.17.11 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.17.11 - Default wood decay classes used in the TT-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Class
whitebark pine	4
limber pine	4
Douglas-fir	3
singleleaf pinyon	4
blue spruce	4
quaking aspen	4
lodgepole pine	4
Engelmann spruce	4
subalpine fir	4

Species	Decay Class
ponderosa pine	4
Utah juniper	2
Rocky Mountain juniper	2
bigtooth maple	4
Rocky Mountain maple	4
narrowleaf cottonwood	4
curl-leaf mountain mahogany	4
other softwood	4
other hardwood	4

4.17.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.17.12) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.17.12 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups. In general they are drier than the default values used in the NI-FFE.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	4	5	8	10
0.25 – 1.0 in. (10-hr)	4	6	10	12
1.0 – 3.0 in. (100-hr)	5	8	12	15
> 3.0 in. (1000+ -hr)	10	15	16	18
Duff	15	50	125	200
Live	70	90	120	140

4.17.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger 'Activity Fuels' conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models; or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the TT-FFE to follow the third of these four options

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.17.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The logical flow shown in Figure 4.17.2 defines which low fuel model(s) will become candidates. According to the logic of Figure 4.17.2, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, snag density, etc.).

The program logic shown in Figure 4.17.2 also uses stand structure classes in some decision rules. The TT-FFE uses the default structure class rules documented in Crookston and Stage (1999) unless model users alter those definitions using the STRCLS keyword.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.17.1 or Figure 4.17.2. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

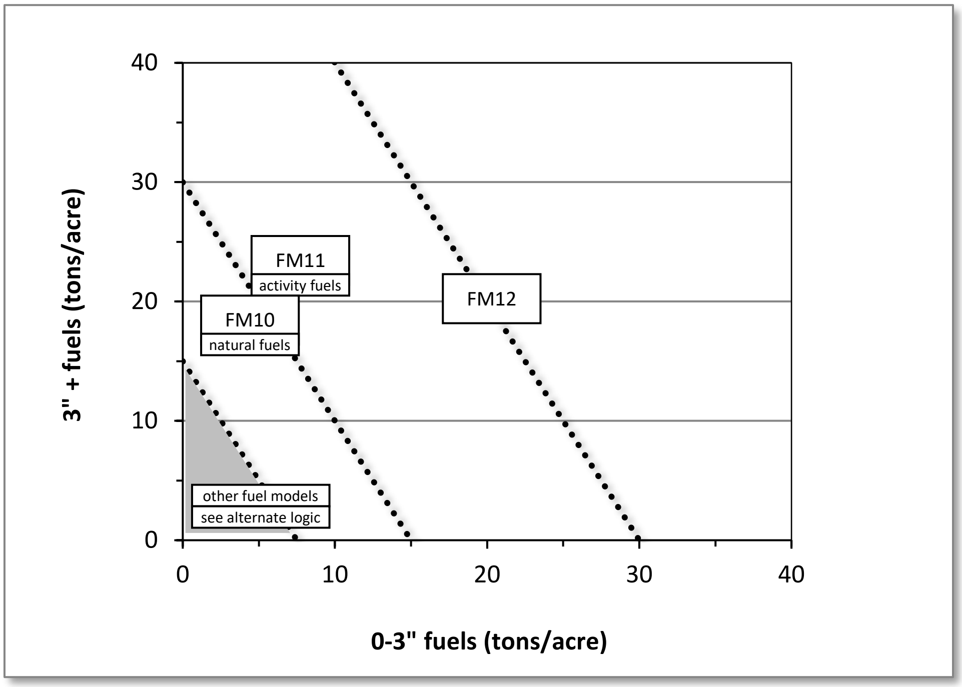
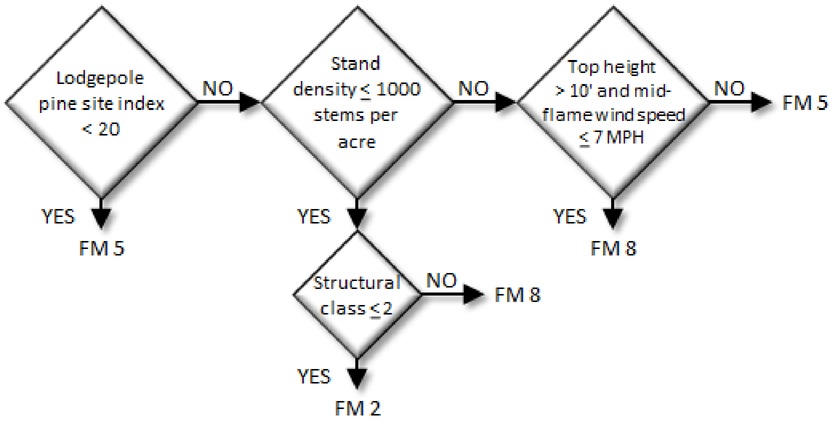
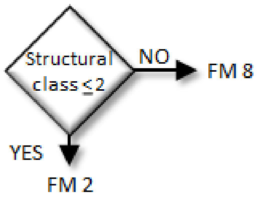


Figure 4.17.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.17.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

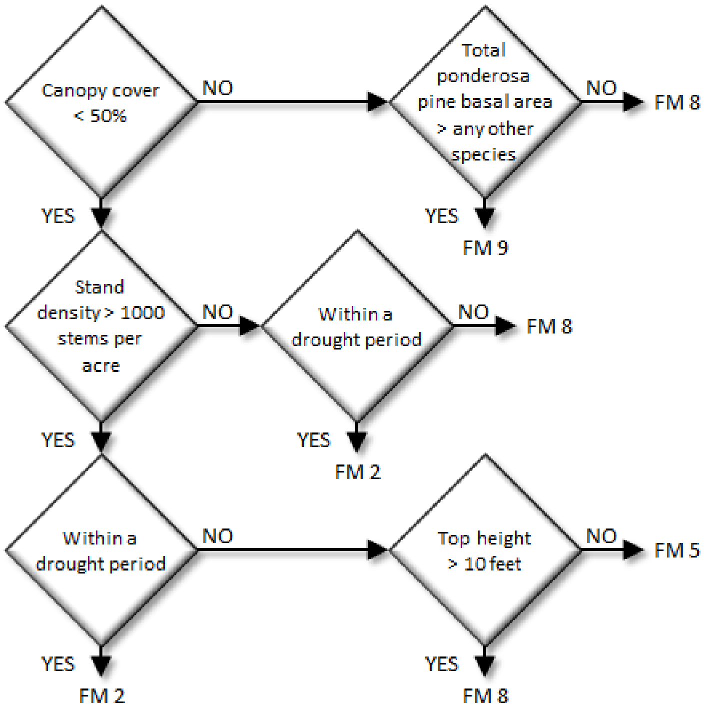
Lodgepole Pine Cover Type



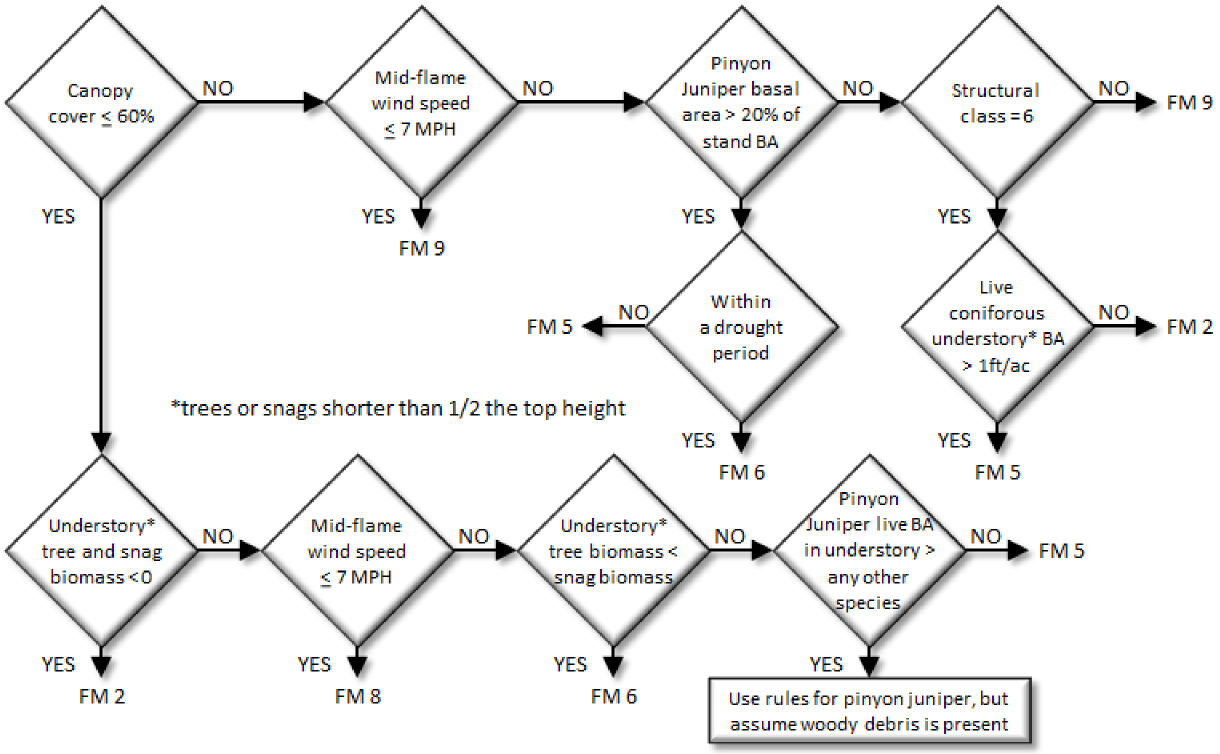
Spruce Fir Cover Type



Mixed Conifer Cover Type

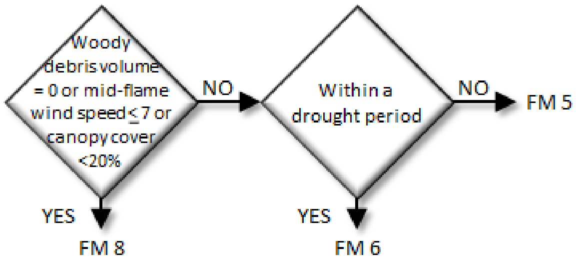


Ponderosa Pine Cover Type



*trees or snags shorter than 1/2 the top height

Pinyon Juniper Cover Type



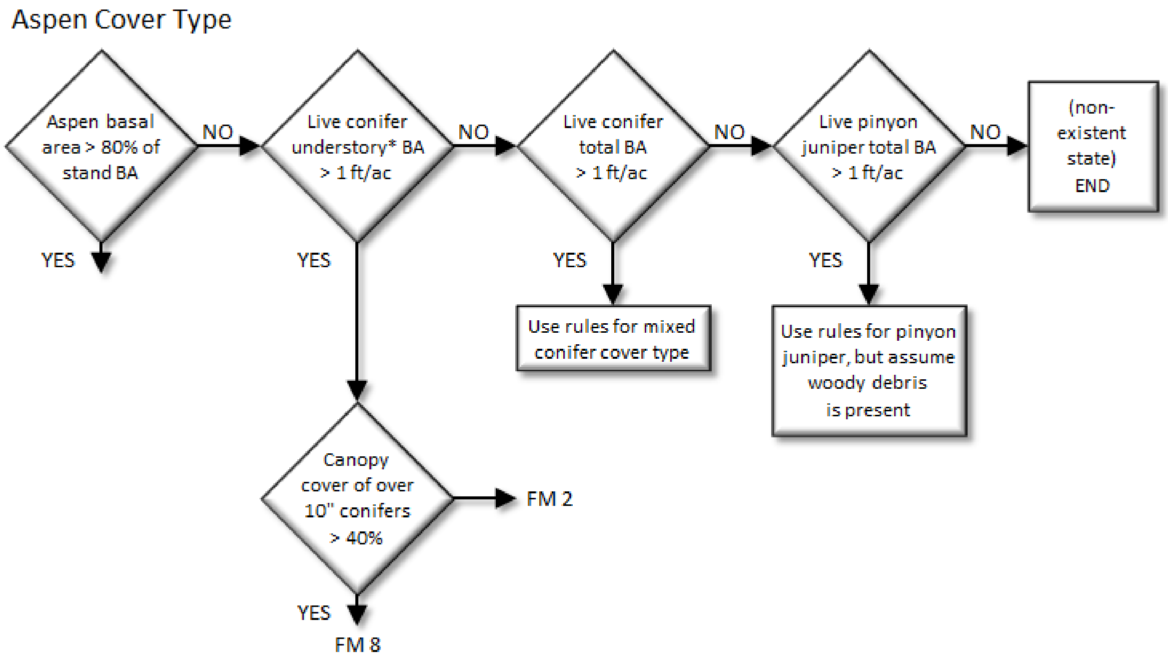


Figure 4.17.2 - Logic for modeling fire at “low” fuel loads in the TT-FFE variant.

4.18 Utah (UT)

4.18.1 Tree Species

The Utah variant models the 22 tree species shown in Table 4.18.1. Surrogate coefficients from the Utah, or other, variants are used for some species. Two additional categories, 'other softwood' and 'other hardwood' are modeled using whitebark pine and Gambel oak coefficients, respectively.

Table 4.18.1 - Tree species simulated by the Utah variant.

Common Name	Scientific Name	Notes
whitebark pine	*Pinus albicaulis*	
limber pine	*Pinus flexilis*	
Douglas-fir	*Pseudotsuga menziesii*	
white fir	*Abies concolor*	
blue spruce	*Picea pungens*	
quaking aspen	*Populus tremuloides*	
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
subalpine fir	*Abies lasiocarpa*	
ponderosa pine	*Pinus ponderosa*	
common pinyon	*Pinus edulis*	
western juniper	*Juniperus occidentalis*	
Gambel oak	*Quercus gambelii*	
singleleaf pinyon	*Pinus monophylla*	= common pinyon
Rocky Mountain juniper	*Juniperus scopulorum*	= western juniper
Utah juniper	*Juniperus osteosperma*	= western juniper
Great Basin bristlecone pine	*Pinus longaeva*	= CR bristlecone pine
narrowleaf cottonwood	*Populus angustifolia*	= CR cottonwoods
Fremont cottonwood	*Populus fremontii*	= CR cottonwoods
curl-leaf mountain mahogany	*Cercocarpus ledifolius*	= SO curlleaf mtn mah
bigtooth maple	*Acer grandidentatum*	= SO bigleaf maple
boxelder	*Acer negundo*	= CR cottonwoods
other softwood		= whitebark pine
other hardwood		= Gambel oak

4.18.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the FFE design workshop. A complete description of the Snag Submodel is provided in section 2.3.

Four variables are used to modify the Snag Submodel for the different species in the UT-FFE variant:

- A multiplier to modify the species' fall rate;
- A multiplier to modify the time required for snags to decay from a "hard" to "soft" state;
- The maximum number of years that snags will remain standing; and
- A multiplier to modify the species' height loss rate.

These variables are summarized in Table 4.18.2 and Table 4.18.3. Height loss rate of quaking aspen is insignificant in comparison to its rapid snag fall rate, and is not modeled. The fall rate of aspen is also halved in the ten years following a burn. In the case of Douglas-fir and spruce snags >18” DBH, the fall rate is reduced to 32% of the rate predicted by Marcot’s equation

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.18.4 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

Table 4.18.2 - Default snag fall, snag height loss and soft-snag characteristics for 20” DBH snags in the UT-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.18.3.

Species	95% Fallen	All Down	50% Height	Hard-to-Soft
	- - - - - - - - - - - Years -	- - - - - - - - - -		
whitebark pine	31	150	310	35
limber pine	31	150	310	35
Douglas-fir	88§	100	33	42
white fir	12	40	20	35
blue spruce	97§	100	658	35
quaking aspen	8	5	–	35
lodgepole pine	31	150	658	35
Engelmann spruce	97§	100	658	35
subalpine fir	12	40	20	35
ponderosa pine	31	150	310	39
common pinyon	31	150	310	35
western juniper	31	150	310	35
Gambel oak	12	40	20	35
singleleaf pinyon	31	150	310	35
Rocky Mountain juniper	31	150	310	35
Utah juniper	31	150	310	35
Great Basin bristlecone pine	–	–	658	35
narrowleaf cottonwood	8	5	–	35
Fremont cottonwood	8	5	–	35
curl-leaf mountain mahogany	31	90	30	39
bigtooth maple	31	90	30	39
boxelder	8	5	–	35
other softwood	31	150	310	35
other hardwood	12	40	20	35

§ This value results from using 32% of the default rate for Douglas-fir and spruce snags >18” DBH, as described in the text.

Table 4.18.3 - Default snag fall, snag height loss and soft-snag multipliers for the UT-FFE. These parameters result in the values shown in Table 4.18.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
whitebark pine	1.0	0.0978	0.9
limber pine	1.0	0.0978	0.9
Douglas-fir	1.0§	0.9	1.1
white fir	2.5	1.494	0.9
blue spruce	1.0§	0.0462	0.9
quaking aspen	4.0	–	0.9
lodgepole pine	1.0	0.0462	0.9
Engelmann spruce	1.0§	0.0462	0.9
subalpine fir	2.5	1.494	0.9
ponderosa pine	1.0	0.0978	1.0
common pinyon	1.0	0.0978	0.9
western juniper	1.0	0.0978	0.9
Gambel oak	2.5	1.494	0.9
singleleaf pinyon	1.0	0.0978	0.9

Species	Snag Fall	Height loss	Hard-to-Soft
Rocky Mountain juniper	1.0	0.0978	0.9
Utah juniper	1.0	0.0978	0.9
Great Basin bristlecone pine	0.001	0.0462	0.9
narrowleaf cottonwood	4.0	–	0.9
Fremont cottonwood	4.0	–	0.9
curl-leaf mountain mahogany	1.0	1.0	1.0
bigtooth maple	1.0	1.0	1.0
boxelder	4.0	–	0.9
other softwood	1.0	0.0978	0.9
other hardwood	2.5	1.494	0.9

§ This value apples to Douglas-fir and spruce snags <18” DBH; see text for details.

4.18.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a ‘bare ground’ stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density values calculated from the green specific gravity values from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.18.4 for Douglas-fir is based on ‘Douglas-fir south’.

Table 4.18.4 - Wood density (ovendry lb/ft^3) used in the UT-FFE variant.

Species	Density (lb/ft3)
whitebark pine	22.5
limber pine	22.5
Douglas-fir	26.8
white fir	23.1
blue spruce	20.6
quaking aspen	21.8
lodgepole pine	23.7
Engelmann spruce	20.6
subalpine fir	19.3
ponderosa pine	23.7
common pinyon	31.8
western juniper	34.9
Gambel oak	39.6
singleleaf pinyon	31.8
Rocky Mountain juniper	34.9
Utah juniper	34.9
Great Basin bristlecone pine	23.7
narrowleaf cottonwood	19.3
Fremont cottonwood	19.3

Species	Density (lb/ft3)
curl-leaf mountain mahogany	21.8
bigtooth maple	27.4
boxelder	19.3
other softwood	22.5
other hardwood	39.6

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the UT-FFE (Table 4.18.5). Common pinyon, singleleaf pinyon, western juniper, Rocky Mountain juniper, Utah juniper, and Gambel oak may have single or multiple stem forms: single stem equations were used to compute biomass in all cases. The FVS base model computes volume of these three species based on firewood utilization with a minimum branch of diameter of 1.5 inches. Crown and bole dynamics compatibility were maintained by defining tree crown as being made up of branches and twigs (including dead material) less than 1.5 inches, and foliage.

Table 4.18.5 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
whitebark pine	Brown (1978)
limber pine	lodgepole pine: Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
white fir	grand fir: Brown and Johnston (1976)
blue spruce	Engelmann spruce: Brown and Johnston (1976)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
lodgepole pine	Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
common pinyon	Grier and others (1992)
western juniper	oneseed juniper; Grier and others (1992)
Gambel oak	Chojnacky (1992)
singleleaf pinyon	common pinyon; Grier and others (1992)
Rocky Mountain juniper	oneseed juniper; Grier and others (1992)
Utah juniper	oneseed juniper; Grier and others (1992)
Great Basin bristlecone pine	common pinyon; Grier and others (1992)
narrowleaf cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Fremont cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
curl-leaf mountain mahogany	aspen; Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
bigtooth maple	Snell and Little (1983)
boxelder	Jenkins et. al. (2003); Snell and Little (1983)
other softwood	whitebark pine; Brown (1978)
other hardwood	Gambel oak; Chojnacky (1992)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.18.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are from Keane and others (1989).

Table 4.18.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the UT-FFE variant.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
whitebark pine	3	2	10	15	15
limber pine	3	2	10	15	15
Douglas-fir	5	2	10	15	15
white fir	7	2	10	15	15

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
blue spruce	6	2	10	10	10
quaking aspen	1	1	10	10	10
lodgepole pine	3	2	10	15	15
Engelmann spruce	6	2	10	10	10
subalpine fir	7	2	10	15	15
ponderosa pine	4	2	10	10	10
common pinyon	3	2	10	15	15
western juniper	4	2	10	15	20
Gambel oak	1	1	10	15	15
singleleaf pinyon	3	2	10	15	15
Rocky Mountain juniper	4	2	10	15	20
Utah juniper	4	2	10	15	20
Great Basin bristlecone pine	3	2	10	15	20
narrowleaf cottonwood	1	1	10	10	10
Fremont cottonwood	1	1	10	10	10
curl-leaf mountain mahogany	1	1	5	5	15
bigtooth maple	1	1	5	5	15
boxelder	1	1	10	10	10
other softwood	3	2	10	15	15
other hardwood	1	1	10	15	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.18.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.18.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Data on pinyon pine, juniper, quaking aspen and Gambel oak were developed after examining live fuels reported in the Stereo Photo Guides for Quantifying Natural Fuels (Ottmar and others 2000a and Ottmar and others 2000b).

Table 4.18.7 - Values (dry weight, tons/acre) for live fuels used in the UT-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		**Herbs**	**Shrubs**	**Notes**
whitebark pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
limber pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
Douglas-fir	E	0.20	0.20	
	I	0.40	2.00	
white fir	E	0.15	0.10	
	I	0.30	2.00	
blue spruce	E	0.15	0.20	Use Engelmann spruce
	I	0.30	2.00	
quaking aspen	E	0.25	0.25	Ottmar and others 2000b
	I	0.18	1.32	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Engelmann spruce	E	0.15	0.20	
	I	0.30	2.00	
subalpine fir	E	0.15	0.20	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	

Species		Herbs	Shrubs	Notes
	I	0.25	0.10	
common pinyon	E	0.04	0.05	Ottmar and others 2000a
	I	0.13	1.63	
western juniper	E	0.04	0.05	Ottmar and others 2000a
	I	0.13	1.63	
Gambel oak	E	0.23	0.22	Ottmar and others 2000b
	I	0.55	0.35	
singleleaf pinyon	E	0.04	0.05	Ottmar and others 2000a
	I	0.13	1.63	
Rocky Mountain juniper	E	0.04	0.05	Ottmar and others 2000a
	I	0.13	1.63	
Utah juniper	E	0.04	0.05	Ottmar and others 2000a
	I	0.13	1.63	
Great Basin bristlecone pine	E	0.04	0.05	Use CR bristlecone pine: pinyon (Ottmar and others 2000a)
	I	0.13	1.63	
narrowleaf cottonwood	E	0.25	0.25	quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
Fremont cottonwood	E	0.25	0.25	quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
curl-leaf mountain mahogany	E	0.25	0.25	quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
bigtooth maple	E	0.20	0.20	Use SO bigleaf maple
	I	0.40	2.00	
boxelder	E	0.25	0.25	quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other softwood	E	0.20	0.10	Use whitebark pine
	I	0.40	1.00	
other hardwood	E	0.23	0.22	Use Gambel oak
	I	0.55	0.35	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.18.8). Data on pinyon, juniper, quaking aspen and oaks were developed based on fuel loadings reported in the Stereo Photo Guides for Quantifying Natural Fuels (Ottmar and others 2000a, Ottmar and others 2000b). (Litter values for pinyon and juniper were lowered because the photo series values seemed too high.) If tree canopy cover is <10 percent, the DWD pools are assigned an "initiating" value and if cover is >60 percent they are assign the "established" value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.18.8 - Canopy cover and cover type are used to assign default dead fuel loads (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

		Size Class (in)							
Species		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
whitebark pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
limber pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
blue spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Engelmann spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
common pinyon	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
western juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Gambel oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
singleleaf pinyon	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Rocky Mountain juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Utah juniper	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Great Basin bristlecone pine	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
narrowleaf cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
Fremont cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
curl-leaf mountain mahogany	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
bigtooth maple	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
boxelder	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other softwood	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
other hardwood	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0

The live and dead surface fuel values for juniper and pinyon pine in Table 4.18.7 and Table 4.18.8 were taken from Ottmar and others (2000a). The litter amounts were switched to 0.5 and 0.3 tons/acre for established and initiating stands, respectively, since the photo series values seemed too high. The live and dead surface fuel values for oak and aspen in tables 4.3.7 and 4.3.8 were taken from Ottmar and others (2000b).

4.18.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.18.9 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003). The pinyon pine coefficient is based on Pinus spp from FOFEM.

Table 4.18.9 - Species-specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
whitebark pine	0.030
limber pine	0.030
Douglas-fir	0.063
white fir	0.048
blue spruce	0.031
quaking aspen	0.044
lodgepole pine	0.028
Engelmann spruce	0.036
subalpine fir	0.041
ponderosa pine	0.063
common pinyon	0.030
western juniper	0.025
Gambel oak	0.045
singleleaf pinyon	0.030
Rocky Mountain juniper	0.025
Utah juniper	0.025
Great Basin bristlecone pine	0.030
narrowleaf cottonwood	0.038
Fremont cottonwood	0.038
curl-leaf mountain mahogany	0.044
bigtooth maple	0.024
boxelder	0.038
other softwood	0.030
other hardwood	0.045

4.18.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.18.10). Workshop participants noted that material decays slower in the area covered by the UT-FFE. This comment was support by data in Brown and others (1998). Decay rate for woody material was therefore reduced 55 percent from the default decay rates based on Abbott and Crossley (1982). A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster.

Table 4.18.10 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. The rates for woody material are 55 percent lower than the rates used in the NI-FFE variant. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.054	0.02
0.25 – 1		
1 – 3	0.041	
3 – 6	0.0068	
6 – 12		
> 12		
Litter	0.50	
Duff	0.002	0.0

By default, FFE decays all wood species at the rates shown in Table 4.18.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.18.11 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.18.11 - Default wood decay classes used in the UT-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Class
whitebark pine	4
limber pine	4
Douglas-fir	3
white fir	4
blue spruce	4
quaking aspen	4
lodgepole pine	4
Engelmann spruce	4
subalpine fir	4
ponderosa pine	4
common pinyon	4
western juniper	2
Gambel oak	2
singleleaf pinyon	4
Rocky Mountain juniper	2
Utah juniper	2
Great Basin bristlecone pine	4
narrowleaf cottonwood	4
Fremont cottonwood	4
curl-leaf mountain mahogany	4
bigtooth maple	4
boxelder	4
other softwood	4
other hardwood	2

4.18.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.18.12) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.18.12 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups. In general they are drier than the default values used in the NI-FFE.

	Moisture Group			
Size Class	Very Dry	Dry	Moist	Wet
0 – 0.25 in. (1-hr)	4	5	8	10
0.25 – 1.0 in. (10-hr)	4	6	10	12
1.0 – 3.0 in. (100-hr)	5	8	12	15
> 3.0 in. (1000+ -hr)	10	15	16	18
Duff	15	50	125	200
Live	70	90	120	140

4.18.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger ‘Activity Fuels’ conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;

3) Allowing FFE to determine a weighted set of fuel models; or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the UT-FFE to follow the third of these four options

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.18.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The logical flow shown in Figure 4.18.2 defines which low fuel model(s) will become candidates. According to the logic of Figure 4.18.2, only in a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover, average height, snag density, etc.).

The program logic shown in Figure 4.18.2 also uses stand structure classes in some decision rules. The UT-FFE uses the default structure class rules documented in Crookston and Stage (1999) unless model users alter those definitions using the **STRCLS** keyword.

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.18.1 or Figure 4.18.2. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

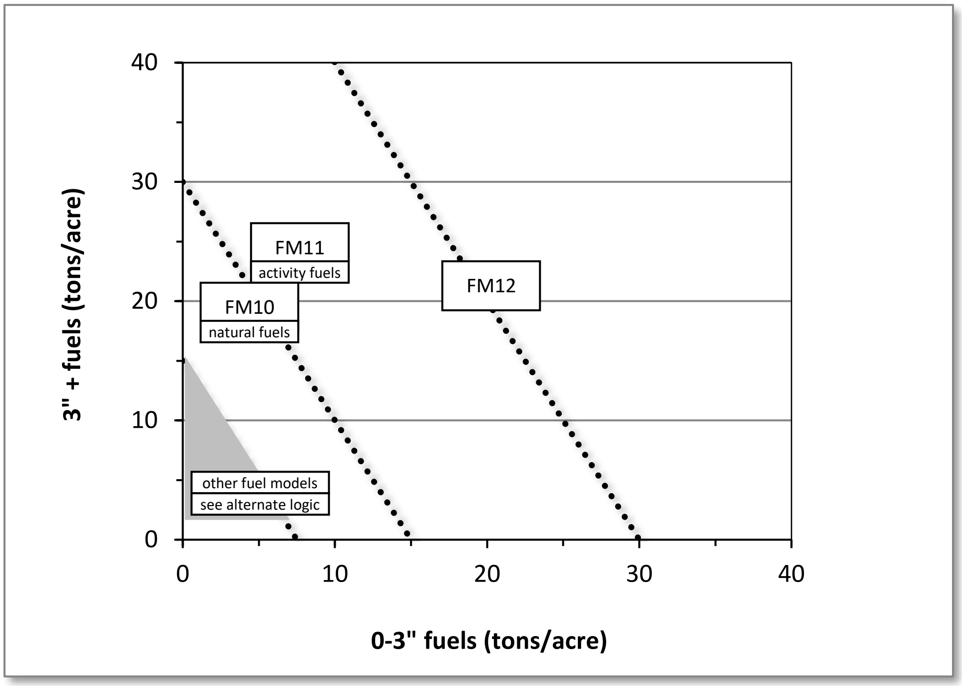
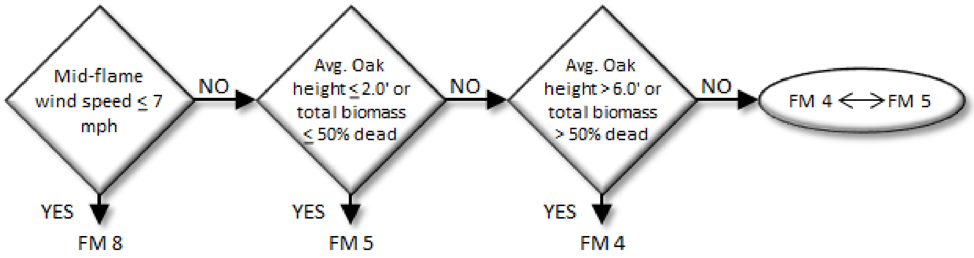
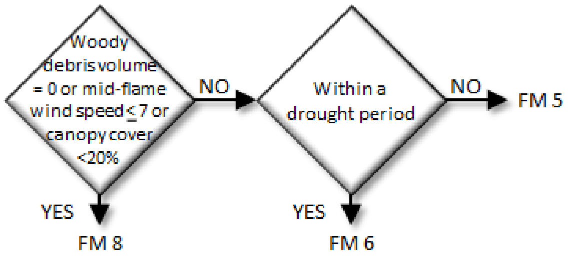


Figure 4.18.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.18.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

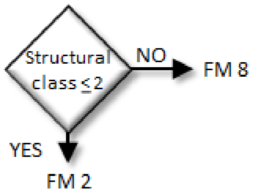
Oak Brush Cover Type



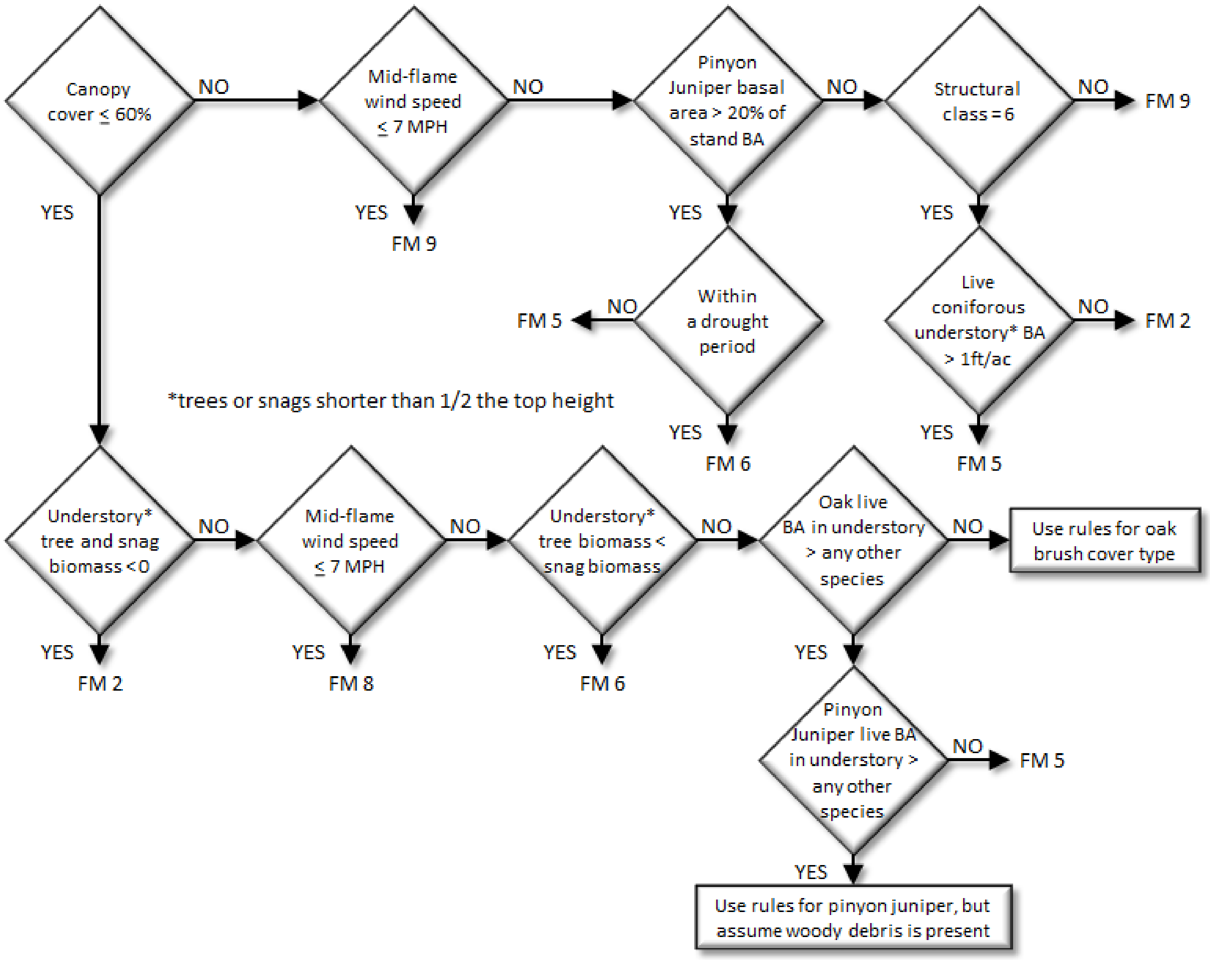
Pinyon Juniper Cover Type



Spruce Fir Cover Type

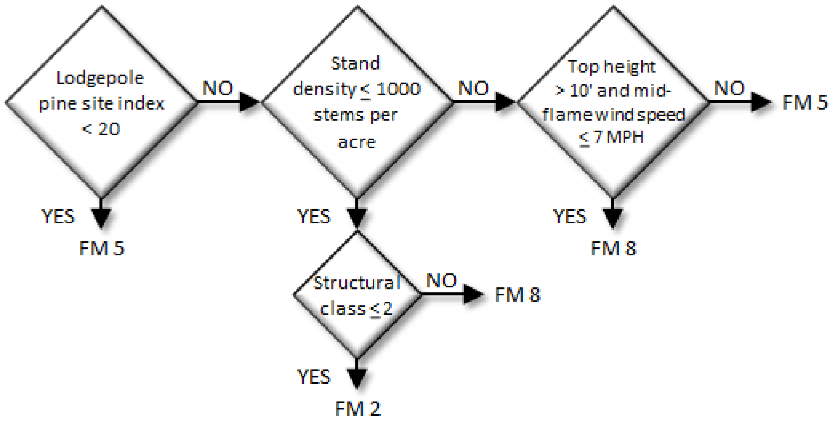


Ponderosa Pine Cover Type

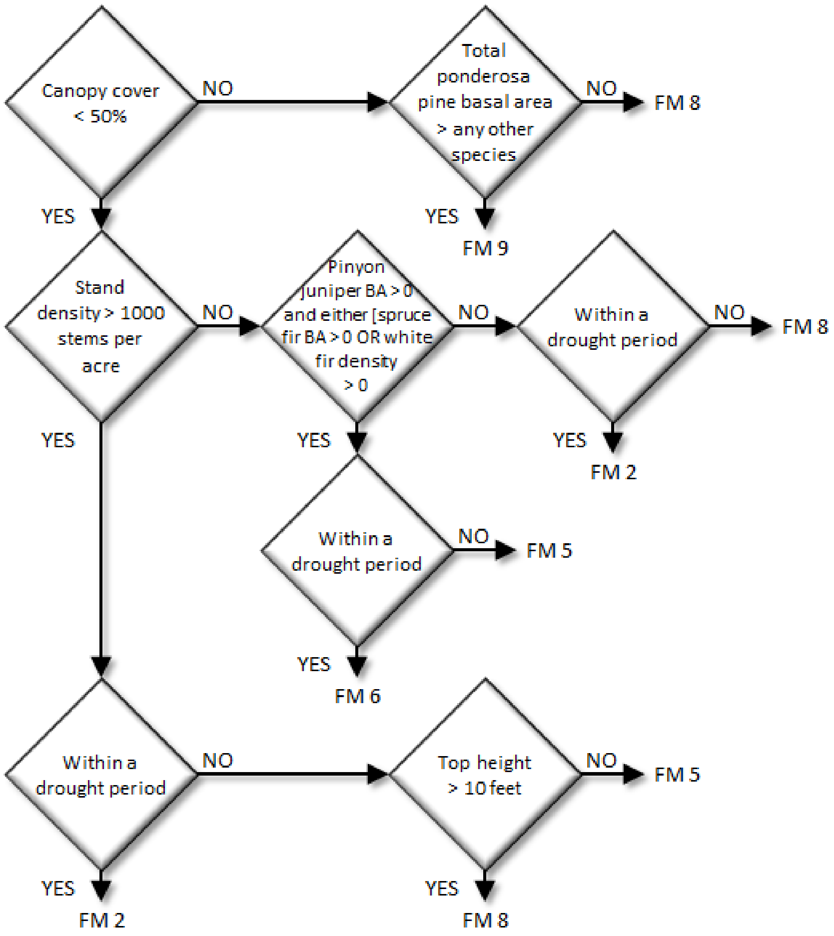


*trees or snags shorter than 1/2 the top height

Lodgepole Pine Cover Type



Mixed Conifer Cover Type



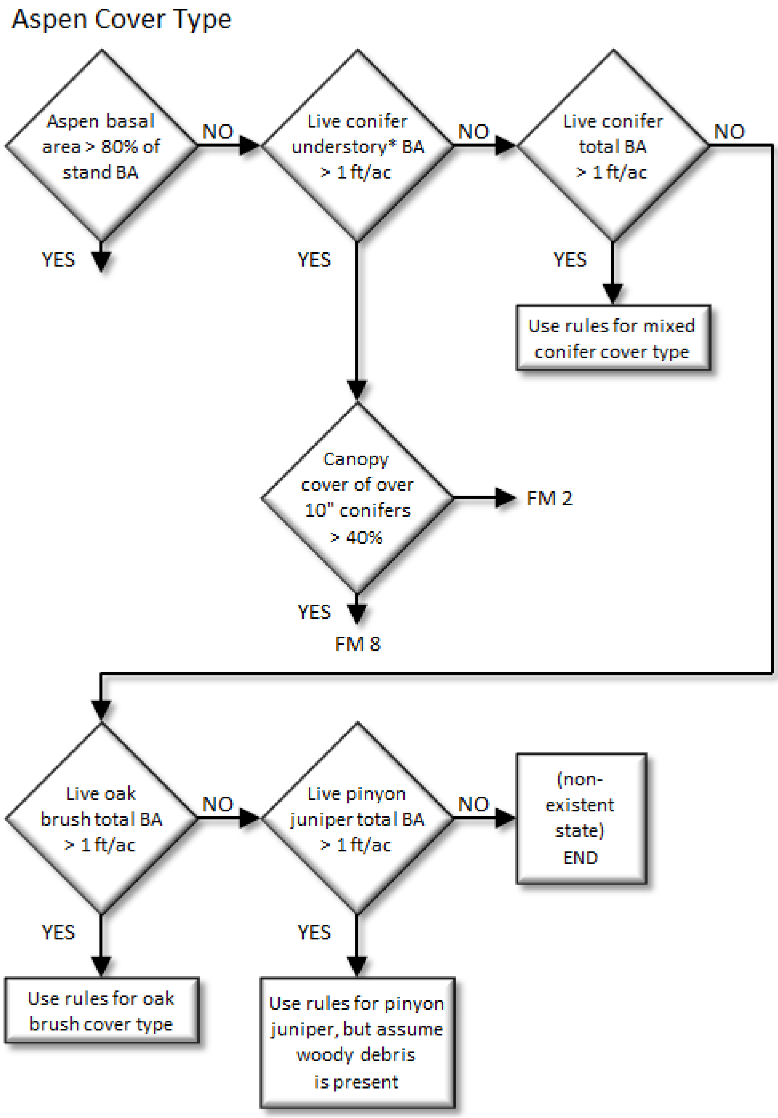


Figure 4.18.2 - Logic for modeling fire at “low” fuel loads in the UT-FFE variant.

4.19 Westside Cascades (WC)

4.19.1 Tree Species

The Westside Cascades variant models the 36 tree species shown in Table 4.19.1. One additional category, 'other', is modeled using quaking aspen.

Table 4.19.1 - Tree species simulated by the Westside Cascades variant.

Common Name	Scientific Name	Notes
Pacific silver fir	*Abies amabilis*	
white fir	*Abies concolor*	
grand fir	*Abies grandis*	
subalpine fir	*Abies lasiocarpa*	
California red fir	*Abies magnifica*	
noble fir	*Abies procera*	
Alaska cedar	*Callitropsis nootkatensis*	
incense cedar	*Calocedrus decurrens*	
Engelmann spruce	*Picea engelmannii*	
lodgepole pine	*Pinus contorta*	
Jeffrey pine	*Pinus jeffreyi*	
sugar pine	*Pinus lambertiana*	
western white pine	*Pinus monticola*	
ponderosa pine	*Pinus ponderosa*	
Douglas-fir	*Pseudotsuga menziesii*	
redwood	*Sequoia sempervirens*	
western redcedar	*Thuja plicata*	
western hemlock	*Tsuga heterophylla*	
mountain hemlock	*Tsuga mertensiana*	
bigleaf maple	*Acer macrophyllum*	
red alder	*Alnus rubra*	
white alder	*Alnus rhombifolia*	
paper birch	*Betula papyrifera*	
giant chinquapin	*Chrysolepis chrysophylla* var. *chrysophylla*	
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	
Oregon white oak	*Quercus garryana*	
western juniper	*Juniperus occidentalis*	
subalpine larch	*Larix lyallii*	
whitebark pine	*Pinus albicaulis*	
knobcone pine	*Pinus attenuata*	
Pacific yew	*Taxus brevifolia*	
Pacific dogwood	*Cornus nuttallii*	
hawthorn	*Crataegus*	
bitter cherry	*Prunus emarginata*	
willow	*Salix*	
other		= *quaking aspen*

4.19.2 Snags

In the WC variant, the snag dynamics were modified based on the work of Kim Mellen-McLean, region 6 wildlife ecologist. These relationships are described in the following document: http://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/R6snags.pdf

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.19.2 are used to convert volume to biomass. Soft snags have 80 percent the density of hard snags.

Snag dynamics can be modified by the user using the **SNAGBRK**, **SNAGFALL**, **SNAGDCAY** and **SNAGPBN** keywords.

4.19.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and dead surface fuel. Live herb and shrub fuel load and the initial dead surface fuel load are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a 'bare ground' stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using wood density calculated from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficient in Table 4.19.2 for Douglas-fir is based on 'Douglas-fir coast'. The value for juniper is from Chojnacky and Moisen (1993).

Table 4.19.2 - Wood density (ovendry lbs/green ft^3) used in the WC-FFE variant.

Species	Density (lbs/ft^3)
Pacific silver fir	24.9
white fir	23.1
grand fir	21.8
subalpine fir	19.3
California red fir	22.5
noble fir	23.1
Alaska cedar	26.2
incense cedar	21.8
Engelmann spruce	20.6
lodgepole pine	23.7
Jeffrey pine	21.2
sugar pine	21.2
western white pine	22.5
ponderosa pine	23.7
Douglas-fir	28.1
redwood	21.2
western redcedar	19.3
western hemlock	26.2
mountain hemlock	26.2
bigleaf maple	27.4
red alder	23.1
white alder	36.2
paper birch	29.9
giant chinquapin	36.2
quaking aspen	21.8
black cottonwood	19.3
Oregon white oak	37.4
western juniper	34.9
subalpine larch	29.9
whitebark pine	22.5
knobcone pine	23.7
Pacific yew	26.2
Pacific dogwood	27.4
hawthorn	27.4
bitter cherry	29.3
willow	22.5
other	21.8

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for many species in the WC-FFE (Table 4.19.3).

Table 4.19.3 - The crown biomass equations used in the WC-FFE. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
Pacific silver fir	grand fir; Brown and Johnston (1976)
white fir	grand fir; Brown and Johnston (1976)

Species	Species Mapping and Equation Source
grand fir	Brown and Johnston (1976)
subalpine fir	Brown and Johnston (1976)
California red fir	subalpine fir; Brown and Johnston (1976)
noble fir	grand fir; Brown and Johnston (1976)
Alaska cedar	western larch; Brown and Johnston (1976)
incense cedar	based on western redcedar; Brown and Johnston (1976)
Engelmann spruce	Brown and Johnston (1976)
lodgepole pine	Brown and Johnston (1976)
Jeffrey pine	western white pine; Brown and Johnston (1976)
sugar pine	western white pine; Brown and Johnston (1976)
western white pine	Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976)
redwood	western redcedar for biomass, western hemlock for partitioning (Mike Lander, pers. comm.; Brown and Johnston 1976)
western redcedar	Brown and Johnston (1976)
western hemlock	Brown and Johnston (1976)
mountain hemlock	Gholz and others (1979); western hemlock (Brown and Johnston 1976)
bigleaf maple	Snell and Little (1983)
red alder	Snell and Little (1983)
white alder	madrone; Snell and Little (1983)
paper birch	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
giant chinquapin	tanoak; Snell and Little (1983), Snell (1979)
quaking aspen	Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
black cottonwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Oregon white oak	tanoak; Snell and Little (1983), Snell (1979)
western juniper	oneseed juniper; Grier and others (1992)
subalpine larch	subalpine fir; Brown and Johnston (1976)
whitebark pine	Johnston (1976)
knobcone pine	lodgepole pine; Brown and Johnston (1976)
Pacific yew	western redcedar; Brown and Johnston (1976)
Pacific dogwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
hawthorn	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
bitter cherry	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
willow	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other	aspen; Jenkins et. al. (2003); Loomis and Roussopoulos (1978)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.19.4. Each year the inverse of the lifespan is added to the litter pool from each biomass category. Leaf lifespan data are based on Keane and others (1989) and in some cases were adapted at the model design workshop. Lifespans are taken from the FFE workshop, with western white pine and mountain hemlock mapped using ponderosa pine, and western hemlock and western redcedar based on Douglas-fir.

Table 4.19.4 - Life span of live and dead foliage (yr) and dead branches for species modeled in the WC-FFE variant.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
Pacific silver fir	7	2	5	5	15
white fir	7	2	5	5	15
grand fir	7	2	5	5	15
subalpine fir	7	2	5	5	15
California red fir	7	2	5	5	15
noble fir	7	2	5	5	15
Alaska cedar	5	2	5	5	20
incense cedar	5	1	5	5	20
Engelmann spruce	6	2	5	5	10

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
lodgepole pine	3	2	5	5	15
Jeffrey pine	3	2	3	10	15
sugar pine	3	2	5	5	15
western white pine	4	2	5	5	15
ponderosa pine	4	2	5	5	15
Douglas-fir	5	2	5	5	15
redwood	5	3	10	15	20
western redcedar	5	2	5	5	20
western hemlock	5	3	10	15	15
mountain hemlock	4	2	5	5	15
bigleaf maple	1	1	10	15	15
red alder	1	1	10	15	15
white alder	1	1	10	15	15
paper birch	1	1	10	15	15
giant chinquapin	1	1	10	15	15
quaking aspen	1	1	10	15	15
black cottonwood	1	1	10	15	15
Oregon white oak	1	1	10	15	15
western juniper	4	2	5	5	15
subalpine larch	1	1	5	5	15
whitebark pine	3	3	10	15	15
knobcone pine	4	3	10	15	15
Pacific yew	7	3	10	15	20
Pacific dogwood	1	1	10	15	15
hawthorn	1	1	10	15	15
bitter cherry	1	1	10	15	15
willow	1	1	10	15	15
other	1	1	10	15	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.19.5). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.19.5). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Values for quaking aspen are from Ottmar and others (2000b). Values for western juniper are from Ottmar and others (1998).

Table 4.19.5 - Values (dry weight, tons/acre) for live fuels used in the WC-FFE. Biomass is linearly interpolated between the “initiating” (I) and “established”(E) values when canopy cover is between 10 and 60 percent.

Species		**Herbs**	**Shrubs**	**Notes**
Pacific silver fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
white fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
subalpine fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
California red fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
noble fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	

Species		Herbs	Shrubs	Notes
Alaska cedar	E	0.20	0.20	Use western redcedar
	I	0.40	2.00	
incense cedar	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
Engelmann spruce	E	0.30	0.20	
	I	0.30	2.00	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Jeffrey pine	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
sugar pine	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
western white pine	E	0.15	0.10	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	
	I	0.25	0.10	
Douglas-fir	E	0.20	0.20	
	I	0.40	2.00	
redwood	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
western redcedar	E	0.20	0.20	
	I	0.40	2.00	
western hemlock	E	0.20	0.20	
	I	0.40	2.00	
mountain hemlock	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
bigleaf maple	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
red alder	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
white alder	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
paper birch	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
giant chinquapin	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	
quaking aspen	E	0.25	0.25	Ottmar and others 2000b
	I	0.18	1.32	
black cottonwood	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
Oregon white oak	E	0.23	0.22	Gambel oak – Ottmar and others 2000b
	I	0.55	0.35	
western juniper	E	0.14	0.35	Ottmar and others (1998)
	I	0.10	2.06	
subalpine larch	E	0.20	0.20	Use western larch
	I	0.40	2.00	
whitebark pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
knobcone pine	E	0.20	0.10	Use lodgepole pine
	I	0.40	1.00	
Pacific yew	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
Pacific dogwood	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
hawthorn	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
bitter cherry	E	0.25	0.25	

Species		Herbs	Shrubs	Notes
	I	0.18	1.32	Use quaking aspen - Ottmar and others 2000b
willow	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) and were reviewed and in some cases modified at the model workshop (Table 4.19.6). Values for quaking aspen are from Ottmar and others (2000b). Values for western juniper are from Ottmar and others (1998). If tree canopy cover is <10 percent, the DWD pools are assigned an "initiating" value and if cover is >60 percent they are assign the "established" value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. All down wood in the > 12" column is put into the 12 – 20" size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.19.6 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

		Size Class (in)							
Species		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
Pacific silver fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
California red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
noble fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Alaska cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
incense cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
Engelmann spruce	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	12.0	0.6	30.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	12.0
Jeffrey pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
sugar pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
ponderosa pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Douglas-fir	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
redwood	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western redcedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
western hemlock	E	0.7	0.7	3.0	7.0	7.0	10.0	1.0	35.0
	I	0.5	0.5	2.0	2.8	2.8	6.0	0.5	12.0
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
bigleaf maple	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
red alder	E	0.7	0.7	1.6	2.5	2.5	5.0	0.8	30.0
	I	0.1	0.1	0.2	0.5	1.4	3.0	0.4	12.0
white alder	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
paper birch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
giant chinquapin	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
Oregon white oak	E	0.7	0.7	0.8	1.2	1.2	0.5	1.4	0.0
	I	0.1	0.1	0.1	0.2	0.2	0.0	0.5	0.0
western juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0
subalpine larch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
whitebark pine	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
knobcone pine	E	0.9	0.9	1.2	7.0	8.0	12.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	12.0
Pacific yew	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
Pacific dogwood	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
hawthorn	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
bitter cherry	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
willow	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.19.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.19.7 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.19.7 - Species-specific constants for determining single bark thickness.

Species	**Multiplier (V_{sp})**	**Species**	**Multiplier (V_{sp})**
Pacific silver fir	0.047	bigleaf maple	0.024
white fir	0.048	red alder	0.026
grand fir	0.046	white alder	0.060
subalpine fir	0.041	paper birch	0.027

Species	Multiplier (V_{sp})
California red fir	0.039
noble fir	0.045
Alaska cedar	0.022
incense cedar	0.081
Engelmann spruce	0.036
lodgepole pine	0.028
Jeffrey pine	0.068
sugar pine	0.072
western white pine	0.035
ponderosa pine	0.063
Douglas-fir	0.063
redwood	0.081
western redcedar	0.035
western hemlock	0.040
mountain hemlock	0.040
giant chinquapin	0.045
quaking aspen	0.044
black cottonwood	0.044
Oregon white oak	0.029
western juniper	0.025
subalpine larch	0.050
whitebark pine	0.030
knobcone pine	0.030
Pacific yew	0.025
Pacific dogwood	0.062
hawthorn	0.038
bitter cherry	0.062
willow	0.041
other	0.044

4.19.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5. Default decay rates (Table 4.19.8) are based on values provided by Kim Mellen-McLean, Pacific Northwest Regional wildlife ecologist, for the Pacific Northwest area. They are from published literature with adjustment factors based on temperature and moisture as determined by an expert panel at the Dead Wood Decay Calibration workshop in July 2003. The habitat code set by the **STDINFO** keyword or read in from an input database determines the temperature and moisture class for a stand, as shown in Table 4.19.9.

A portion of the loss is added to the duff pool each year. Loss rates are for hard material; soft material in all size classes, except litter and duff, decays 10% faster. The decay rates for individual species vary based on the decay rate class of that species (Table 4.19.10). The decay rates may be modified for each decay class using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.19.8 - Default annual loss rates are applied based on size class, temperature and moisture class, and decay rate class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

	Size Class (inches)	Annual Loss Rate				Proportion of Loss Becoming Duff
		decay class 1	decay class 2	decay class 3	decay class 4	
warm, dry	< 0.25	0.117	0.138	0.165	0.223	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.024	0.050	0.082	0.154	
	6 – 12					
	> 12	0.020	0.043	0.070	0.131	
moderate, wet	< 0.25	0.060	0.071	0.085	0.116	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.018	0.038	0.062	0.116	
	6 – 12					
	> 12	0.011	0.022	0.036	0.067	
moderate, mesic	< 0.25	0.069	0.081	0.097	0.154	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.024	0.050	0.082	0.154	
	6 – 12					
	> 12	0.012	0.025	0.041	0.077	
moderate, dry	< 0.25	0.083	0.098	0.117	0.159	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.024	0.050	0.082	0.154	
	6 – 12					
	> 12	0.015	0.030	0.050	0.093	
cold, wet	< 0.25	0.052	0.061	0.073	0.098	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.012	0.025	0.041	0.077	
	6 – 12					
	> 12	0.009	0.019	0.031	0.058	
cold, mesic	< 0.25	0.057	0.067	0.080	0.108	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.016	0.033	0.053	0.100	
	6 – 12					
	> 12	0.010	0.021	0.034	0.064	
cold, dry	< 0.25	0.060	0.071	0.085	0.116	0.02
	0.25 – 1					
	1 – 3					
	3 – 6	0.018	0.038	0.062	0.116	
	6 – 12					
	> 12	0.011	0.022	0.036	0.067	
All	Litter	0.50	0.50	0.50	0.50	0.02
	Duff	0.002	0.002	0.002	0.002	0.0

Table 4.19.9 - Habitat type - moisture and temperature regime relationships for the WC-FFE variant. The moisture and temperature classes affect the default decay rates. The original class is an older classification still used in the fuel model selection logic of this variant and was provided by Tom DeMeo and Kim Mellen-McLean, USFS, Portland, OR (pers. comm. 2003).

Habitat Type Code	Orig. Class	Temperature	Moisture	Habitat Type Code	Orig. Class	Temperature	Moisture
CAF211	Dry	cold	dry	CHF222	Moist	moderate	wet
CAF311	Mesic	cold	mesic	CHF250	Moist	moderate	mesic
CAG211	Mesic	cold	mesic	CHF321	Mesic	moderate	mesic
CAG311	Mesic	cold	mesic	CHF421	Moist	moderate	wet
CAG312	Mesic	cold	mesic	CHM121	Moist	moderate	wet
CAS211	Moist	cold	mesic	CHS111	Dry	warm	dry
CAS411	Dry	cold	dry	CHS113	Moist	moderate	wet
CDC711	Dry	warm	dry	CHS114	Mesic	moderate	mesic
CDC712	Mesic	moderate	mesic	CHS124	Mesic	moderate	mesic
CDC713	Dry	warm	dry	CHS125	Mesic	moderate	mesic
CDS211	Dry	warm	dry	CHS126	Mesic	moderate	mesic
CDS212	Dry	warm	dry	CHS127	Mesic	moderate	mesic
CDS213	Dry	warm	dry	CHS128	Mesic	moderate	mesic
CDS641	Dry	warm	dry	CHS129	Mesic	moderate	mesic
CFC251	Dry	warm	dry	CHS130	Mesic	moderate	mesic
CFC311	Dry	warm	dry	CHS135	Mesic	moderate	mesic
CFF152	Moist	moderate	wet	CHS140	Dry	moderate	dry
CFF153	Moist	moderate	wet	CHS141	Dry	moderate	mesic
CFF154	Moist	cold	mesic	CHS223	Dry	moderate	dry
CFF250	Mesic	cold	mesic	CHS224	Dry	moderate	dry
CFF253	Mesic	moderate	mesic	CHS251	Mesic	moderate	mesic
CFF312	Dry	cold	mesic	CHS325	Dry	cold	dry
CFF450	Moist	cold	mesic	CHS326	Mesic	moderate	mesic
CFM111	Moist	cold	wet	CHS327	Dry	moderate	dry
CFS110	Mesic	cold	mesic	CHS328	Dry	moderate	dry
CFS151	Mesic	moderate	mesic	CHS351	Dry	warm	dry
CFS152	Mesic	moderate	mesic	CHS352	Dry	moderate	dry
CFS154	Mesic	cold	mesic	CHS353	Dry	cold	dry
CFS216	Mesic	cold	mesic	CHS354	Moist	moderate	wet
CFS221	Dry	cold	mesic	CHS355	Mesic	moderate	mesic
CFS222	Mesic	cold	mesic	CHS511	Moist	moderate	wet
CFS223	Dry	cold	mesic	CHS513	Moist	moderate	wet
CFS224	Mesic	cold	mesic	CHS522	Moist	moderate	wet
CFS225	Moist	cold	mesic	CHS523	Moist	moderate	wet
CFS226	Moist	cold	mesic	CHS524	Moist	moderate	wet
CFS229	Dry	cold	mesic	CHS611	Moist	moderate	wet
CFS230	Mesic	cold	mesic	CHS612	Dry	cold	dry
CFS231	Moist	cold	mesic	CHS613	Moist	moderate	wet
CFS251	Dry	cold	dry	CHS614	Mesic	moderate	mesic
CFS252	Dry	cold	mesic	CHS615	Mesic	moderate	mesic
CFS253	Moist	moderate	wet	CHS625	Mesic	moderate	mesic
CFS254	Mesic	moderate	mesic	CHS626	Mesic	moderate	mesic
CFS255	Mesic	moderate	mesic	CMF250	Moist	cold	mesic
CFS256	Mesic	moderate	mesic	CMF251	Moist	cold	wet
CFS257	Mesic	moderate	mesic	CMS114	Dry	cold	dry
CFS258	Mesic	cold	mesic	CMS210	Mesic	cold	mesic
CFS259	Mesic	cold	mesic	CMS216	Dry	cold	dry
CFS260	Mesic	cold	mesic	CMS218	Mesic	cold	mesic
CFS351	Moist	moderate	wet	CMS221	Moist	cold	wet
CFS352	Moist	cold	wet	CMS223	Moist	cold	wet
CFS550	Moist	cold	wet	CMS241	Moist	cold	mesic
CFS551	Moist	cold	wet	CMS244	Mesic	cold	mesic
CFS552	Moist	cold	wet	CMS245	Dry	cold	mesic
CFS554	Dry	cold	dry	CMS246	Dry	cold	mesic

Habitat Type Code	Orig. Class	Temperature	Moisture	Habitat Type Code	Orig. Class	Temperature	Moisture
CFS555	Dry	cold	mesic	CMS250	Moist	cold	mesic
CFS651	Moist	moderate	wet	CMS251	Mesic	cold	mesic
CFS652	Mesic	cold	mesic	CMS252	Mesic	cold	mesic
CFS653	Dry	cold	dry	CMS253	Moist	cold	mesic
CFS654	Mesic	cold	mesic	CMS254	Dry	cold	mesic
CHC212	Dry	warm	dry	CMS255	Moist	cold	mesic
CHC213	Dry	warm	dry	CMS350	Moist	cold	mesic
CHF111	Moist	moderate	wet	CMS351	Mesic	cold	mesic
CHF123	Moist	moderate	wet	CMS352	Mesic	cold	mesic
CHF124	Moist	moderate	wet	CMS353	Moist	cold	mesic
CHF125	Moist	moderate	wet	CMS450	Moist	cold	wet
CHF133	Mesic	moderate	mesic	CMS612	Mesic	cold	mesic
CHF134	Mesic	moderate	mesic	CWF211	Dry	warm	dry
CHF135	Moist	moderate	wet	CWS521	Dry	warm	dry
CHF151	Moist	moderate	wet	CWS522	Dry	warm	dry
CHF221	Dry	moderate	dry				

Table 4.19.10 - Default wood decay classes used in the WC-FFE variant. Classes are based on the advice of an expert panel at the Dead Wood Decay Calibration workshop organized by Kim Mellen-McLean in July 2003.

Species	Decay Rate Class	Species	Decay Rate Class
Pacific silver fir	3	bigleaf maple	4
white fir	3	red alder	4
grand fir	3	white alder	4
subalpine fir	3	paper birch	4
California red fir	3	giant chinquapin	3
noble fir	3	quaking aspen	4
Alaska cedar	1	black cottonwood	4
incense cedar	1	Oregon white oak	3
Engelmann spruce	2	western juniper	1
lodgepole pine	2	subalpine larch	1
Jeffrey pine	3	whitebark pine	1
sugar pine	1	knobcone pine	2
western white pine	1	Pacific yew	1
ponderosa pine	3	Pacific dogwood	4
Douglas-fir	1	hawthorn	4
redwood	1	bitter cherry	4
western redcedar	1	willow	4
western hemlock	2	other	4
mountain hemlock	2		

4.19.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups (Table 4.19.11) or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.19.11 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	4	8	12	16
0.25 – 1.0 in. (10-hr)	4	8	12	16
1.0 – 3.0 in. (100-hr)	5	10	14	18
> 3.0 in. (1000+ -hr)	10	15	25	50
Duff	15	50	125	200
Live	70	110	150	150

4.19.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are used to estimate flame length and fire effects stemming from flame length. Fuel models are determined using fuel load and stand attributes specific to each FFE variant. In addition, stand management actions such as thinning and harvesting can abruptly increase fuel loads and can trigger ‘Activity Fuels’ conditions, resulting in the selection of alternative fuel models. At their discretion, FFE users have the option of:

1) Defining and using their own fuel models;
2) Defining the choice of fuel models and weights;
3) Allowing FFE to determine a weighted set of fuel models; or
4) Allowing FFE to determine a weighted set of fuel models, then using the dominant model.

This section explains the steps taken by the WC-FFE to follow the third of these four options. The fuel model selection logic is based on information provided at the WC-FFE design workshop. The appropriate fuel model is determined using measures of cover type, canopy cover (CC) and average size (QMD). Fuel model selection begins by summing the basal area for six species groups:

- Pacific silver fir, western hemlock, Engelmann spruce/Sitka spruce, western redcedar (SF or WH or SS or RC in Figure 4.15.2);
- Douglas-fir, grand fir, western white pine (DF or GF or WP);
- mountain hemlock, subalpine fir, whitebark pine (MH or AF or WB);
- red alder (RA);
- lodgepole pine (LP); and
- Oregon white oak, tanoak (WO or TA).

Species not included in the list are pooled with the Douglas-fir group. The two highest basal area groups are then selected and assigned weights in proportion to their basal area. For example, if a stand is 25% alder and 75% Douglas-fir, then the logic of the red alder rules will account for one quarter of the fuel selection and the logic for the Douglas-fir rules will account for the remainder.

When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.19.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The two dominant cover types described above, along with the flow diagrams in Figure 4.19.2, define which low fuel model(s) will become candidates. According to the logic of each of the figures, only a single fuel model will be chosen for a given stand structure. Consequently, as a stand undergoes structural changes due to management or maturation, the selected fire model can jump from one model selection to another, which in turn may cause abrupt changes in predicted fire behavior. To smooth out changes resulting from changes in fuel model, the strict logic is augmented by linear transitions between states that involve continuous variables (for example, percent canopy cover and QMD), as well as by the blended contribution of the two dominant cover types.

Some of the rules shown in Figure 4.19.2 include information about site-specific moisture regime or site-specific ground cover type. Moisture regime is based on the habitat code provided by the **STDINFO** keyword, using the classification shown in Table 4.19.9. Ground cover type is also based on habitat code, as shown in Table 4.19.12.

Table 4.19.12 - Habitat type – ground cover mapping for the WC-FFE variant. Ground cover classes modify default fuel model selection, as described in the text. Unclassified habitat groups default to 'Grass'.

Habitat Type Code	Regime	Habitat Type Code	Regime	Habitat Type Code	Regime	Habitat Type Code	Regime
CAF211	–	CFS229	Shrub	CHF222	Forb	CHS611	Shrub
CAF311	–	CFS230	Shrub	CHF250	Forb	CHS612	Shrub
CAG211	–	CFS231	Shrub	CHF321	Forb	CHS613	Shrub
CAG311	–	CFS251	Shrub	CHF421	Forb	CHS614	Shrub
CAG312	–	CFS252	Shrub	CHM121	Forb	CHS615	Shrub
CAS211	–	CFS253	Shrub	CHS111	Shrub	CHS625	Shrub
CAS411	–	CFS254	Shrub	CHS113	Shrub	CHS626	Shrub
CDC711	Shrub	CFS255	Shrub	CHS114	Shrub	CMF250	Forb
CDC712	Shrub	CFS256	Shrub	CHS124	Shrub	CMF251	–
CDC713	Shrub	CFS257	Shrub	CHS125	Shrub	CMS114	Shrub
CDS211	Grass	CFS258	Shrub	CHS126	Shrub	CMS210	Shrub
CDS212	Grass	CFS259	Shrub	CHS127	Shrub	CMS216	Shrub
CDS213	Shrub	CFS260	Shrub	CHS128	Shrub	CMS218	Shrub
CDS641	Shrub	CFS351	Shrub	CHS129	Shrub	CMS221	Shrub
CFC251	Shrub	CFS352	Shrub	CHS130	Shrub	CMS223	Shrub
CFC311	Forb	CFS550	Shrub	CHS135	Shrub	CMS241	Shrub
CFF152	Forb	CFS551	Shrub	CHS140	Shrub	CMS244	Shrub
CFF153	Forb	CFS552	Shrub	CHS141	Shrub	CMS245	Shrub
CFF154	Forb	CFS554	Shrub	CHS223	Shrub	CMS246	Shrub
CFF250	Forb	CFS555	Shrub	CHS224	Forb	CMS250	Shrub
CFF253	Forb	CFS651	Shrub	CHS251	Shrub	CMS251	Shrub
CFF312	Forb	CFS652	Shrub	CHS325	Shrub	CMS252	Shrub
CFF450	Forb	CFS653	Shrub	CHS326	Shrub	CMS253	Shrub
CFM111	Forb	CFS654	Shrub	CHS327	Shrub	CMS254	Shrub
CFS110	Shrub	CHC212	Shrub	CHS328	Shrub	CMS255	Shrub
CFS151	Shrub	CHC213	Shrub	CHS351	Shrub	CMS350	Shrub
CFS152	Shrub	CHF111	Forb	CHS352	Shrub	CMS351	Shrub
CFS154	Shrub	CHF123	Forb	CHS353	Shrub	CMS352	Shrub
CFS216	Shrub	CHF124	Forb	CHS354	Shrub	CMS353	–
CFS221	Shrub	CHF125	Forb	CHS355	Shrub	CMS450	Shrub
CFS222	Shrub	CHF133	Forb	CHS511	Shrub	CMS612	Shrub
CFS223	Shrub	CHF134	Forb	CHS513	Shrub	CWF211	Shrub
CFS224	Shrub	CHF135	Forb	CHS522	Shrub	CWS521	Shrub
CFS225	Shrub	CHF151	Forb	CHS523	Shrub	CWS522	Shrub
CFS226	Shrub	CHF221	Forb	CHS524	Shrub		

If the **STATFUEL** keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.19.1 or Figure 4.19.2. The **FLAMEADJ** keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

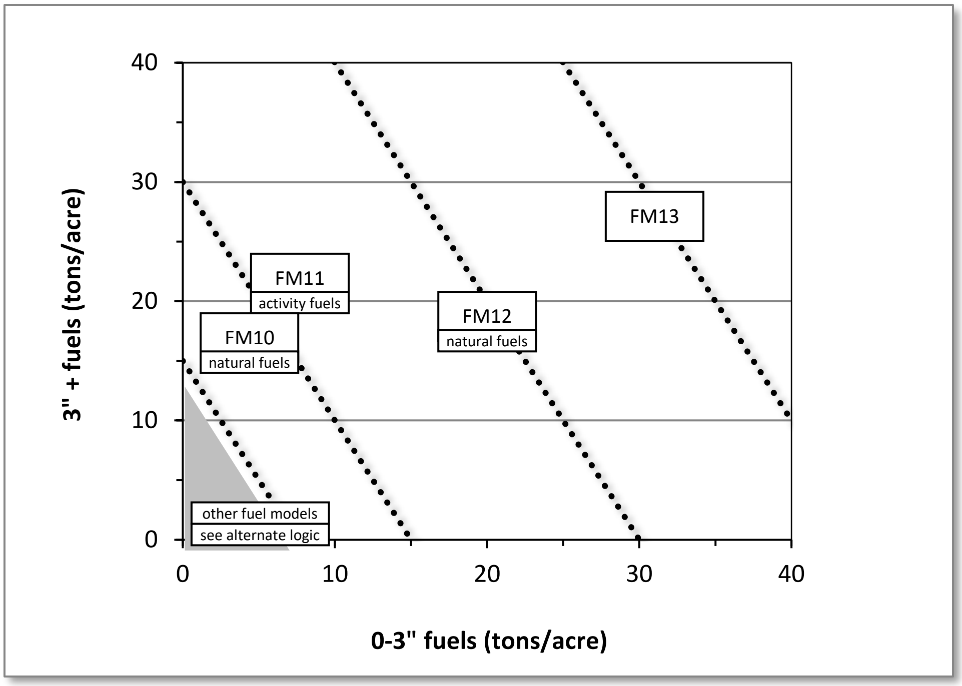


Figure 4.19.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.19.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description section 4.8 for further details).

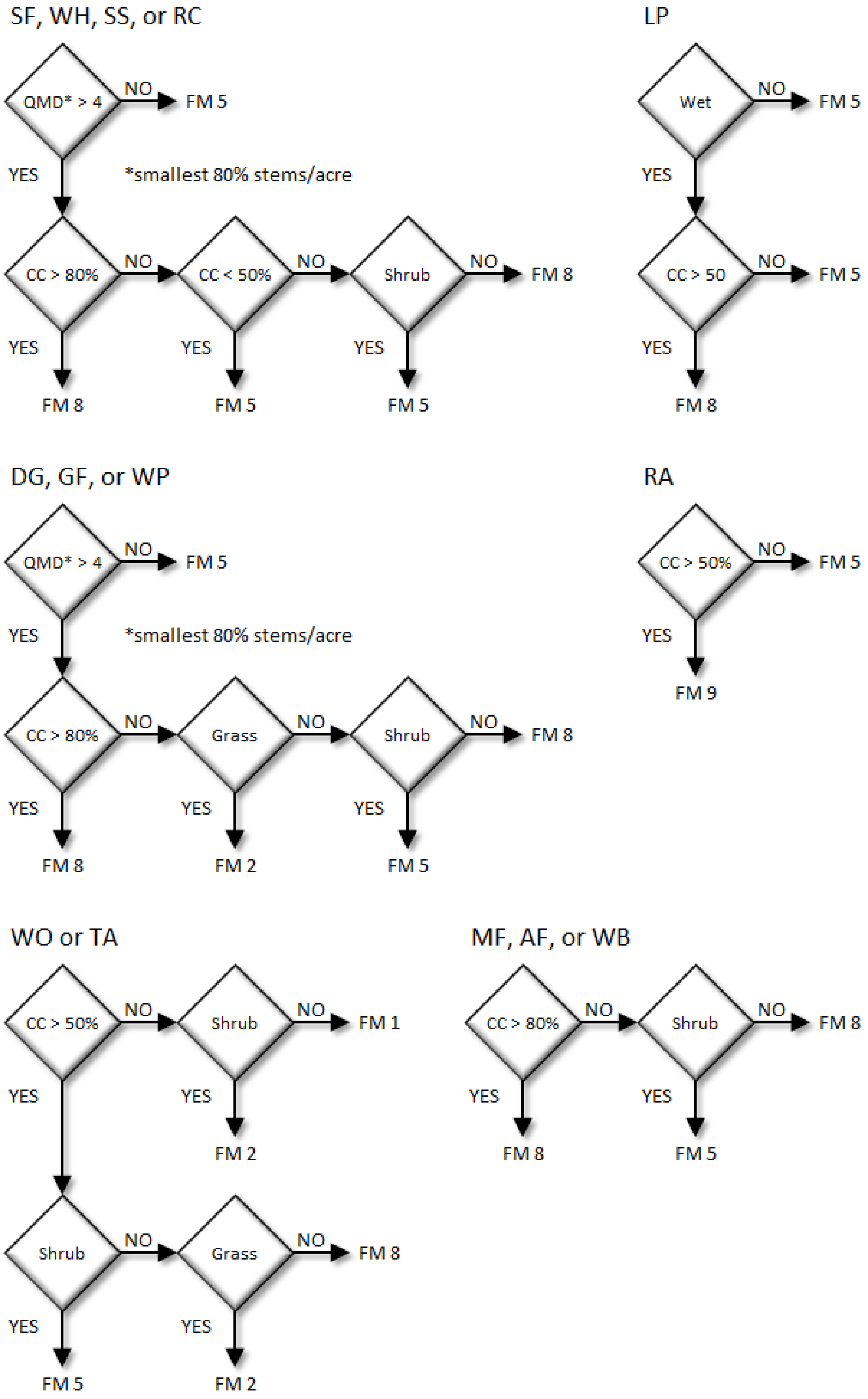


Figure 4.19.2 - Fuel models for the WC-FFE variant.

4.20 Western Sierras (WS)

4.20.1 Tree Species

The Western Sierras variant models the 41 tree species shown in Table 4.20.1. Two additional categories, 'other hardwood' and 'other softwood' are modeled using California black oak and lodgepole pine, respectively.

Table 4.20.1 - Tree species simulated by the Western Sierras variant.

Common Name	Scientific Name	Notes
sugar pine	*Pinus lambertiana*	
Douglas-fir	*Pseudotsuga menziesii*	
white fir	*Abies concolor*	
giant sequoia	*Sequoiadendron giganteum*	
incense cedar	*Calocedrus decurrens*	
Jeffrey pine	*Pinus Jeffreyi*	
California red fir	*Abies magnifica*	
ponderosa pine	*Pinus ponderosa*	
lodgepole pine	*Pinus contorta*	use CA lodgepole pine
whitebark pine	*Pinus albicaulis*	use CA/SO whitebark pine
western white pine	*Pinus monticola*	use CA/SO western white pine
singleleaf pinyon	*Pinus monophylla*	use Pinus sp (as done in UT)
Pacific silver fir	*Abies amabilis*	use SO Pacific silver fir
knobcone pine	*Pinus attenuate*	use CA knobcone pine
foxtail pine	*Pinus balfouriana*	use CA knobcone pine
Coulter pine	*Pinus coulteri*	use CA Coulter pine
limber pine	*Pinus flexilis*	use CA knobcone pine
Monterey pine	*Pinus radiata*	use CA Monterey pine
California foothill pine	*Pinus sabiniana*	use CA gray pine
Washoe pine	*Pinus washoensis*	use CA knobcone pine
Great Basin bristlecone pine	*Pinus longaeva*	use UT bristlecone pine
bigcone Douglas-fir	*Pseudotsuga macrocarpa*	use Douglas-fir
redwood	*Sequoia sempervirens*	use giant sequoia
mountain hemlock	*Tsuga mertensiana*	use CA/SO mountain hemlock
western juniper	*Juniperus occidentalis*	use CA western juniper
Utah juniper	*Juniperus osteosperma*	use CA western juniper
California juniper	*Juniperus californica*	use CA western juniper
California live oak	*Quercus agrifolia*	use CA California live oak
canyon live oak	*Quercus chrysolepsis*	use CA canyon live oak
blue oak	*Quercus douglasii*	use CA blue oak
California black oak	*Quercus kelloggii*	
valley oak	*Quercus lobata*	use CA valley oak
interior live oak	*Quercus wislizeni*	use CA interior live oak
tanoak	*Lithocarpus densiflorus*	
giant chinquapin	*Chrysolepis chrysophylla* var. *chrysophylla*	use CA/SO giant chinquapin
quaking aspen	*Populus tremuloides*	use CA/SO quaking aspen
California laurel	*Umbellularia californica*	use CA California laurel
Pacific madrone	*Arbutus menziesii*	use CA/NC Pacific madrone
Pacific dogwood	*Cornus nuttallii*	use CA Pacific dogwood
bigleaf maple	*Acer macrophyllum*	use CA/SO bigleaf maple
curl-leaf mountain mahogany	*Cercocarpus ledifolius*	use SO curl-leaf mtn mahogany
other softwood		use lodgepole pine
other hardwood		use California black oak

4.20.2 Snags

The majority of the snag model logic is based on unpublished data provided by Bruce Marcot (USFS, Portland, OR, unpublished data 1995). Snag fall parameters were developed at the WS-FFE workshop. A complete description of the Snag Submodel is provided in section 2.3.

Three variables are used to modify the Snag Submodel for the different species in the WS-FFE variant:

- A multiplier to modify the species' fall rate;
- The maximum number of years that snags will remain standing; and
- A multiplier to modify the species' height loss rate.

These variables are summarized in Table 4.20.2 and Table 4.20.3.

Unlike the some other FFE variants, snags in the WS-FFE do not decay from a hard to soft state. Users can initialize soft snags using the **SNAGINIT** keyword if they wish, but these initialized soft snags will eventually disappear as they are removed by snag fall. In addition, snags lose height only until they are reduced to half the height of the original live tree. The maximum standing lifetime for many snag species is set to 100 years (Mike Landram, USFS, Vallejo, CA, pers. comm., 2000).

Table 4.20.2 - Default snag fall, snag height loss and soft-snag characteristics for 20” DBH snags in the WS-FFE variant. These characteristics are derived directly from the parameter values shown in Table 4.20.3.

Species	**95% Fallen**	**All Down**	**50% Height**	**Hard-to-Soft**
	- - - - - - - - - -	- Years -	- - - - - - - - -	
sugar pine	25	100	30	–
Douglas-fir	35	100	30	–
white fir	35	100	30	–
giant sequoia	45	150	30	–
incense cedar	45	100	30	–
Jeffrey pine	25	100	30	–
California red fir	35	100	30	–
ponderosa pine	25	100	30	–
lodgepole pine	25	100	30	–
whitebark pine	25	100	30	–
western white pine	25	100	30	–
singleleaf pinyon	31	150	311	35
Pacific silver fir	35	100	30	–
knobcone pine	25	100	30	–
foxtail pine	25	100	30	–
Coulter pine	25	100	30	–
limber pine	25	100	30	–
Monterey pine	25	100	30	–
California foothill pine	25	100	30	–
Washoe pine	25	100	30	–
Great Basin bristlecone pine	–	–	658	35
bigcone Douglas-fir	35	100	30	–
redwood	45	150	30	–
mountain hemlock	25	100	30	–
western juniper	45	150	30	–
Utah juniper	45	150	30	–
California juniper	45	150	30	–
California live oak	20	50	30	–
canyon live oak	20	50	30	–
blue oak	20	50	30	–
California black oak	20	50	30	–
valley oak	20	50	30	–
interior live oak	20	50	30	–
tanoak	20	50	30	–
giant chinquapin	20	50	30	–
quaking aspen	20	50	30	–
California laurel	20	50	30	–
Pacific madrone	20	50	30	–
Pacific dogwood	20	50	30	–
bigleaf maple	20	50	30	–
curl-leaf mountain mahogany	31	90	30	39
other softwood	25	100	30	–
other hardwood	20	50	30	–

Note: For all species, soft snags do not normally occur; height loss stops at 50% of original height.

Table 4.20.3 - Default snag fall, snag height loss and soft-snag multipliers for the WS-FFE. These parameters result in the values shown in Table 4.20.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height Loss	Hard-to-Soft
sugar pine	1.235	1.00	–
Douglas-fir	0.882	1.00	–
white fir	0.882	1.00	–
giant sequoia	0.687	1.00	–
incense cedar	0.687	1.00	–
Jeffrey pine	1.235	1.00	–
California red fir	0.882	1.00	–
ponderosa pine	1.235	1.00	–
lodgepole pine	1.235	1.00	–
whitebark pine	1.235	1.00	–
western white pine	1.235	1.00	–
singleleaf pinyon	1.000	0.0978	0.9
Pacific silver fir	0.882	1.00	–
knobcone pine	1.235	1.00	–
foxtail pine	1.235	1.00	–
Coulter pine	1.235	1.00	–
limber pine	1.235	1.00	–
Monterey pine	1.235	1.00	–
California foothill pine	1.235	1.00	–
Washoe pine	1.235	1.00	–
Great Basin bristlecone pine	0.001	0.0462	0.9
bigcone Douglas-fir	0.882	1.00	–
redwood	0.687	1.00	–
mountain hemlock	1.235	1.00	–
western juniper	0.687	1.00	–
Utah juniper	0.687	1.00	–
California juniper	0.687	1.00	–
California live oak	1.545	1.00	–
canyon live oak	1.545	1.00	–
blue oak	1.545	1.00	–
California black oak	1.545	1.00	–
valley oak	1.545	1.00	–
interior live oak	1.545	1.00	–
tanoak	1.545	1.00	–
giant chinquapin	1.545	1.00	–
quaking aspen	1.545	1.00	–
California laurel	1.545	1.00	–
Pacific madrone	1.545	1.00	–
Pacific dogwood	1.545	1.00	–
bigleaf maple	1.545	1.00	–
curl-leaf mountain mahogany	1.000	1.00	1.0
other softwood	1.235	1.00	–
other hardwood	1.545	1.00	–

Note: For all species, soft snags do not normally occur; height loss stops at 50% of original height.

Snag bole volume is determined in using the base FVS model equations. The coefficients shown in Table 4.20.4 are used to convert volume to biomass.

4.20.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt 2003) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in section 2.4.

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and down woody debris (DWD). Live herb and shrub fuel load, and initial DWD are assigned based on the cover species with greatest basal area. If there is no basal area in the first simulation cycle (a 'bare ground' stand) then the initial fuel loads are assigned by the vegetation code provided with the **STDINFO** keyword. If the vegetation code is missing or does not identify an overstory species, the model uses a ponderosa pine cover type to assign the default fuels. If there is no basal area in other cycles of the simulation (after a simulated clearcut, for example) herb and shrub fuel biomass is assigned by the previous cover type.

Live Tree Bole: The fuel contribution of live trees is divided into two components: bole and crown. Bole volume is calculated by the FVS model, then converted to biomass using ovendry wood density values calculated from the green specific gravity values from Table 4-3a of The Wood Handbook (Forest Products Laboratory 1999). The coefficients in Table 4.20.4 for giant sequoia are based on 'Redwood Young-growth'; Douglas-fir is based on 'Douglas-fir Interior west.'

Table 4.20.4 - Wood density (ovendry lb/ft^3) used in the WS-FFE variant.

Species	Density (lb/ft^3)
sugar pine	21.2
Douglas-fir	28.7
white fir	23.1
giant sequoia	21.2
incense cedar	21.8
Jeffrey pine	21.2
California red fir	22.5
ponderosa pine	23.7
lodgepole pine	23.7
whitebark pine	22.5
western white pine	22.5
singleleaf pinyon	31.8
Pacific silver fir	24.9
knobcone pine	23.7
foxtail pine	23.7
Coulter pine	23.7
limber pine	22.5
Monterey pine	23.7
California foothill pine	23.7
Washoe pine	23.7
Great Basin bristlecone pine	23.7
bigcone Douglas-fir	28.7
redwood	21.2
mountain hemlock	26.2
western juniper	34.9
Utah juniper	34.9
California juniper	34.9
California live oak	49.9
canyon live oak	49.9
blue oak	37.4
California black oak	34.9
valley oak	37.4
interior live oak	49.9
tanoak	36.2
giant chinquapin	36.2
quaking aspen	21.8
California laurel	36.2
Pacific madrone	36.2
Pacific dogwood	27.4
bigleaf maple	27.4
curl-leaf mountain mahogany	21.8
other softwood	23.7
other hardwood	34.9

Tree Crown: As described in the section 2.4.3, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for most species in the WS-FFE. Some species mappings are used, as shown below in Table 4.20.5. California black oak and tanoak/giant chinquapin crown biomass equations are taken from new sources.

Table 4.20.5 - The crown biomass equations listed here determine the biomass of foliage and branches. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
sugar pine	western white pine (Brown and Johnston 1976)
Douglas-fir	Brown and Johnston 1976
white fir	grand fir (Brown and Johnston 1976)
giant sequoia	western redcedar for biomass, western hemlock for partitioning (Mike Lander, pers. comm.; Brown and Johnston 1976)
incense cedar	western redcedar (Brown and Johnston 1976)
Jeffrey pine	western white pine (Brown and Johnston 1976)
California red fir	grand fir (Brown and Johnston 1976)
ponderosa pine	Brown and Johnston 1976
lodgepole pine	Brown and Johnston 1976
whitebark pine	lodgepole pine (Brown and Johnston 1976)
western white pine	western white pine (Brown and Johnston 1976)
singleleaf pinyon	common pinyon; Grier and others (1992)
Pacific silver fir	grand fir (Brown and Johnston 1976)
knobcone pine	lodgepole pine (Brown and Johnston 1976)
foxtail pine	lodgepole pine (Brown and Johnston 1976)
Coulter pine	lodgepole pine (Brown and Johnston 1976)
limber pine	lodgepole pine (Brown and Johnston 1976)
Monterey pine	ponderosa pine (Brown and Johnston 1976)
California foothill pine	lodgepole pine (Brown and Johnston 1976)
Washoe pine	lodgepole pine (Brown and Johnston 1976)
Great Basin bristlecone pine	common pinyon; Chojnacky (1999), Grier and others (1992)
bigcone Douglas-fir	Douglas-fir (Brown and Johnston 1976)
redwood	western redcedar for biomass, western hemlock for partitioning (Mike Lander, pers. comm.; Brown and Johnston 1976)
mountain hemlock	western hemlock (Brown and Johnston 1976); Gholz and others 1979
western juniper	oneseed juniper (Grier and others 1992)
Utah juniper	oneseed juniper (Grier and others 1992)
California juniper	oneseed juniper (Grier and others 1992)
California live oak	tanoak (Snell and Little 1983, Snell 1979)
canyon live oak	tanoak (Snell and Little 1983, Snell 1979)
blue oak	California black oak (Snell and Little 1983, Snell 1979)
California black oak	Snell and Little 1983; Snell 1979
valley oak	California black oak (Snell and Little 1983, Snell 1979)
interior live oak	tanoak (Snell and Little 1983, Snell 1979)
tanoak	Snell and Little 1983, Snell 1979
giant chinquapin	tanoak (Snell and Little 1983, Snell 1979)
quaking aspen	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
California laurel	tanoak (Snell and Little 1983, Snell 1979)
Pacific madrone	Snell and Little 1983
Pacific dogwood	Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
bigleaf maple	Snell and Little 1983
curl-leaf mountain mahogany	aspen; Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
other softwood	lodgepole pine (Brown and Johnston 1976)
other hardwood	California black oak (Snell and Little 1983, Snell 1979)

Live leaf lifespan is used to simulate the contribution of needles and leaves to annual litter fall. Dead foliage and branch materials also contribute to litter fall, at the rates shown in Table 4.20.6. Each year the inverse of the lifespan is added to the litter pool from each biomass category. These data are from the values provided at the WS-FFE workshop.

Table 4.20.6 - Life span of live and dead foliage (yr) and dead branches for species modeled in the WS-FFE variant.

Species	Live	Dead			
	Foliage	Foliage	<0.25”	0.25–1”	> 1”
sugar pine	3	3	10	15	15
Douglas-fir	5	3	10	15	15
white fir	7	3	10	15	15
giant sequoia	5	3	10	15	20
incense cedar	5	1	10	15	20
Jeffrey pine	3	3	10	15	15
California red fir	7	3	10	15	15
ponderosa pine	3	3	10	10	10
lodgepole pine	3	3	10	15	15
whitebark pine	3	3	10	15	15
western white pine	3	3	10	15	15
singleleaf pinyon	3	2	10	15	15
Pacific silver fir	7	3	10	15	15
knobcone pine	4	3	10	15	15
foxtail pine	4	3	10	15	15
Coulter pine	3	3	10	15	15
limber pine	3	3	10	15	15
Monterey pine	3	3	10	15	15
California foothill pine	3	3	10	15	15
Washoe pine	4	3	10	15	15
Great Basin bristlecone pine	3	3	10	15	20
bigcone Douglas-fir	5	3	10	15	15
redwood	5	3	10	15	20
mountain hemlock	4	3	10	15	15
western juniper	4	3	10	15	20
Utah juniper	4	3	10	15	20
California juniper	4	3	10	15	20
California live oak	1	1	10	15	15
canyon live oak	1	1	10	15	15
blue oak	1	1	10	15	15
California black oak	1	1	10	15	15
valley oak	1	1	10	15	15
interior live oak	1	1	10	15	15
tanoak	1	1	10	15	15
giant chinquapin	1	1	10	15	15
quaking aspen	1	1	10	15	15
California laurel	1	1	10	15	15
Pacific madrone	1	1	10	15	15
Pacific dogwood	1	1	10	15	15
bigleaf maple	1	1	10	15	15
curl-leaf mountain mahogany	1	1	10	15	15
other softwood	3	3	10	15	15
other hardwood	1	1	10	15	15

Live Herbs and Shrubs: Live herb and shrub fuels are modeled very simply. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.20.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.20.7). When canopy cover is >60 percent, biomass is assigned an “established” value (the ‘E’ rows). Live fuel loads are linearly interpolated when canopy cover is between 10 and 60 percent. When more than one species is present, the final estimate is computed by combining the interpolated estimates from the rows (Table 4.20.7) representing the two dominant species. Those two estimates are themselves weighted by the relative amount of the two dominant species. Data are based on NI-FFE data taken from FOFEM 4.0 (Reinhardt and others 1997) with modifications provided by

Jim Brown, USFS, Missoula, MT (pers. comm., 1995). Hardwood estimates are from Ottmar and others (2000b). Pinyon and juniper estimates are from Ottmar and others (2000a) and Ottmar and others (1998). Many of the minor species are unlikely to be dominant. In these cases, values of the likely dominant overstory are used.

Table 4.20.7 - Values (dry weight, tons/acre) for live fuels used in the WS-FFE. Biomass is linearly interpolated between the "initiating" (I) and "established"(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
sugar pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
Douglas-fir	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
white fir	E	0.15	0.10	Grand fir, NI-FFE
	I	0.30	2.00	
giant sequoia	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
incense cedar	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
Jeffrey pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
California red fir	E	0.15	0.10	grand fir, NI-FFE
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	based on NI-FFE
	I	0.25	1.00	
lodgepole pine	E	0.20	0.10	based on NI-FFE
	I	0.40	1.00	
whitebark pine	E	0.20	0.10	based on lodgepole pine, NI-FFE
	I	0.40	1.00	
western white pine	E	0.15	0.10	based on NI-FFE
	I	0.30	2.00	
singleleaf pinyon	E	0.04	0.05	use UT singleleaf pinyon: Ottmar and others (2000a)
	I	0.13	1.63	
Pacific silver fir	E	0.15	0.10	use white fir
	I	0.30	2.00	
knobcone pine	E	0.20	0.10	based on lodgepole pine, NI-FFE
	I	0.40	1.00	
foxtail pine	E	0.20	0.10	based on lodgepole pine, NI-FFE
	I	0.40	1.00	
Coulter pine	E	0.20	0.10	based on lodgepole pine, NI-FFE
	I	0.40	1.00	
limber pine	E	0.20	0.10	based on lodgepole pine, NI-FFE
	I	0.40	1.00	
Monterey pine	E	0.20	0.20	based on Douglas-fir, NI-FFE
	I	0.40	2.00	
California foothill pine	E	0.23	0.22	use CA gray pine: Gambel oak, Ottmar and others (2000b)
	I	0.55	0.35	
Washoe pine	E	0.20	0.10	based on lodgepole pine, NI-FFE
	I	0.40	1.00	
Great Basin bristlecone pine	E	0.04	0.05	use UT bristlecone: pinyon, Ottmar and others (2000a)
	I	0.13	1.63	
bigcone Douglas-fir	E	0.20	0.20	use Douglas-fir
	I	0.40	2.00	
redwood	E	0.20	0.20	use giant sequoia
	I	0.40	2.00	
mountain hemlock	E	0.15	0.20	subalpine fir, NI-FFE
	I	0.30	2.00	
western juniper	E	0.14	0.35	

Species		Herbs	Shrubs	Notes
	I	0.10	2.06	use CA western juniper, Ottmar and others (1998)
Utah juniper	E	0.14	0.35	use CA western juniper, Ottmar and others (1998)
	I	0.10	2.06	
California juniper	E	0.14	0.35	use CA western juniper, Ottmar and others (1998)
	I	0.10	2.06	
California live oak	E	0.23	0.22	use CA California live oak: Gambel oak, Ottmar and others (2000b)
	I	0.55	0.35	
canyon live oak	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	
blue oak	E	0.23	0.22	use CA blue oak: Gambel oak, Ottmar and others (2000b)
	I	0.55	0.35	
California black oak	E	0.23	0.22	Gambel oak, CR-FFE, Ottmar and others (2000b)
	I	0.55	0.35	
valley oak	E	0.23	0.22	use CA California white / valley oak: Gambel oak, Ottmar and others (2000b)
	I	0.55	0.35	
interior live oak	E	0.23	0.22	use CA interior live oak: Gambel oak, Ottmar and others (2000b)
	I	0.55	0.35	
tanoak	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	
giant chinquapin	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b (modified)
	I	0.18	2.00	
quaking aspen	E	0.25	0.25	Ottmar and others 2000b
	I	0.18	1.32	
California laurel	E	0.20	0.20	based on Douglas-fir, NI-FFE
	I	0.40	2.00	
Pacific madrone	E	0.20	0.20	based on Douglas-fir, NI-FFE
	I	0.40	2.00	
Pacific dogwood	E	0.20	0.20	based on Douglas-fir, NI-FFE
	I	0.40	2.00	
bigleaf maple	E	0.20	0.20	based on Douglas-fir, NI-FFE
	I	0.40	2.00	
curl-leaf mountain mahogany	E	0.25	0.25	Use quaking aspen - Ottmar and others 2000b
	I	0.18	1.32	
other softwood	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
other hardwood	E	0.23	0.22	use California black oak: Gambel oak, Ottmar and others (2000b)
	I	0.55	0.35	

Dead Fuels: Initial default DWD pools are based on overstory species. When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand. Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.20.8). Hardwood estimates are from Ottmar and others (2000b). Pinyon and juniper estimates are from Ottmar and others (2000a) and Ottmar and others (1998). If tree canopy cover is <10 percent, the DWD pools are assigned an “initiating” value and if cover is >60 percent they are assign the “established” value. Fuels are linearly interpolated when canopy cover is between 10 and 60 percent. When more than one species is present, the final estimate is computed by combining the interpolated estimates from the rows (Table 4.20.8) representing the two dominant species. Those two estimates are themselves weighted by the relative amount of the two dominant species. All down wood in the > 12” column is put into the 12 – 20” size class. Initial fuel loads can be modified using the **FUELINIT** and **FUELSOFT** keywords.

Table 4.20.8 - Canopy cover and cover type are used to assign default down woody debris (tons/acre) by size class for established (E) and initiating (I) stands. The loadings below are put in the hard down wood categories; soft down wood is set to 0 by default.

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
sugar pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
giant sequoia	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
incense cedar	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Jeffrey pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
California red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
ponderosa pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
lodgepole pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
whitebark pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
singleleaf pinyon	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
Pacific silver fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
knobcone pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
foxtail pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Coulter pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
limber pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Monterey pine	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California foothill pine	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
Washoe pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Great Basin bristlecone pine	E	0.2	0.8	2.3	1.4	3.0	0.0	0.5	0.0
	I	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
bigcone Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
redwood	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
western juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0
Utah juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0
California juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
California live oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
canyon live oak	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
blue oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
California black oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
valley oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
interior live oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
tanoak	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
giant chinquapin	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
California laurel	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Pacific madrone	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Pacific dogwood	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
bigleaf maple	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
curl-leaf mountain mahogany	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other softwood	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
other hardwood	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0

4.20.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.20.9 are used to calculate single bark thickness and are used in the mortality equations (section 2.5.5). The bark thickness equation used in the mortality equation is unrelated to the bark thickness used in the base FVS model. Data are from FOFEM 5.0 (Reinhardt 2003).

Table 4.20.9 - Species specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
sugar pine	0.072
Douglas-fir	0.063
white fir	0.048
giant sequoia	0.081
incense cedar	0.060
Jeffrey pine	0.068
California red fir	0.039
ponderosa pine	0.063
lodgepole pine	0.028
whitebark pine	0.030
western white pine	0.035
singleleaf pinyon	0.030
Pacific silver fir	0.047
knobcone pine	0.030
foxtail pine	0.030
Coulter pine	0.063
limber pine	0.030
Monterey pine	0.030
California foothill pine	0.033
Washoe pine	0.030
Great Basin bristlecone pine	0.030
bigcone Douglas-fir	0.063
redwood	0.081
mountain hemlock	0.040
western juniper	0.025
Utah juniper	0.025
California juniper	0.025
California live oak	0.050
canyon live oak	0.024
blue oak	0.033
California black oak	0.030
valley oak	0.043
interior live oak	0.034
tanoak	0.052
giant chinquapin	0.045
quaking aspen	0.044
California laurel	0.026
Pacific madrone	0.060
Pacific dogwood	0.062
bigleaf maple	0.024
curl-leaf mountain mahogany	0.044
other softwood	0.028
other hardwood	0.030

4.20.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class class as described in section 2.4.5 (Table 4.20.10). Default decay rates are based on what was used in the Sierra Nevada Framework.

Table 4.20.10 - Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.025	0.02
0.25 – 1		
1 – 3		
3 – 6	0.0125	
6 – 12		
> 12		
Litter	0.5	
Duff	0.002	0.0

The default decay rates are modified by incorporating information from the R5 site class. The multipliers shown in Table 4.20.11 modify the default decay rates of Table 4.20.10 to by incorporating a measure of site quality and moisture availability.

Table 4.20.11 - The WS-FFE modifies default decay rate (Table 4.7.10) using R5 Site Code to improve simulated decomposition. Lower R5 Site Classes indicate moister sites.

R5 Site Class	Multiplier
0	1.5
1	1.5
2	1.0
3	1.0
4	1.0
5	0.5
6	0.5
7	0.5

By default, FFE decays all wood species at the rates shown in Table 4.20.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.20.12 using the **FUELDCAY** keyword. Users can also reassign species to different classes using the **FUELPOOL** keyword.

Table 4.20.12 - Default wood decay classes used in the WS-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or

nonresistant). Modified decay classes for California black oak, tanoak/giant chinquapin and other hardwoods were adopted at a WS-FFE review workshop (Stephanie Rebain, pers. comm., February 2003)

Species	Decay Class
sugar pine	4
Douglas-fir	3
white fir	4
giant sequoia	2
incense cedar	2
Jeffrey pine	4
California red fir	4
ponderosa pine	4
lodgepole pine	4
whitebark pine	4
western white pine	4
singleleaf pinyon	4
Pacific silver fir	4
knobcone pine	4
foxtail pine	4
Coulter pine	4
limber pine	4
Monterey pine	4
California foothill pine	4
Washoe pine	4
Great Basin bristlecone pine	4
bigcone Douglas-fir	3
redwood	2
mountain hemlock	4
western juniper	2
Utah juniper	2
California juniper	2
California live oak	2
canyon live oak	2
blue oak	2
California black oak	2
valley oak	2
interior live oak	2
tanoak	4
giant chinquapin	4
quaking aspen	4
California laurel	2
Pacific madrone	3
Pacific dogwood	4
bigleaf maple	2
curl-leaf mountain mahogany	4
other softwood	4
other hardwood	2

4.20.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption. Users can choose from four predefined moisture groups shown in Table 4.20.13, or they can specify moisture conditions for each class using the **MOISTURE** keyword.

Table 4.20.13 - Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1 hr.)	3	8	12	12
0.25 – 1.0 in. (10 hr.)	4	8	12	12
1.0 – 3.0 in. (100 hr.)	5	10	14	14
> 3.0 in. (1000+ hr.)	10	15	25	25
Duff	15	50	125	125
Live	70	110	150	150

4.20.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are determined in two steps: determination of cover classification and determination of dominant species. The first step uses tree cover attributes classified by the California Wildlife Habitat Relationships (CWHR) system (Mayer and Laudenslayer 1988) shown in Table 4.20.14. The Table classifies stands by their canopy cover and the size of the larger trees in the stand, predicting CWHR size class and CWHR density class3 (the third and fourth columns).

Table 4.20.14 - California Wildlife Habitat Relationships, as defined by Mayer and Laudenslayer (1988).

Tree size (DBH in.)*	Canopy cover (%)	CWHR Size Class	CWHR Density Class	Stand Description
< 1	< 10	1	–	Seedlings
1 - 6	10 – 24	2	S	Sapling – sparse
1 - 6	25 – 39	2	P	Sapling – open cover
1 - 6	40 – 59	2	M	Sapling – moderate cover
1 - 6	> 60	2	D	Sapling – dense cover
6 – 11	10 – 24	3	S	Pole tree – sparse
6 – 11	25 – 39	3	P	Pole tree – open cover
6 – 11	40 – 59	3	M	Pole tree – moderate cover
6 – 11	> 60	3	D	Pole tree – dense cover
11 – 24	10 – 24	4	S	Small tree – sparse
11 – 24	25 – 39	4	P	Small tree – open cover
11 – 24	40 – 59	4	M	Small tree – moderate cover
11 – 24	> 60	4	D	Small tree – dense cover
> 24	10 – 24	5	S	Med/Lg tree – sparse
> 24	25 – 39	5	P	Med/Lg tree – open cover
> 24	40 – 59	5	M	Med/Lg tree – moderate cover
> 24	> 60	5	D	Med/Lg tree – dense cover
> 24	> 60	6	–	Multi-layer canopy, dense cover
*QMD of the 75 percent largest trees based on basal area.				

The WS-FFE modifies the internal CWHR logic slightly, making use of two additional measures internal to the CWHR: unadjusted percent canopy cover and overlap-adjusted percent canopy cover, respectively. The two kinds of canopy estimate are used in combination with the CWHR logic to create weights for the predicted CWHR density class. Each stand's CWHR density class becomes a combination of one or two adjacent classes. Figure 4.20.1 shows how the two measures are used to weight the S, P, M or D classes at each timestep of the simulation. When a point (defined by the two kinds of canopy cover estimate) lies on a dashed line in the figure, that CWHR density class is given a 100% weight. Otherwise, the distance from the point to the nearest dashed lines is used to create weights for the nearest CWHR density classes.

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[3] A BASIC-language function named 'CWHRSizeDensity' was provided at the WS-FFE workshop. This function is incorporated into the WS-FFE with some minor housekeeping modifications.

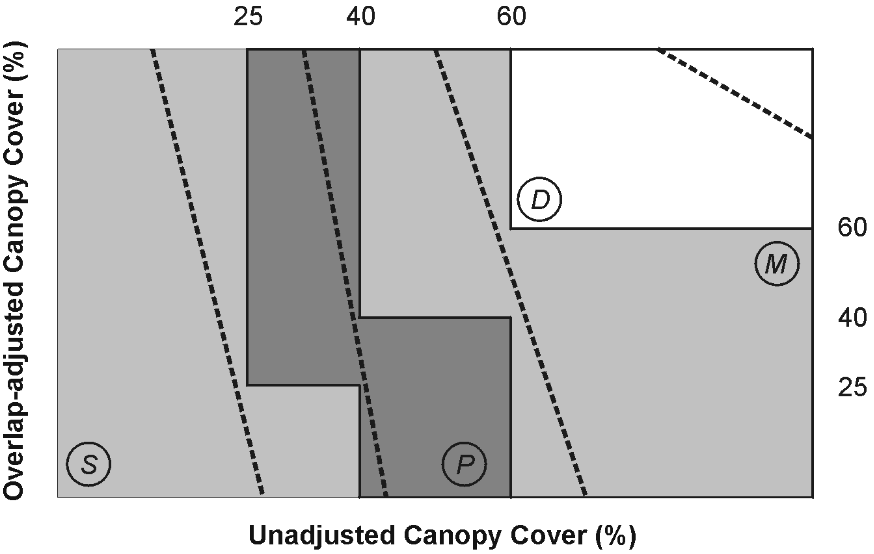

Figure 4.20.1 - Two measures of canopy cover, unadjusted and overlap-adjusted percent canopy cover, are used to deriveweighted estimates of the four CWHR density classes. (S = sparse, P = open, M = moderate and D = dense)

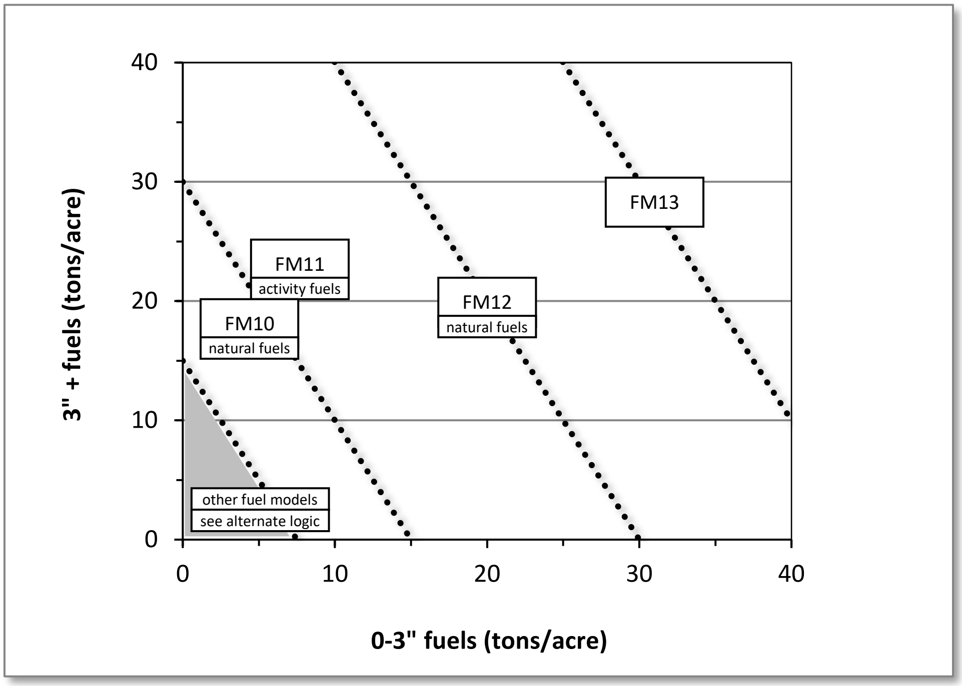

Figure 4.20.2 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.20.15. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

The second step determines the dominant species. A species is considered dominant if it comprises more than 80 percent of the stand basal area. The search starts with pine and moves down the column of forest types listed in the leftmost column of Table 4.20.15. If no species is dominant, then fir-mixed conifer is the default cover type.

The rules governing Table 4.20.15 select one or two candidate (usually low) fuel models. These are used along with the high fuels models to select the final set of weighted fuel models. The table has been modified from Landram's original table so that with the exception of the right-most column (mature Size Class 6 stands), cells with fuel model 10 or 12 in the original table have been replaced with fuel model 8. This change was made so that when appropriate, the default FFE fuel model logic (described in section 2.4.8) is not constrained in its selection of a candidate high fuel models: combinations of fuel models 10, 11,12 and 13 may still be selected when fuel loads are high. Finally, in order to give Table 4.20.15 priority, FM10 is removed from the list of candidate models when FM11 has been selected from the table.

Fuel models 25 and 26 are custom fire models developed in California and are described fully in Table 2.4.8. Model 25 is used to describe fire behavior in plantations greater than 25 years old with shrub understory and low crown mass. Model 26 is used on sites similar to those where Model 4 would be used but with lower fuelbed depth and loading.

In some situations a thinning or disturbance may cause one of the selected fuel models to switch from FM8 or FM9 to FM5 or FM26. When this happens, the transition to these brush fuel models is modified to simulate a delay in brush ingrowth. In the case where an FM8 or FM9 fuel model is predicted to change to FM5, the change is made over five years, gradually shifting from FM8 or FM9 to FM5. In the case where the fuel model is predicted to change to FM26, the model first changes to FM5 over 5 years, and then changes to FM26 over the next 10 years, finally resulting in FM 26 15 years after the initial disturbance.

Finally, flame length is calculated using the weights from above the appropriate fuel models. The **FLAMEADJ** keyword allows users to scale the calculated flame length or override the calculated flame length with a value they choose.

Table 4.20.15 - Fire behavior fuels models for the WS-FFE are determined using forest type and CWHR class, as described in the text. The modeling logic allows one or more fuel models to be selected.

Size Class	**1**	**2**				**3**				**4**				**5**				**6**
Density Class		**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	
Forest Type																		
Pine – east side	9	2	2	9	9	2	2	2	9	2	2	8	8	2	2	8	8	10
Pine – west side	9	5	5	9	9	26	26	25	9	26	26	8	8	26	26	8	8	10
Red fir	8	8	8	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
White fir – east side	8	8	8	8	8	11	11	11	8	8	8	8	8	8	8	8	8	10
White fir – west side	8	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
Douglas-fir	8	5	5	8	8	5	5	8	8	11	11	9	8	11	11	9	8	10
Giant sequoia	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	10
Jeffrey pine	9	9	9	9	9	2	2	2	9	2	2	2	9	2	2	2	9	10
Hardwoods	8	5	5	9	9	11	11	11	9	9	9	9	9	9	9	9	9	10
Lodgepole pine	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	10
Pine mixed – conifer	9	5	5	9	9	26	26	25	9	26	26	8	8	26	26	8	8	10
Fir mixed – conifer	8	9	9	8	8	26	26	11	8	5	5	8	8	5	5	8	8	10
Other softwood	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	10

Appendix A P-Torch

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DRAFT: April 25, 2004

A new stand-level torching index is introduced. The index estimates the probability of finding a torching situation in a forest stand. A torching situation is generally defined as one where tree crowns of significantly large trees are ignited by the flames of a surface fire or flames from burning crowns of small trees that reach the larger trees. The proportion of small places where torching is possible is estimated using a Monte Carlo simulation technique. This estimate is called P-Torch and is reported as the percentage of small places in a stand where torching can occur, given specific surface fire intensity, which in turn depends on surface fuel characteristics, moisture, and windspeed.

This report says why a new torching index is needed, describes how the index is computed, displays some examples, and summarizes its features and differences between it and torching index.

A.1 Introduction

Will a surface fire stay on the surface? If it ignites the crowns of one or a group of trees, it is called a torching, passive, or candling fire. Torching fires have more extreme fire intensity and more radical effects than surface fires—assessing the likelihood of torching is an important part of assessing potential fire behavior (Scott and Reinhardt 2001). Torching fires are distinguished from more serious active crown fires that burn continuously through the forest canopy. They are ignited by surface fires and can be responsible for creating an active crown fire.

Scott and Reinhardt (2001) proposed a way to assess the hazard of both these kinds of fires by introducing Torching Index (TI) and Crowning Index (CI). Both these indices are outputs of the Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS, Reinhardt and Crookston 2003). Scott and Reinhardt (2001, p17) say that TI is the windspeed at which crown fires are expected to initiate, computed as "a function of surface fuel characteristics (fuel model), surface fuel moisture contents, foliar moisture content, canopy base height, slope steepness, and wind reduction by the canopy." High values of TI imply a low risk of torching.

TI is quite sensitive to canopy base height (CBH). When it is computed in the context of FFE-FVS, CBH is a stand average value. CBH is difficult to assess at a stand level, however. As computed in FFE-FVS, canopy base height is the lowest height at which a threshold amount of canopy biomass occurs. The threshold value is arbitrarily set at 30 lbs/acre/ft. When stand development is simulated over time, predicted CBH often fluctuates dramatically, causing unrealistic erratic behavior in predicted TI. To understand what can happen, imagine a well-stocked, single-storied stand with medium sized trees and a CBH of about 20 feet. In this case, TI is often predicted to be a relatively large number indicating a low hazard of torching. Now, further imagine that there is one full-crown 20-foot tall tree below the larger trees. If this tree causes the 30 lbs/acre/ft threshold to be exceeded, the CBH drops to ground level. At that point, any surface fire will cause torching and the predicted TI drops radically. Sometimes, the number of small trees, and therefore the amount of biomass near ground level, will hover near the threshold. Then, if a single tree dies, TI will radically increase, only to be followed by another tree growing large enough to cause TI to radically decrease. Several threshold values have been tried, and a number of modifications to the algorithm for computing CBH have been made. These adjustments have only transferred the problem from one stand to another. Experience has shown that many stands have conditions that exhibit radically changing CBH and uninformative radical changes in predicted TI.

A.2 P-Torch Defined

P-Torch was developed to address this difficulty. It is the probability of finding a small place where torching can happen in a forest stand. A torching situation is generally defined as one where tree crowns of significantly large trees can be ignited by the flames of a surface fire or flames from burning crowns of small trees that reach the larger trees. P-Torch is the proportion of small places where trees are present and torching is possible. Like TI, P-Torch requires a set of fire conditions: surface fuels, fuel moisture, and windspeed, but does not rely on an estimate of stand level CBH, as TI does.

A.2.1 Details

A small place where torching can happen is defined as a randomly located 0.025-acre (about 33 feet by 33 feet, or 10 m by 10 m) virtual plot that satisfies following conditions:

A surface fire must be intense enough to ignite tree crowns of smaller trees that in turn ignite the crowns of larger trees, or where large trees have long crowns that are directly ignited by the surface fire.

The height of the largest tree ignited must be greater than 50 percent of the stand top height (top height is the average height of the largest 40 trees per acre), or 50 feet, which ever is smaller. Furthermore, the size of the largest tree ignited must be greater than five feet.

Thirty virtual plots are generated and populated with sample trees using the following logic. Let TPAi be number of trees per acre represented for sample tree i and let Xi be the number of these sample trees on a specific virtual plot. Sample tree i is considered to be on the virtual plot if one or more are on the virtual plot. The probability that one or more trees are on the plot is:

$\Pr(X_i \geq 1) = 1 - \Pr(X_i = 0)$. The Poisson distribution (Evans and others 2000, p. 155) can be used to compute this probability under the assumption that the trees and the virtual plots are randomly distributed in space. That is, $\Pr(X_i = x) = \lambda_i^x \exp(-\lambda_i)/x!$ where λi is the average number of sample trees expected on the virtual plot ($\lambda_i = 0.025 \times TPA_i$). Note that $\Pr(X_i = 0) = \lambda_i^0 \exp(-\lambda_i)/0! = \exp(-\lambda_i)$ and therefore, $\Pr(X \geq 1) = 1 - \exp(-\lambda_i)$. To decide that tree i is on the virtual plot a uniform random number is generated and compared to this probability.

Once each virtual plot is populated with trees, the program computes Hj, the height of crown material a surface fire must be capable of igniting to cause torching on virtual plot j. This calculation is done by checking the vertical distribution of tree crowns on the plot. Assumptions are that a small tree can cause the branches of a taller tree to ignite if the bottom of the taller tree's crown is lower than 1.25 times the height of the smaller tree. The foliage density of the trees and horizontal distance between them is not considered. When no trees are present, Hj = ∞.

Next, Tj, the probability that a surface fire can torch virtual plot j is computed. This probability depends on two key assumptions. The first is that a flame of length F can ignite a tree crown that is further off the ground than the flame is long. Let $I = (F / 0.0775)^{1.45} / 30.5$ be the height off the ground a flame of length F can ignite (Figure A.2.1). This relationship is based on the discussion in Scott and Reinhardt (2001, p13).

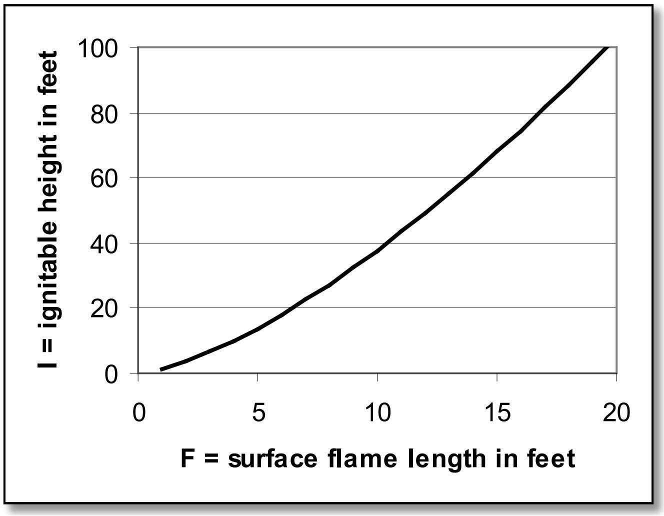

Figure A.2.1 - The relationship between surface flame length (F) and the height off the ground that flame can ignite (I).

The second assumption is that the distribution of I within a stand is lognormal with a constant standard deviation of 0.25. Figure A.2.2 illustrates the probability function used in this calculation for two values of I. When I=5 feet, the probability that a plot will torch (T) is nearly 1.0 for values of Hj between 0.0 and 3.0. When values of Hj exceed 8.5 feet the chance they will torch is very low. When I=10 feet, the probability that a plot will torch is nearly 1.0 until the value of Hj is greater than 6.0 and falls to nearly zero at about 18. Note that the curves are steeper for small values of I compared to large values.

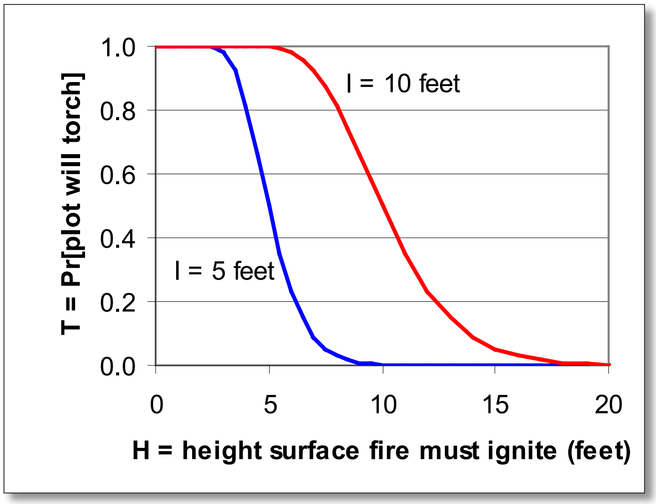

Figure A.2.2 - The probability that plot j will torch (Tj) is illustrated for two values of average ignition height (I). Hj is the height the surface fire must be able to ignite (feet) and is a function of the vertical crown structure on virtual plot j.

The actual calculations are done using Wichura's (1988) method to compute the percentage points in the normal distribution and the relationship between the normal and lognormal cumulative distribution functions.

Once Tj is known for each plot, P-Torch (Pr[Torch]) is computed as the sum of the products of a plot torching and the virtual plot sampling probability (1/N where N is the number of virtual plots), as follows:

$$\Pr[Torch] = \sum_{i=1}^{N} T_i \times \frac{1}{N}.$$

A.2.2 Sensitivity to conditions.

The advantage of P-Torch over TI is that it does not rely on the calculation of stand level CBH. In addition, P-Torch is not overly sensitive to small changes in the number of small trees. Yet it is sensitive to the flame length and key processes in stand development—the development of an understory, the decline of old overstory trees, and crown recession. Management actions that modify these key processes modify the predicted value of P-Torch in realistic ways.

P-Torch can be very sensitive to flame length. When several virtual plots have about the same value of H and I is about equal to H, small changes in I can create large changes in P-Torch.

A.3 Examples

A major problem in devising an index like P-Torch is that the correct answer is difficult to observe. Acceptance of the index depends on creating one that is relevant to the professionals that use it. Looking at many runs and forming an opinion is the first step toward evaluating the index's utility. Two examples are presented to illustrate some of the impressions gained by computing P-Torch each year of 100-year projections on hundreds of stands.

Example 1: Stand 3024006

The first example is from a mesic, grand fir stand from the Colville National Forest. Besides grand fir, the stand contains Douglas-fir and western larch, with cedar and hemlock in the understory. Fire is not a major part of the natural ecology of stands like this example as the fire return interval is 100+ years. Nonetheless, the example illustrates important features of both TI and P-Torch. Figure A.3.1 illustrates the predicted TI and P-Torch values for this stand under two regimes, one without any management and the other with a prescription designed to reduce the risk of torching. Both indices indicate that torching is a potential problem. TI indicates that the hazard diminishes by 2040 but P-Torch indicates that the hazard is high throughout the simulation period. To reduce the hazard, two prescribed fires were simulated, both with moderately wet fuel conditions. The fires were set to burn at 10 and 20 years into the simulation. Both indices show that the fires had an immediate effect of reducing torching hazard. The first fire burned surface fuels and caused a lot of understory mortality. After the first fire, the addition of unconsumed-killed trees to the surface fuels caused the hazard to increase. The second fire cleaned up these fuels and killed off the understory that was stimulated by the first fire. P-Torch indicates that the strategy worked resulting in the long-term reduction of torching hazard. TI indicates that the strategy failed; at 2062, TI changed from 189 to zero miles per hour of wind. This change is completely attributable to a change in stand level CBH.

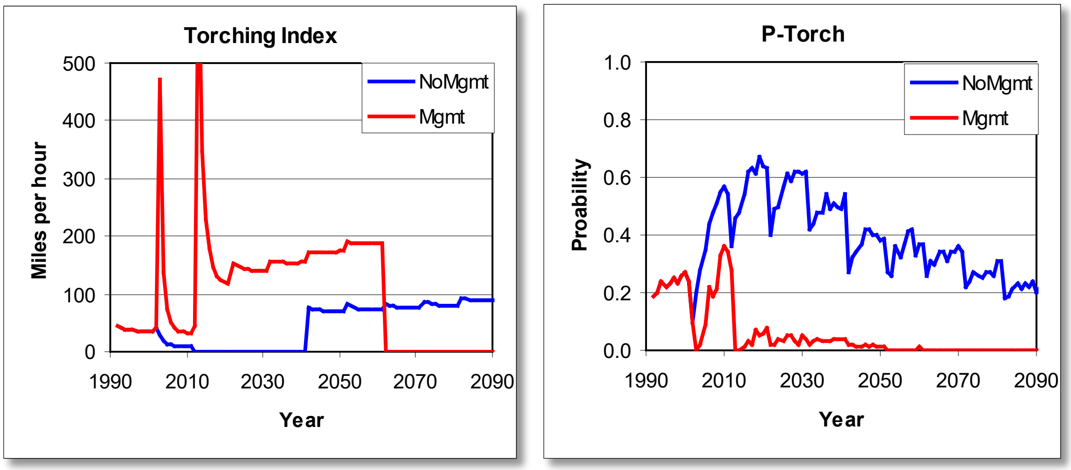

Figure A.3.1 - TI and P-Torch for stand 3024006. Both indices indicate that prescribed fire reduced the hazard of torching, but TI showed that the hazard greatly increased in 2062 when a few understory trees caused the CBH to drop to zero. P-Torch more realistically indicates that those trees do not adversely increase the torching hazard.

Figure A.3.2 and Figure A.3.3 show how this stand might look 10 years after the prescribed fires. Comparing the overstory confirms that the fires killed few large trees and comparing the profile views show that the understory structure was substantially changed. The lack of mid-sized trees greatly reduced the chance of finding a situation where fire can reach the main canopy. P-Torch indicates that this was an enduring change. Without additional disturbances, only small numbers of new trees enter the understory and these are generally suppressed by the heavy overstory. Yet the chance of finding a small plot with the necessary conditions for torching rarely reaches zero. It is interesting to note that an incidental result of the prescribed fires was an increase in merchantable volume 100 after the simulation started, compared to the no action alternative.

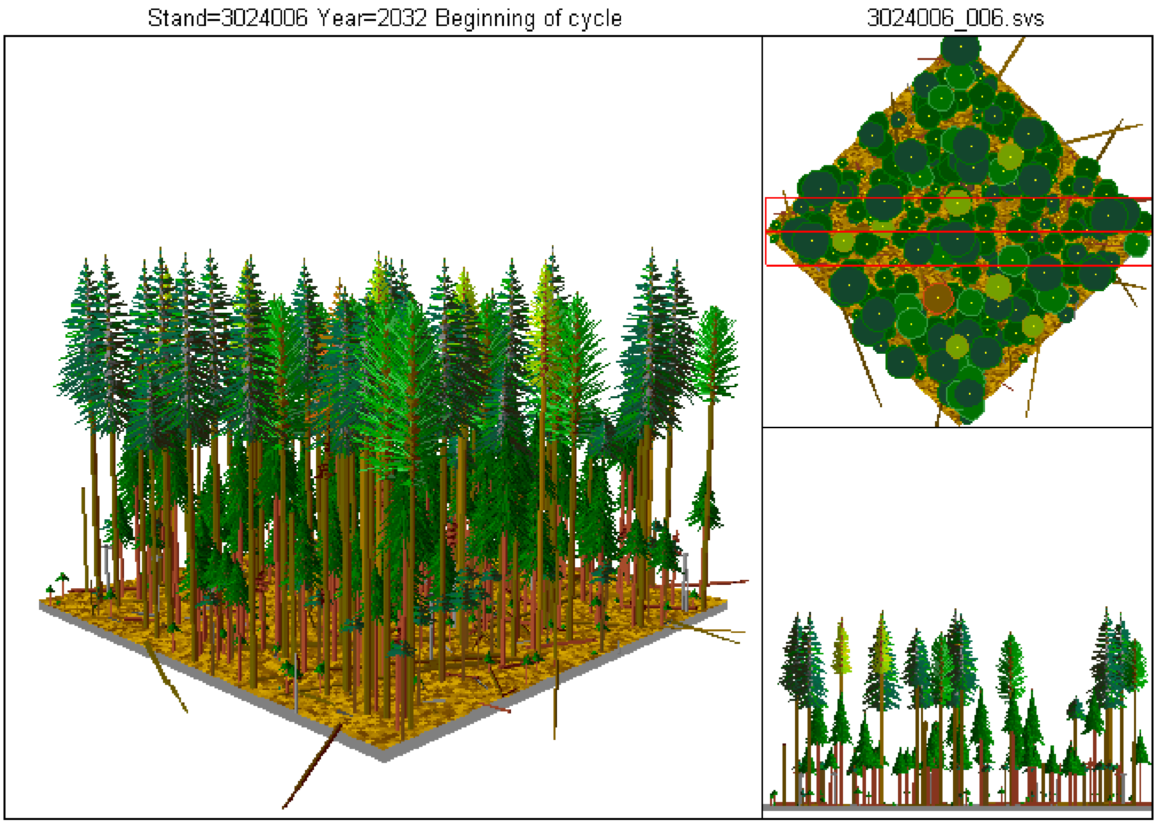

Figure A.3.2 - Example stand 30240006 shown at year 2032 without management using SVS (McGaughey 1997; http://www.fs.fed.us/pns/svs).

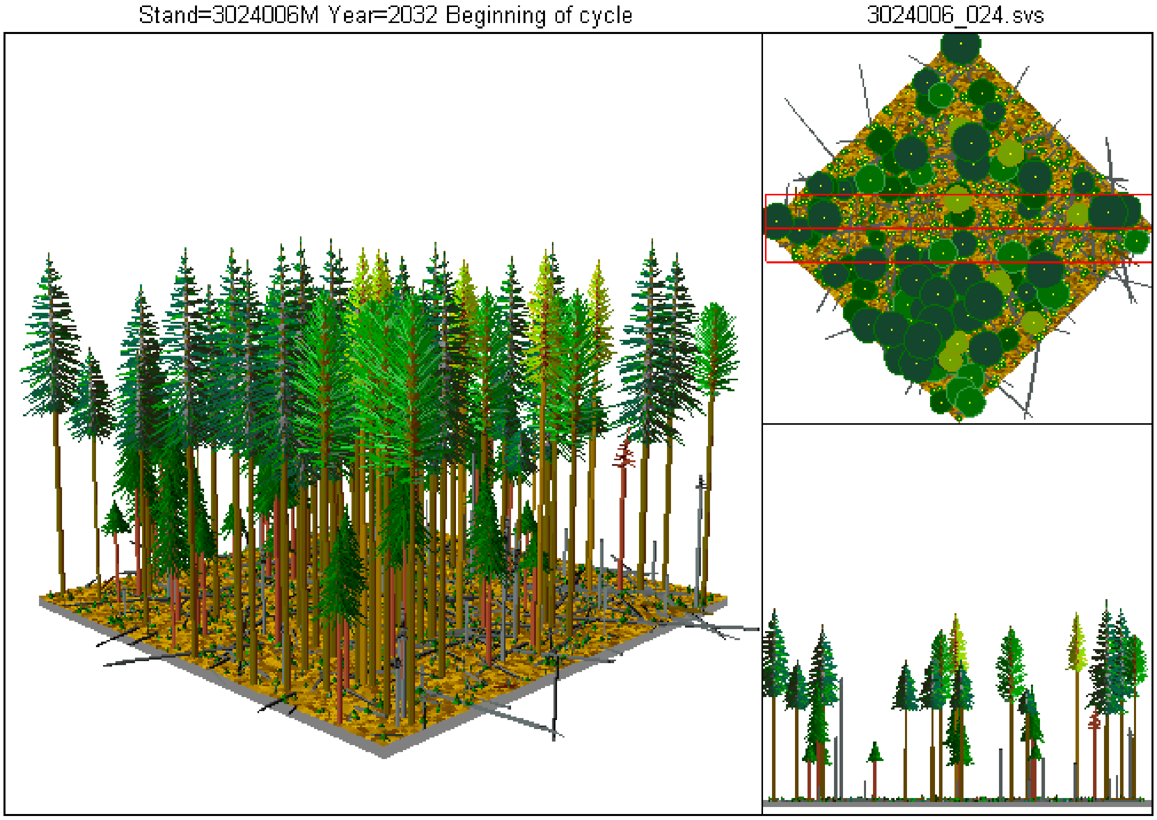

Figure A.3.3 - Example stand 30240006 shown at year 2032 with prescribed fires in 2002 and 2012.

Example 2: Stand 300290023601

The second example is a young xeric Douglas-fir stand with lodgepole pine, growing on the Flathead National Forest in western Montana (Figure A.3.4). Stands like these have much shorter natural fire return intervals than stands like those used in the first example. Catastrophic losses can be avoided if the fires remain on the surface and are not intense. However, almost any fires burning in the early stages of this stands life would likely leave the stand poorly stocked.

Two scenarios demonstrate that unlike the first example, TI and P-Torch convey about the same information albeit in different ways. The reason is that the major driver of torching hazard in this example is surface fuel load rather than CBH.

Figure A.3.5 illustrates the two indices plotted over time. Torching hazard starts out high and drops as the stand develops. According to P-Torch, the hazard rises at year 2030; TI continues to increase (showing a reduced hazard) and then it levels off showing that the hazard remains moderate. A series of prescribed fires, one every 15 years starting in 2025 and ending in 2070 was simulated to reduce the torching hazard. Both indices show that the prescriptions met the objective, yet P-Torch seems simpler to comprehend. A major goal of the prescribed fires was to improve the prospects for this stand if a fire burns when conditions are severe. Therefore, for both scenarios, a fire was simulated in year 2093 resulting in the loss of most trees in the unmanaged case and the loss of few trees otherwise (Figure A.3.6).

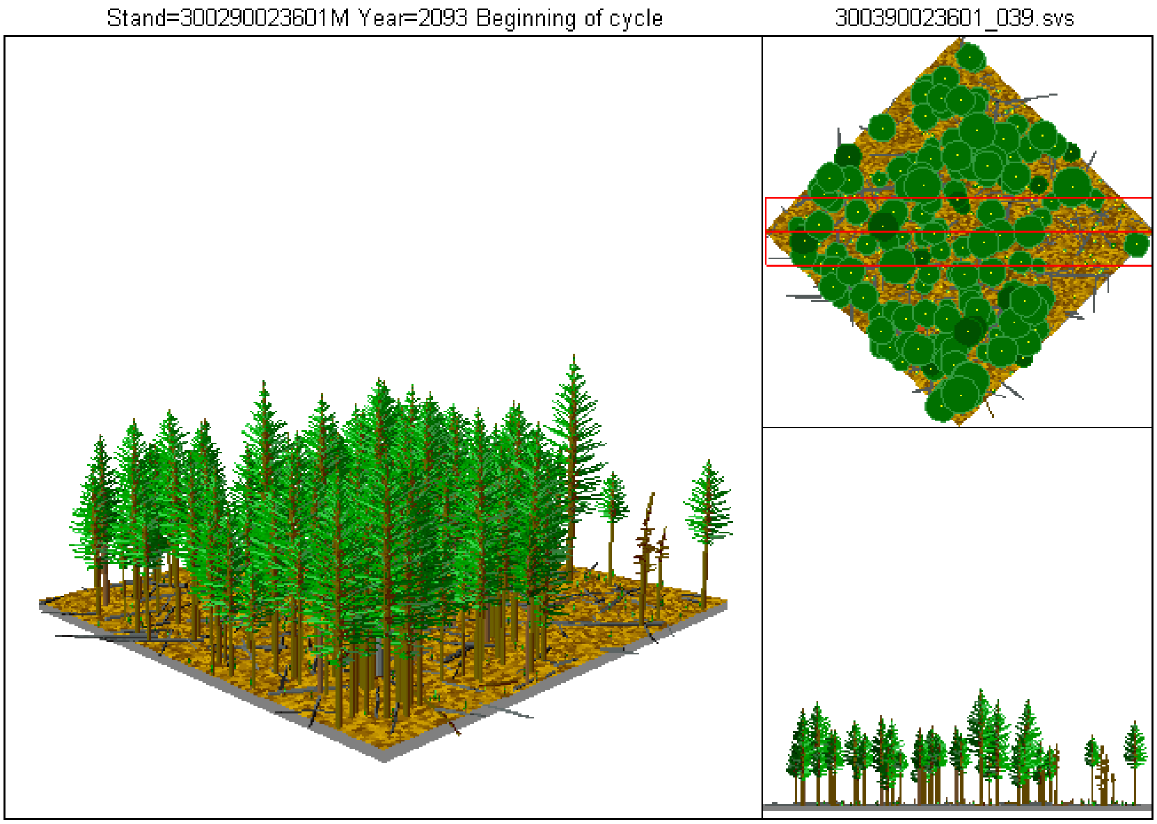

Figure A.3.4 - Stand 300290023601 at year 2093, after repeated prescribed surface fires. The appearance of this stand is about the same as it would be without the repeated prescribed fires and it is also about the same as it looks after an additional fire burns in year 2093 in severe fire conditions.

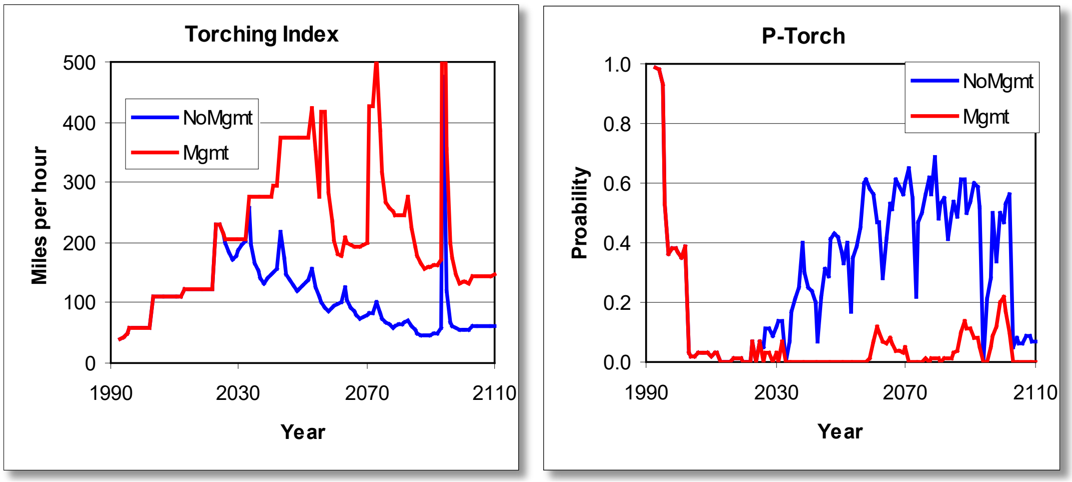

Figure A.3.5 - TI and P-Torch for stand 300290023601. Both indices indicate that the hazard of torching is high in the beginning and that a series of prescribed fire reduced the hazard. The saw-tooth appearance of the lines is partly due to spikes in fine fuels loads caused by simulated fires but mostly caused by modeling artifacts related to the way fuels are modeled in FFE.

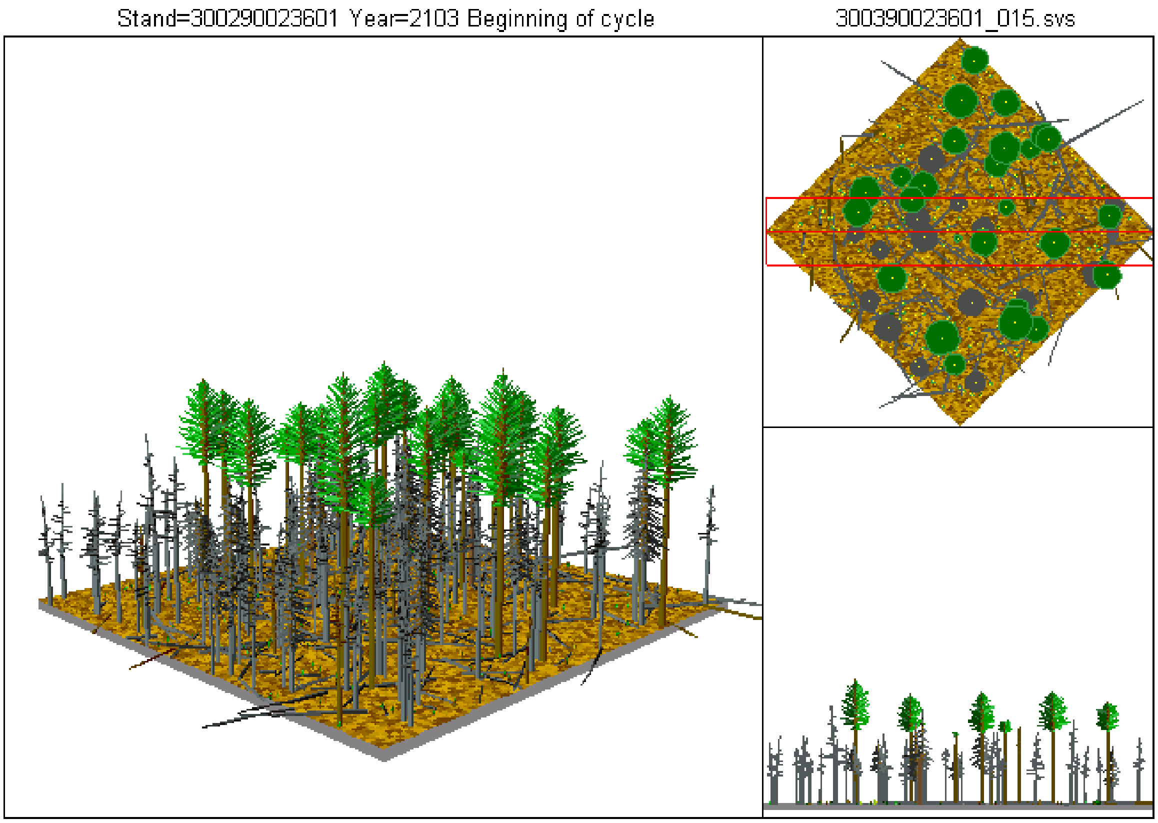

Figure A.3.6 - Stand 300290023601 in year 2103 given a fire burns with severe conditions in year 2093 and without any previous prescribed fire.

A.4 Conclusions

P-Torch has an intuitive appeal. It goes up when torching hazard increases and down when it decreases; the opposite is true of TI. P-Torch is sensitive to tree density in a way that TI cannot be—a lower density of trees reduces P-Torch even when all the trees have a 100 percent crown ratio. That is, the chances of finding a small place where torching can occur declines with tree density. This is easy to understand when you note that the probability of finding zero trees in a randomly placed small plot approaches one as the density approaches zero. TI is not directly sensitive to tree density unless the density falls below the threshold needed to compute the stand's CBH. That is, TI can indicate a high hazard of torching when there are only a few trees per acre. While it may be true that those few trees would all torch if exposed to a surface fire, this case would show a very low value of P-Torch simply because most of the randomly placed plots in a nearly unstocked stand would also be empty. This difference between the two indices can be considered philosophical, yet important. TI is indirectly sensitive to stand density because surface fire wind is a function of canopy cover and twenty-foot wind speed.

P-Torch does not require canopy base height to be assessed on a stand level. Since the calculation of CBH is problematic, and since TI depends so strongly on that calculation, this is an advantage.

P-Torch is sensitive to surface fire intensity. Longer flames can reach higher crowns and the chances of torching increases when a larger proportion of the trees in a stand can be ignited.

P-Torch is sensitive to the wind speed you specify for the burning conditions while TI is the predicted wind speed necessary to cause torching. The two indices are fundamentally different in this respect.

In FFE-FVS, TI is used in predicting fire behavior while P-Torch is not, at least not yet. Exactly how to include this new indicator of torching risk in fire behavior calculations is an open question.

Lastly, note that P-Torch takes more computer time to compute than TI. The additional computer time is mostly taken in creating the virtual plots.

Appendix B Adjusting the Fire Behavior Calculations

This appendix describes two new fire behavior modeling options in FFE-FVS. First, a method of using the modeled fuel loads directly in simulating fire behavior was developed; identifying a standard fuel model is not required. Second, a new procedure for selecting a standard fire behavior fuel model was designed. The primary purpose of the new procedure is to select one or two of the 53 standard fire behavior fuel models (Albini 1976, Anderson 1982, Scott and Burgan 2005).

B.1 Modeled Fuel Loads to Custom Fuel Model

A fuel model is a listing of 13 surface fuelbed inputs to the Rothermel surface fire spread model. A standard fuel model is a set of those inputs that is available for generic use in many situations. A custom fuel model is a listing of those inputs developed to represent a specific situation. In this new feature of FFE-FVS, the modeled fuel loads are used to create a custom fuel model for each situation. (In this case, no standard fuel model is actually selected and used, but the use of this option is reported as fm89.) The term "modeled loads" refers to the fuel load in the various fuel pools simulated by FFE-FVS. The fuel pools relevant to fire behavior modeling (spread rate and intensity) are shown in Table B.1.1. Larger dead and down fuel particles (1000-h timelag class) and duff are not considered in surface or crown fire modeling.

Table B.1.1 - Fuel pools used in creating a custom fire behavior fuel model or selecting a standard fire behavior fuel model.

Fuel pool	Description	FFE Fuel Pool Used
Litter	The litter fuel pool consists of freshly fallen leaf litter and dead herbaceous material that is no longer in an upright position.	Litter
1-h timelag dead fuel	The 1-h timelag fuel pool consists of dead and down fuel particles less than ¼-inch (6 mm) in diameter.	0 - .25" dead surface fuel
10-h timelag dead fuel	The 10-h timelag fuel pool consists of dead and down fuel particles between ¼-inch (6 mm) and 1-inch (25 mm) in diameter.	0.25 – 1" dead surface fuel
100-h timelag dead fuel	The 100-h timelag fuel pool consists of dead and down fuel particles between 1-inch (25 mm) and 3 inches (75 mm) in diameter.	1 – 3" dead surface fuel
Herbaceous fuel	The herbaceous fuel pool is the load of standing live and dead grass stems and other herbaceous fuel. Both the live and dead standing components are included in this fuel pool; the live and dead components are separated at the time of fire behavior simulation.	Herb fuel, as estimated in the All Fuels Report
Live woody fuel	The live woody fuel pool is the foliage of shrubs and small trees plus the fine live branchwood of shrubs and small trees. Fine live branchwood is generally considered branches less than ¼-inch (6 mm) in diameter.	Shrub fuel, as estimated in the All Fuels Report, plus the foliage and half the fine branchwood of all trees less than 6 ft (by default, this height is adjusted if CanCalc is used.)

The 13 parameters required for a fire behavior fuel model are listed in Table B.1.2 below.

Table B.1.2 - Fuel model parameters, their standard English units, and how each is mapped to a fuel pool quantity, a default value, or a calculation.

Fuel model parameter	units	Description
1-h load	t/a	The litter load plus the 1-h timelag dead fuel load as described in Table 1.
10-h load	t/a	The 10-h timelag dead fuel load as described in Table 1.
100-h load	t/a	The 100-h timelag dead fuel load as described in Table 1.
Live herbaceous load	t/a	The herbaceous fuel load as described in Table 1.
Live woody load	t/a	The live woody fuel load as described in Table 1.
1-h SAV	1/ft	User-specified SAV ratio of the 1-h timelag class. Default = 2000 1/ft. (See FireCalc keyword.)
Herbaceous SAV	1/ft	User-specified SAV ratio of the herbaceous fuel class. Default = 1800 1/ft. (See FireCalc keyword.)
Live woody SAV	1/ft	User-specified SAV ratio of the live woody fuel class. Default = 1500 1/ft. (See FireCalc keyword.)
Fuel bed depth	Ft	Calculation described below.
Dead fuel extinction moisture	Percent	Calculation described below.
Heat content	BTU/lb	Heat content of the fuel. All but one of the 53 standard fuel models uses a value of 8000 BTU/lb. Default = 8000 BTU/lb. (See FireCalc keyword.)

Of the parameters listed in Table B.1.2, all but two of them are simple to gather from either a user-defined value (a default value for each is specified) or from the loads in various FFE-FVS fuel pools. Fuelbed depth and dead fuel extinction moisture are calculated from other fuelbed quantities as described in the sections below.

B.1.1 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 is 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 in FFE-FVS 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 all five fuel load parameters; fine dead fuel load is just the 1-h load; and fine fuel load is the sum of the 1-h load, herbaceous load, and live woody load parameters. All of these parameters are specified in Table 2.

The fuelbed depth and bulk density are directly related:

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

where:

TFL = total fuel load (t/ac)

BD = 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} = bulk density of the live fuel component of the fuelbed

BD_{dead} = bulk density of the dead fuel component of the fuelbed

WF = 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/ft3; default BD_{dead} is 0.75 lb/ft3. (These can be adjusted with the FireCalc keyword.) The weighting factor (WF) is calculated as follows:

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

where:

$FDFL$ = fine dead fuel load (t/ac)

FFL = fine fuel load (t/ac)

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}.

B.1.2 Dead Fuel Extinction Moisture Content

Dead fuel extinction moisture content (MX_{dead}) is calculated as a function of the fuelbed packing ratio, which itself is simply *BD* divided by particle density. For an assumed particle density value of 32 lb/ft^3, MX_{dead} is

$$MX_{dead} = 12 + 480 * \left(\frac{BD}{32} \right)$$

where:

MX_{dead} = dead fuel extinction moisture content (in percent)

BD = fuelbed bulk density (lb/ft^3); as calculated above

B.2 Modeled Fuel Loads to Standard Fuel Model

The procedure described in section 1 above can be used within FFE-FVS for simulating fire behavior by selecting the appropriate option on the FireCalc keyword. Another option on the FireCalc keyword is to use the “new” fuel model logic. This selects 2 standard fire behavior fuel models using a new set of rules that determine which of the standard fuel models is most similar, based on the modeled fuel loads. Two sets of standard fuel models are available for use: the original 13 fuel models (Albini 1976, Anderson 1982) and a more recently developed set of 40 standard fuel models (Scott and Burgan 2005). Although each of those fuel model sets is designed to stand alone, some fuel modelers prefer to use them together as a virtual set of 53 fuel models. For that reason, this fuel model selection process is designed to, at the user’s discretion, select from the original 13 fuel models, from the 40 fuel models, or from the compiled set of 53 fuel models.

Selecting a standard fuel model from fuel loads modeled by FFE-FVS is a two-step process. The first step is narrowing the range of fuel model choices to a reasonable handful based on three factors: fuel type, climate type (extinction moisture content), and which set of fuel models to choose from. Step two is selecting from the narrowed list based on a departure index of fuelbed characteristics: fine fuel load, characteristic surface-area-to-volume ratio, and bulk density.

B.2.1 Narrowing the Fuel Model Choices

For any given fuelbed, three pieces of information are used to narrow the list of fuel model choices: major fire-carrying fuel type, climate type, and fuel model set. A set of rules is used to classify the fuelbed into a major fire-carrying fuel type. Climate type is set based on the variant. The fuel model set (13, 40, or 53 fuel models) is a direct input from the user.

B.2.1.1 Fire-carrying fuel type

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

LiveFraction is the ratio of live fuel load (grass/herbaceous load plus live woody load to the fine fuel load (FFL), which is the live fuel load plus the 1-h timelag class dead fuel load. LiveFraction is a dimensionless ratio, so it does not matter what units are used to calculate the fuel loads as long as the same units are used for both live fuel load and fine 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. The fuel load values needed to compute LiveFraction are listed in Table B.1.2.

HerbFraction is the ratio of the herbaceous load to the 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 and down fuel (grass litter, for example), so the HerbFraction normally approaches 1.0 without reaching it. A grass dominated fuelbed will have a high HerbFraction. The fuel load values needed to compute HerbFraction are listed in Table B.1.2.

HerbRatio is the ratio of the herbaceous load to the live woody load. Because it is possible for the herbaceous load to exceed the live woody load, HerbRatio is open-ended with a minimum possible value of 0.0. If the fuelbed has no live woody load, this ratio should be set to 10.

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

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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)
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)
IF HerbFraction ≥ 0.75, THEN the fuel bed is dominated by herbaceous fuel and a grass dominated fuel model will be available for selection (FuelType = GR)
IF HerbFraction < 0.75, THEN the fuelbed is not dominated by grass or herbaceous fuel (continue with i. below)
IF HerbRatio > 2.0, THEN grass/herbaceous component is dominant and fuel type is GR

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)

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 or TU)

B.2.1.2 Climate Type

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

Therefore, two climate types are available:

Arid to semi-arid climates (low extinction moisture content)

Humid to sum-humid climates (high extinction moisture content)

This document describes a process in which the available fuel models are determined from the climate type. Each FFE-FVS variant was assigned to one of these climate types (Table B.2.1).

Table B.2.1 - Listing of climate type for each FFE-FVS variant. Climate type applies only to fuel modeling and was assigned based on generally expected MXdead values. Arid means semi-arid to arid climate; humid means sub-humid to humid climate.

FFE-FVS Variant	Climate type
Northeast (NE)	Humid
Southern (SN)	Humid
Lake States (LS)	Humid
Central States (CS)	Humid
Alaska (AK)	Humid
Pacific Northwest Coast (PN)	Humid
West Cascades (WC)	Humid
Northern California/Klamath Mountains (NC)	Arid
Western Sierra (WS)	Arid
Inland California and Southern Cascades (CA)	Arid
Southern Oregon and Northeast California (SO)	Arid
Blue Mountains (BM)	Arid
Utah (UT)	Arid
Central Rockies (CR)	Arid
Tetons (TT)	Arid
Central Idaho (CI)	Arid
Eastern Montana (EM)	Arid
Inland Empire (IE)	Arid
East Cascades (EC)	Arid
KooKanTL (KT)	Arid

B.2.1.3 Fuel model set

The last piece of information needed is which fuel model set 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). Although those sets were designed to stand alone, some people prefer to draw from among all 53 fuel models. This method allows three choices for fuel model set:

1) Original 13
2) 40 fuel models
3) All 53 fuel models

Table B.2.2 below identifies the standard fire behavior fuel models appropriate for each of the four fuel types, for both arid climates and for humid climates.

Table B.2.2 - Standard fire behavior fuel models appropriate for each fuel type and climate.

		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 the user's preference, the final narrowed list could include fuel models from 1) only the 13 original fuel models, 2) from only the set of 40 fuel models, or 3) from either set of fuel models. The FMODLIST keyword can be used to add or remove a fuel model from the narrowed potential pick list shown in Table B.2.2.

B.2.2 Selecting a Fuel Model from the Narrowed List

Once the list of potential fuel models has been narrowed from step 1, the next step is to compute a 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.

B.2.2.1 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:

$SAV_{fuelbed}$ = surface area to volume ratio of the subject fuelbed
SAV_{fm} = surface area to volume ratio of the subject standard fuel model
405.2 = standard deviation of SAV of the 53 standard fuel models
$BD_{fuelbed}$ = bulk density (lb/ft^3) of the subject fuelbed
BD_{fm} = bulk density (lb/ft^3) of the subject standard fuel model
0.3992 = standard deviation of BD of the 53 standard fuel models
$FFL_{fuelbed}$ = fine fuel load (t/a) of the subject fuelbed
FFL_{fm} = fine fuel load (t/a) of the subject standard fuel model
3.051 = standard deviation of FFL of the 53 standard fuel models

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

B.2.2.2 Choosing a Single Standard Fuel Model

The single best standard fuel model for the subject fuelbed is the one with the lowest departure index. A departure index value of 0.0 indicates that all three fuel characteristics of the subject fuelbed exactly match one of the standard fuel models. By default, two fuel models will be chosen, unless the StatFuel keyword is used.

B.2.2.3 Choosing More Than One Standard Fuel Model

By default, FFE identifies and uses the two fuel models most similar to the subject fuelbed, along with weighting factors for each fuel model. The departure index described in section B.2.2.1 provides a method for doing just that. For selecting two fuel models, the two fuel models with the lowest departure indices are selected. Each of those fuel models is given a weighting factor according to the inverse of its departure.

$$WF_x = \frac{1/DI_x}{1/DI_x + 1/DI_y}$$

and

$$WF_y = \frac{1/DI_y}{1/DI_x + 1/DI_y}$$

For example, if DIx is 25 and DIy is 75, then WFx is 0.75 and WFy is 0.25.

Appendix C Fire Behavior Fuel Models

This appendix describes the fire behavior fuel models used in FFE-FVS. Values can be changed using the DEFULMOD keyword.

		DEFULMOD keyword field numbers												
		2	3	4	5	6	7	8	9	10	11	12	13	14
			SAV Ratio (1/ft)				Fuel Load (lb/ft^2)							
Fuel model Code	Name	Fuel model number	1-hr	10-hr	100-hr	Live woody	1-hr	10-hr	100-hr	Live woody	Fuel bed depth (ft)	Dead fuel extinction moisture	SAV Ratio Live Herb	Fuel Load Live Herb
-	Short grass	1	3500	109	30	1500	0.034	0.000	0.000	0.000	1	0.12	0	0.000
-	Timber (grass & understory)	2	3000	109	30	0	0.092	0.046	0.023	0.000	1	0.15	1500	0.023
-	Tall grass	3	1500	109	30	1500	0.138	0.000	0.000	0.000	2.5	0.25	0	0.000
-	Chaparral	4	2000	109	30	1500	0.230	0.184	0.092	0.230	6	0.20	0	0.000
-	Brush	5	2000	109	30	1500	0.046	0.023	0.000	0.092	2	0.20	0	0.000
-	Dormant brush, hardwood slash	6	1750	109	30	1550	0.069	0.115	0.092	0.000	2.5	0.25	0	0.000
-	Southern rough	7	1750	109	30	1550	0.052	0.086	0.069	0.017	2.5	0.40	0	0.000
-	Closed timber litter	8	2000	109	30	1500	0.069	0.046	0.115	0.000	0.2	0.30	0	0.000
-	Hardwood litter	9	2500	109	30	1500	0.134	0.019	0.007	0.000	0.2	0.25	0	0.000
-	Timber (litter & understory)	10	2000	109	30	1500	0.138	0.092	0.230	0.092	1	0.25	0	0.000
-	Light logging slash	11	1500	109	30	1500	0.069	0.207	0.253	0.000	1	0.15	0	0.000
-	Light-medium logging slash	12	1500	109	30	1500	0.184	0.644	0.759	0.000	2.3	0.20	0	0.000
-	Medium logging slash	13	1500	109	30	1500	0.322	1.058	1.288	0.000	3	0.25	0	0.000
-	Heavy logging slash	14	1500	109	30	1500	0.126	0.426	0.506	0.000	1.8	0.20	0	0.000
-	Plantation older than 25 years	25	2000	109	30	1500	0.069	0.069	0.092	0.207	3.5	0.25	0	0.000
-	Modified FM 4	26	2000	109	30	1500	0.1242	0.1242	0.0828	0.1656	3.6	0.25	0	0.000
GR1	Short, sparse dry climate grass	101	2200	109	30	9999	0.005	0.000	0.000	0.000	0.4	0.15	2000	0.014
GR2	Low load, dry climate grass	102	2000	109	30	9999	0.005	0.000	0.000	0.000	1	0.15	1800	0.046
GR3	Low load, very coarse, humid climate grass	103	1500	109	30	9999	0.005	0.018	0.000	0.000	2	0.30	1300	0.069
GR4	Moderate load, dry climate grass	104	2000	109	30	9999	0.011	0.000	0.000	0.000	2	0.15	1800	0.087
GR5	Low load, humid climate grass	105	1800	109	30	9999	0.018	0.000	0.000	0.000	1.5	0.40	1600	0.115
GR6	Moderate load, humid climate grass	106	2200	109	30	9999	0.005	0.000	0.000	0.000	1.5	0.40	2000	0.156
GR7	High load, dry climate grass	107	2000	109	30	9999	0.046	0.000	0.000	0.000	3	0.15	1800	0.248
GR8	High load, very coarse, humid climate grass	108	1500	109	30	9999	0.023	0.046	0.000	0.000	4	0.30	1300	0.335
GR9	Very high load, humid climate grass	109	1800	109	30	9999	0.046	0.046	0.000	0.000	5	0.40	1600	0.413
GS1	Low load, dry climate grass-shrub	121	2000	109	30	1800	0.009	0.000	0.000	0.030	0.9	0.15	1800	0.023
GS2	Moderate load, dry climate grass-shrub	122	2000	109	30	1800	0.023	0.023	0.000	0.046	1.5	0.15	1800	0.028
GS3	Moderate load, humid climate grass-shrub	123	1800	109	30	1600	0.014	0.011	0.000	0.057	1.8	0.40	1600	0.067
GS4	High load, humid climate grass-shrub	124	1800	109	30	1600	0.087	0.014	0.005	0.326	2.1	0.40	1600	0.156

		DEFULMOD keyword field numbers												
		2	3	4	5	6	7	8	9	10	11	12	13	14
			SAV Ratio (1/ft)				Fuel Load (lb/ft^2)							
Fuel model Code	Name	Fuel model number	1-hr	10-hr	100-hr	Live woody	1-hr	10-hr	100-hr	Live woody	Fuel bed depth (ft)	Dead fuel extinction moisture	SAV Ratio Live Herb	Fuel Load Live Herb
SH1	Low load, dry climate shrub	141	2000	109	30	1600	0.011	0.011	0.000	0.060	1	0.15	1800	0.007
SH2	Moderate load, dry climate shrub	142	2000	109	30	1600	0.062	0.110	0.034	0.177	1	0.15	9999	0.000
SH3	Moderate load, humid climate shrub	143	1600	109	30	1400	0.021	0.138	0.000	0.285	2.4	0.40	9999	0.000
SH4	Low load, humid climate timber-shrub	144	2000	109	30	1600	0.039	0.053	0.009	0.117	3	0.30	1800	0.000
SH5	High load, dry climate shrub	145	750	109	30	1600	0.165	0.096	0.000	0.133	6	0.15	9999	0.000
SH6	Low load, humid climate shrub	146	750	109	30	1600	0.133	0.067	0.000	0.064	2	0.30	9999	0.000
SH7	Very high load, dry climate shrub	147	750	109	30	1600	0.161	0.243	0.101	0.156	6	0.15	9999	0.000
SH8	High load, humid climate shrub	148	750	109	30	1600	0.094	0.156	0.039	0.200	3	0.40	9999	0.000
SH9	Very high load, humid climate shrub	149	750	109	30	1500	0.207	0.112	0.000	0.321	4.4	0.40	1800	0.071
TU1	Low load, dry climate timber-grass-shrub	161	2000	109	30	1600	0.009	0.041	0.069	0.041	0.6	0.20	1800	0.009
TU2	Moderate load, humid climate timber-shrub	162	2000	109	30	1600	0.044	0.083	0.057	0.009	1	0.30	9999	0.000
TU3	Moderate load, humid climate timber-grass-shrub	163	1800	109	30	1400	0.051	0.007	0.011	0.051	1.3	0.30	1600	0.030
TU4	Dwarf conifer with understory	164	2300	109	30	2000	0.207	0.000	0.000	0.092	0.5	0.12	9999	0.000
TU5	Very high load, dry climate timber-shrub	165	1500	109	30	750	0.184	0.184	0.138	0.138	1	0.25	9999	0.000
TL1	Low load, compact conifer litter	181	2000	109	30	9999	0.046	0.101	0.165	0.000	0.2	0.30	9999	0.000
TL2	Low load, broadleaf litter	182	2000	109	30	9999	0.064	0.106	0.101	0.000	0.2	0.25	9999	0.000
TL3	Moderate load, conifer litter	183	2000	109	30	9999	0.023	0.101	0.129	0.000	0.3	0.20	9999	0.000
TL4	Small downed logs	184	2000	109	30	9999	0.023	0.069	0.193	0.000	0.4	0.25	9999	0.000
TL5	High load, conifer litter	185	2000	109	30	1600	0.053	0.115	0.202	0.000	0.6	0.25	9999	0.000
TL6	Moderate load, broadleaf litter	186	2000	109	30	9999	0.110	0.055	0.055	0.000	0.3	0.25	9999	0.000
TL7	Large downed logs	187	2000	109	30	9999	0.014	0.064	0.372	0.000	0.4	0.25	9999	0.000
TL8	Long-Needle litter	188	1800	109	30	9999	0.266	0.064	0.051	0.000	0.3	0.35	9999	0.000
TL9	Very high load, broadleaf litter	189	1800	109	30	1600	0.305	0.152	0.191	0.000	0.6	0.25	9999	0.000
SB1	Low load, activity fuel	201	2000	109	30	9999	0.069	0.138	0.505	0.000	1	0.25	9999	0.000
SB2	Moderate load, activity fuel or low load, blowdown	202	2000	109	30	9999	0.207	0.195	0.184	0.000	1	0.25	9999	0.000
SB3	High load, activity fuel or moderate load, blowdown	203	2000	109	30	9999	0.253	0.126	0.138	0.000	1.2	0.25	9999	0.000
SB4	High load, blowdown	204	2000	109	30	9999	0.241	0.161	0.241	0.000	2.7	0.25	9999	0.000

Appendix D Photo Series References

The photo series reference numbers are listed below. Some reference numbers (4,10) are not used and one is a replicate of another (14, 15). This was not changed to maintain consistency with the photo reference numbers used in FSVEG.

When used in conjunction with the FuelInit or FuelSoft keywords or associated DB StandInit fields, the specific tons/acre values entered will override those associated with the photo series photo. Likewise, if a photo series photo did not include fuel loading information for a certain class (litter or duff), the default that would have been assumed for that category is used. So the fuel loadings start out at the default values, are overwritten with any photo series information provided, and are then overwritten if any specific fuel loadings (tons/acre) are provided. When multiple FuelFoto keywords are in a simulation, the last one is used (this matches how the FuelInit and FuelSoft keywords are processed.)

Photo series reference numbers and associated photo reference codes:

1 – Fischer, W.C. 1981. Photo guide for appraising downed woody fuels in Montana forests: grand fir-larch-Douglas-fir, western hemlock, western redcedar-western hemlock, and western redcedar cover types. Gen. Tech. Rep. INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 53 p.

2 – Fischer, W.C. 1981. Photo guide for appraising downed woody fuels in Montana forests: interior ponderosa pine, ponderosa pine-larch-Douglas-fir, larch-Douglas-fir, and interior Douglas-fir cover types. Gen. Tech. Rep. INT-97. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 133 p.

Also published by the National Wildfire Coordinating Group as PMS 820 / NFES 2293

3 – Fischer, W.C. 1981. Photo guide for appraising downed woody fuels in Montana forests: lodgdpole pine and Engelmann spruce-subalpine fir cover types. Gen. Tech. Rep. INT-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 143 p.

Also published by the National Wildfire Coordinating Group as PMS 821 / NFES 2294

5 – Koski, W.H. and W.C. Fischer. 1979. Photo series for appraising thinning slash in north Idaho: western hemlock, grand fir, and western redcedar timber types. Gen. Tech. Rep. INT-46. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 50 p.

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Table D.1 Valid character and integer codes for each photo within each photoseries reference available for use with the FUELFOTO keyword. When dashes are present in any character codes provided by the user, they are ignored by FVS to ensure that the provided codes will be read in properly.

Ref	Char Code	Int Code	Ref	Char Code	Int Code	Ref	Char Code	Int Code
1	16	1	9	3RAPRE05	15	19	HP01	1
1	15	2	9	3RAPRE06	16	19	HP02	2
1	63	3	9	3RAPRE07	17	19	HP03	3
1	65	4	9	4DFWHPOST01	18	19	HP04	4
1	67	5	9	4DFWHPOST02	19	19	HP05	5
1	25	6	9	4DFWHPOST03	20	19	HP06	6
1	66	7	9	4DFWHPOST04	21	19	HP07	7
1	9A	8	9	5RAPOST01	22	19	LLP01	8
1	4A	9	9	5RAPOST02	23	19	LLP02	9
1	17A	10	9	5RAPOST03	24	19	LLP03	10

Ref	Char Code	Int Code
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1	18A	14
1	10A	15
1	7A	16
1	19A	17
1	11A	18
1	5A	19
1	8A	20
1	16A	21
1	15A	22
2	24	1
2	18	2
2	23	3
2	33A	4
2	30A	5
2	32A	6
2	17	7
2	31A	8
2	29A	9
2	72	10
2	76	11
2	69	12
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2	79	16
2	75	17
2	73	18
2	77	19
2	84	20
2	74	21
2	78	22
2	68	23
2	31	24
2	36A	25
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2	14	27
2	88	28
2	13	29
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9	5RAPOST05	26
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11	3PP1TH	3
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11	5PP1TH	5
11	6PP1TH	6
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11	1PP2PC	8
11	2PP2PC	9
11	3PP2PC	10
11	4PP2PC	11
11	5PP2PC	12
11	1PP3PC	13
11	2PP3PC	14
11	3PP3PC	15
11	1PP3CC	16
11	2PP3CC	17
11	1PPSP3PC	18
11	2PPSP3PC	19
11	3PPSP3PC	20
11	1SP3PC	21
11	2SP3PC	22
11	1PP1	23
11	1PP2	24
11	2PP2	25
11	1PP3	26
12	1PP1TH(BH)	1
12	2PP1TH(BH)	2
12	3PP1TH(BH)	3
12	4PP1TH(BH)	4
12	5PP1TH(BH)	5
12	6PP1TH(BH)	6
12	7PP1TH(BH)	7
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12	2PP2PC	9
12	3PP2PC	10
12	4PP2PC	11
12	5PP2PC	12
12	1PP3PC	13
19	LLP04	11
19	LLP05	12
19	LLP06	13
19	LLP07	14
19	LLP08	15
19	LLP09	16
19	LLP10	17
19	PW01	18
19	PW02	19
19	SH01	20
19	SH02	21
19	SH03	22
19	SH04	23
19	SH05	24
19	SH06	25
19	SH07	26
19	SH08	27
19	SH09	28
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20	4PP2PC	11
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20	3PP3PC	15
20	1PP3CC	16
20	2PP3CC	17

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2	28A	47
2	27A	48
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2	37A	50
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2	48	58
2	95	59
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3	26A	2
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12	3PPSP3PC	20
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12	2SP3PC	22
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12	2PP2(BH)	25
12	1PP3(BH)	26
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12	1AZPPSPPRE02	28
12	1AZPPSPPRE03	29
12	1AZPPSPPRE04	30
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12	3MC2	33
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12	3PP&Assoc3	39
12	4PP&Assoc3	40
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12	1PP&Assoc4	42
12	2PP&Assoc4	43
12	3PP&Assoc4	44
12	1PP1	45
12	2PP1	46
12	3PP1	47
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12	2PP2(PNW105)	49
12	3PP2(PNW105)	50
12	4PP2(PNW105)	51
12	1PP3(PNW105)	52
12	2PP3(PNW105)	53
12	3PP3(PNW105)	54
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20	1PP3	26
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21	PJ07	7
21	PJ08	8
21	PJ09	9
21	PJ10	10
21	PJ11	11
21	PJ12	12
21	PJ13	13
21	PJ14	14
21	SWSB01	15
21	SWSB02	16
21	SWSB03	17
21	SWSB04	18
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21	SWSB07	21
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21	SWSB09	23
21	SWSB10	24
21	SWSB11	25
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3	81	26
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3	22A	42
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3	59	52
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12	8PP3	59
12	1PP4(PNW105)	60
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12	3PP4(PNW105)	62
12	4PP4	63
12	1JU2	64
12	2JU2	65
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12	3PP4PC	68
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12	5PP4PC	70
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12	3WF3	90
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22	HIW01	30
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22	HIW05	34
22	HIW06	35
22	HIW07	36
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23	1DFWHPRE10	10
23	1DFWHPRE11	11
23	1DFWHPRE12	12

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3	62	59
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5	7WC1TH	17
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6	4PP4PC	6
6	5PP4PC	7
6	1PP1TH	8
6	2PP1TH	9
6	3PP1TH	10
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13	6DFHD4CC	35
13	7DFHD4CC	36
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13	4DFHD4PC	40
13	5DFHD4PC	41
13	6DFHD4PC	42
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14	BG02	2
14	BG03	3
14	BG04	4
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23	1DFWHPRE14	14
23	1DFWHPRE15	15
23	1DFWHPRE16	16
23	1DFWHPRE17	17
23	1DFWHPRE18	18
23	1DFWHPRE19	19
23	2DFWHPOST01	20
23	2DFWHPOST02	21
23	2DFWHPOST03	22
23	2DFWHPOST04	23
23	2DFWHPOST05	24
23	2DFWHPOST06	25
23	2DFWHPOST07	26
24	1LL2N	1
24	2LL2H	2
24	3LL3N	3
24	4LL2H	4
24	5LL1P	5
24	6LL3H	6
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24	9LL3H	9
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24	5PP2N	21
24	6PP2N	22
24	7PP3H	23
24	1VP2N	24
24	2VP2N	25
24	3VP3N	26
24	4VP2N	27

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6	2PP&ASSOC4PC	15
6	3PP&ASSOC4PC	16
6	4PP&ASSOC4PC	17
6	5PP&ASSOC4PC	18
6	6PP&ASSOC4PC	19
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6	8PP&ASSOC4PC	21
6	1LP3CC	22
6	1LP3PC	23
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6	3LP3PC	25
6	4LP3PC	26
6	5LP3PC	27
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7	2LP2	23
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14	SB02	23
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14	WJ02	27
14	WJ03	28
14	WJ04	29
15	BG01	1
15	BG02	2
15	BG03	3
15	BG04	4
15	MC01	5
15	MC02	6
15	MC03	7
15	MC04	8
15	MC05	9
15	MC06	10
15	MC07	11
15	MC08	12
15	MC09	13
15	MC10	14
15	MC11	15
15	MC12	16
25	1A21N	1
25	2A22N	2
25	3B21N	3
25	4A22N	4
25	5B12N	5
25	6A12N	6
25	7B22N	7
25	8A22N	8
25	9A11N	9
25	10A22CC	10
25	11B22CC	11
25	12A22CC	12
25	13A22CC	13
25	14B23CC	14
26	FC1PRE	1
26	FC1POST	2
26	FC2PRE	3
26	FC2POST	4
26	FC3PRE	5
26	FC3POST	6
26	FC4PRE	7
26	FC4POST	8
26	FC5PRE	9
26	FC5POST	10
26	FC6PRE	11
26	FC6POST	12
26	FC7PRE	13
26	FC7POST	14
26	FC8PRE	15
26	FC8POST	16
27	CDO01	1
27	CDO02	2
27	CDO03	3
27	CDO04	4
27	CDO05	5
27	CDO06	6
27	CDO07	7
27	CDO08	8
27	CDO09	9
27	MCS01	10
27	MCS02	11

Ref	Char Code	Int Code	Ref	Char Code	Int Code	Ref	Char Code	Int Code
7	4LP2	25	15	MC13	17	27	MCS03	12
7	5LP2	26	15	MC14	18	27	MCS04	13
7	1LP3	27	15	MC15	19	27	MCS05	14
7	2LP3	28	15	MC16	20	27	MCS06	15
7	3LP3	29	15	MC17	21	27	MCS07	16
7	4LP3	30	15	SB01	22	27	MCS08	17
7	1LP4	31	15	SB02	23	27	MCS09	18
7	1WF2	32	15	SB03	24	27	MCS10	19
7	2WF2	33	15	SB04	25	27	MCS11	20
7	3WF2	34	15	WJ01	26	27	WO01	21
7	4WF2	35	15	WJ02	27	27	WO02	22
7	1WF3	36	15	WJ03	28	27	WO03	23
7	2WF3	37	15	WJ04	29	27	WO04	24
7	3WF3	38	16	AH01	1	27	WO05	25
7	4WF3	39	16	AH02	2	27	WO06	26
7	5WF3	40	16	AH03	3	27	WO07	27
7	1WF4	41	16	AH04	4	27	WO08	28
7	2WF4	42	16	AH05	5	27	WO09	29
7	3WF4	43	16	AH06	6	27	WO10	30
7	4WF4	44	16	AH07	7	28	1MC4RC	1
7	5WF4	45	16	AH08	8	28	2MC4RC	2
7	1RF3	46	16	AH09	9	28	3MC4RC	3
7	2RF3	47	16	AH10	10	28	1MC4PC	4
7	3RF3	48	16	AH11	11	28	2MC4PC	5
7	4RF3	49	16	AH12	12	28	3MC4PC	6
7	5RF3	50	16	AH13	13	28	4MC4PC	7
7	1RF4	51	16	AH14	14	28	5MC4PC	8
7	2RF4	52	16	AH15	15	28	6MC4PC	9
7	3RF4	53	16	BS01	16	28	7MC4PC	10
7	4RF4	54	16	BS02	17	28	8MC4PC	11
7	5RF4	55	16	BS03	18	28	1MC3PC	12
7	1MH4	56	16	BS04	19	28	2MC3PC	13
8	1DFHD3	1	16	BS05	20	28	3MC3PC	14
8	2DFHD3	2	16	BS06	21	28	4MC3PC	15
8	3DFHD3	3	16	BS07	22	28	5MC3PC	16
8	1DFHD4	4	16	BS08	23	28	6MC3PC	17
8	2DFHD4	5	16	BS09	24	28	7MC3PC	18
8	3DFHD4	6	16	BS10	25	28	8MC3PC	19
8	4DFHD4	7	16	BS11	26	28	1TF4RC	20
8	5DFHD4	8	16	BS12	27	28	2TF4RC	21
8	1HD2	9	16	BS13	28	28	3TF4RC	22

Ref	Char Code	Int Code
8	2HD2	10
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8	2DF2	12
8	1DF3	13
8	2DF3	14
8	1DF4	15
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8	3DF4	17
8	4DF4	18
8	5DF4	19
8	6DF4	20
8	7DF4	21
8	1SA1	22
8	2SA1	23
8	3SA1	24
8	1SA2	25
8	2SA2	26
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8	2SA3	28
8	3SA3	29
8	1SA4	30
8	2SA4	31
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8	2MC2	33
8	3MC2	34
8	1MC3	35
8	2MC3	36
8	3MC3	37
8	1MC4	38
8	2MC4	39
8	1LP1	40
8	2LP1	41
8	3LP1	42
8	1LP2	43
8	2LP2	44
8	3LP2	45
8	4LP2	46
8	1LP3	47
8	2LP3	48
8	3LP3	49
8	1PP&Assoc3	50
16	BS14	29
16	WS01	30
16	WS02	31
16	WS03	32
16	WS04	33
16	WS05	34
16	WS06	35
16	WS07	36
16	WS08	37
16	WS09	38
16	WS10	39
16	WS11	40
16	WS12	41
17	GO01	1
17	GO02	2
17	GO03	3
17	GO04	4
17	GO05	5
17	GO06	6
17	GO07	7
17	GO08	8
17	GO09	9
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17	LP03	12
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17	LP08	17
17	LP09	18
17	LP10	19
17	LP11	20
17	LP12	21
17	LP13	22
17	QA01	23
17	QA02	24
17	QA03	25
17	QA04	26
17	QA05	27
17	QA06	28
28	4TF4RC	23
28	5TF4RC	24
28	6TF4RC	25
28	1TF4PC	26
28	2TF4PC	27
28	3TF4PC	28
28	4TF4PC	29
28	5TF4PC	30
29	6A	1
29	6B	2
29	8A	3
29	8B	4
29	10A	5
29	10B	6
29	12A	7
29	12B	8
29	14A	9
29	14B	10
29	16A	11
29	16B	12
29	18A	13
29	18B	14
29	20A	15
29	20B	16
30	3D	1
30	3Dpost	2
30	2A	3
30	2Apost	4
30	3B	5
30	3Bpost	6
30	2C	7
30	2Cpost	8
30	2D	9
30	2Dpost	10
30	1A	11
30	1Apost	12
30	1C	13
30	1Cpost	14
30	1D	15
30	1Dpost	16
31	1	1

Ref	Char Code	Int Code	Ref	Char Code	Int Code	Ref	Char Code	Int Code
8	2PP&Assoc3	51	17	QA07	29	31	2	2
8	3PP&Assoc3	52	17	QA08	30	31	3	3
8	4PP&Assoc3	53	17	QA09	31	31	4	4
8	5PP&Assoc3	54	17	QA10	32	31	5	5
8	1PP&Assoc4	55	17	QA11	33	31	6	6
8	2PP&Assoc4	56	17	QA12	34	31	7	7
8	3PP&Assoc4	57	17	QA13	35	31	8	8
8	1PP1	58	18	JP01	1	31	9	9
8	2PP1	59	18	JP02	2	31	10	10
8	3PP1	60	18	JP03	3	32	1A	1
8	1PP2	61	18	JP04	4	32	1B	2
8	2PP2	62	18	JP05	5	32	1C	3
8	3PP2	63	18	JP06	6	32	2A	4
8	4PP2	64	18	JP07	7	32	2B	5
8	1PP3	65	18	JP08	8	32	3A	6
8	2PP3	66	18	JP09	9	32	3B	7
8	3PP3	67	18	JP10	10	32	4A	8
8	4PP3	68	18	JP11	11	32	4B	9
8	5PP3	69	18	JP12	12	32	4C	10
8	6PP3	70	18	JP13	13	32	5A	11
8	7PP3	71	18	JP14	14	32	5B	12
8	8PP3	72	18	JP15	15	32	5C	13
8	1PP4	73	18	JP16	16	32	6A	14
8	2PP4	74	18	JP17	17	32	6B	15
8	3PP4	75	18	JP18	18	32	6C	16
8	4PP4	76	18	JP19	19	32	7A	17
8	5PP4	77	18	MO01	20	32	7B	18
8	6PP4	78	18	MO02	21	32	7C	19
8	7PP4	79	18	MO03	22	32	8A	20
8	8PP4	80	18	MO04	23	32	9A	21
8	1BR	81	18	MO05	24	32	9B	22
8	2BR	82	18	MO06	25	32	10A	23
8	1JU2	83	18	MO07	26	32	10B	24
8	2JU2	84	18	MO08	27	32	10C	25
8	1GR	85	18	MO09	28	32	11A	26
8	2GR	86	18	MO10	29	32	12A	27
9	1DFWHPRE01	1	18	MO11	30	32	12B	28
9	1DFWHPRE02	2	18	MP01	31	32	12C	29
9	1DFWHPRE03	3	18	MP02	32	32	13A	30
9	1DFWHPRE04	4	18	MP03	33	32	13B	31
9	1DFWHPRE05	5	18	MP04	34	32	13C	32

Ref	Char Code	Int Code	Ref	Char Code	Int Code	Ref	Char Code	Int Code
9	1DFWHPRE06	6	18	MP05	35	32	13D	33
9	1DFWHPRE07	7	18	MP06	36	32	13E	34
9	1DFWHPRE08	8	18	MP07	37	32	14A	35
9	1DFWHPRE09	9	18	MP08	38	32	14B	36
9	2WHSSPRE01	10	18	MP09	39	32	14C	37
9	3RAPRE01	11	18	MP10	40	32	14D	38
9	3RAPRE02	12	18	MP11	41	32	14E	39
9	3RAPRE03	13	18	MP12	42			
9	3RAPRE04	14	18	MP13	43			

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