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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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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.

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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.

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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.

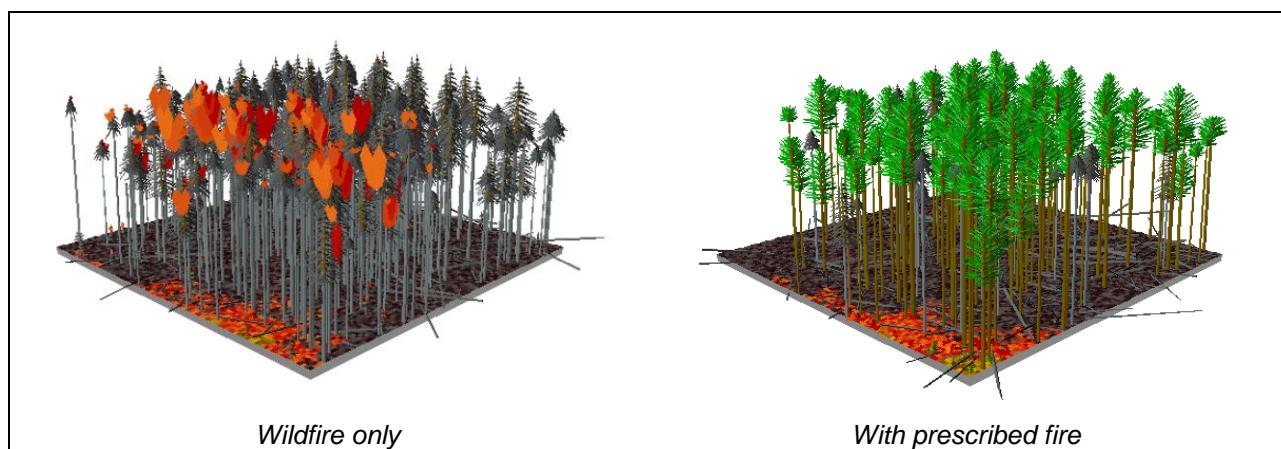


Figure 1.2.1 – Stand Visualization System (McGaughey 1997) images show how the fire behavior is different during the 2065 wildfire under the two scenarios. In the *Wildfire only* case (left), the fire is burning in the crown, while in the *With prescribed fire* case (right), only a surface fire is burning.

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.

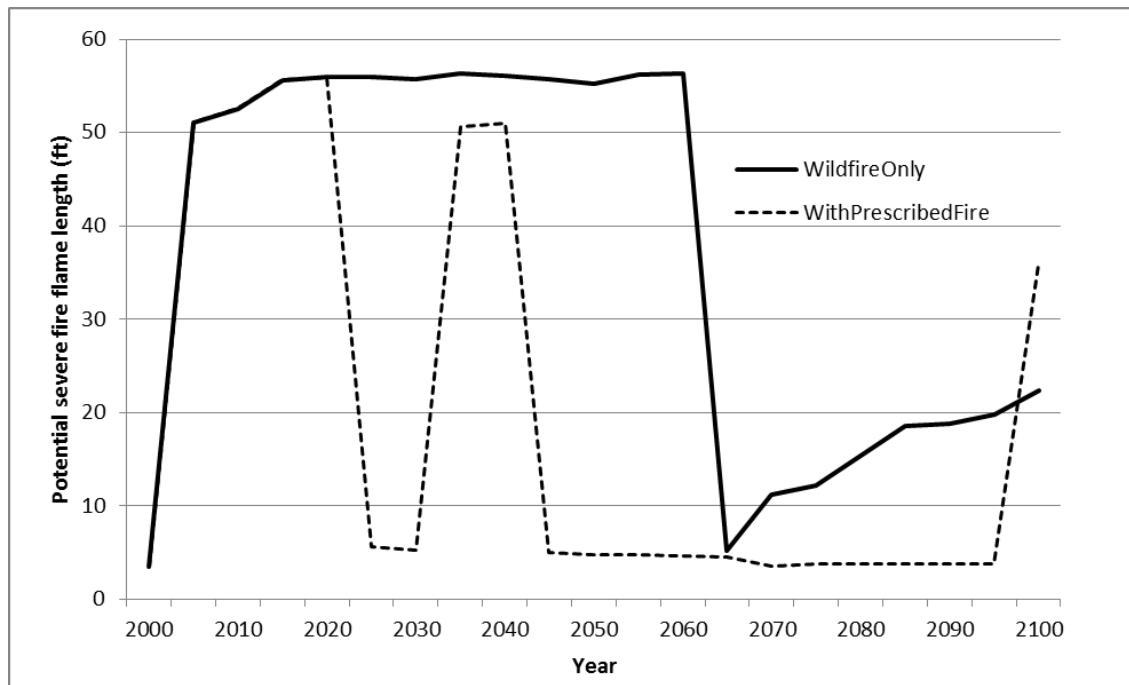


Figure 1.2.2 - The potential fire flame length for severe burning conditions is illustrated with both scenarios. The *With prescribed fire* scenario generally has a lower potential flame length in this example until the end of the simulation where it jumps to 35 feet. The large fluctuations in flame 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.

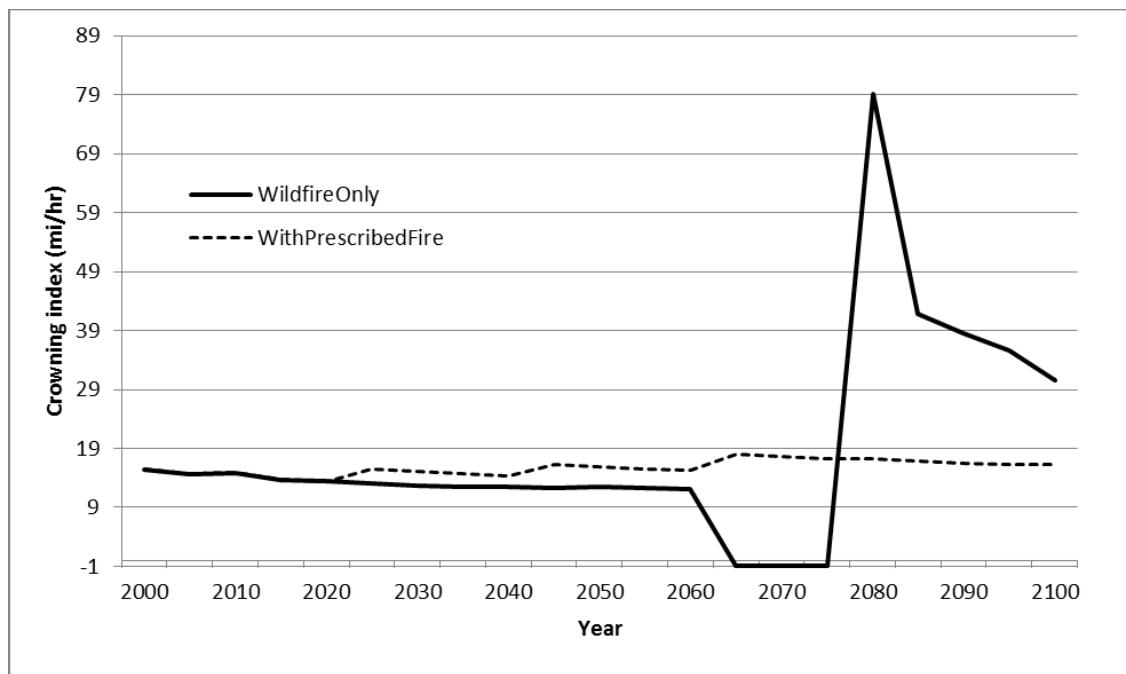


Figure 1.2.3 – The crowning index is one measure of crown fire hazard and is the windspeed needed to support an active crown fire. In this case, the crowning index is higher (less hazardous) when prescribed fire is included. In the wildfire only simulation, the crowning index increases after the wildfire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

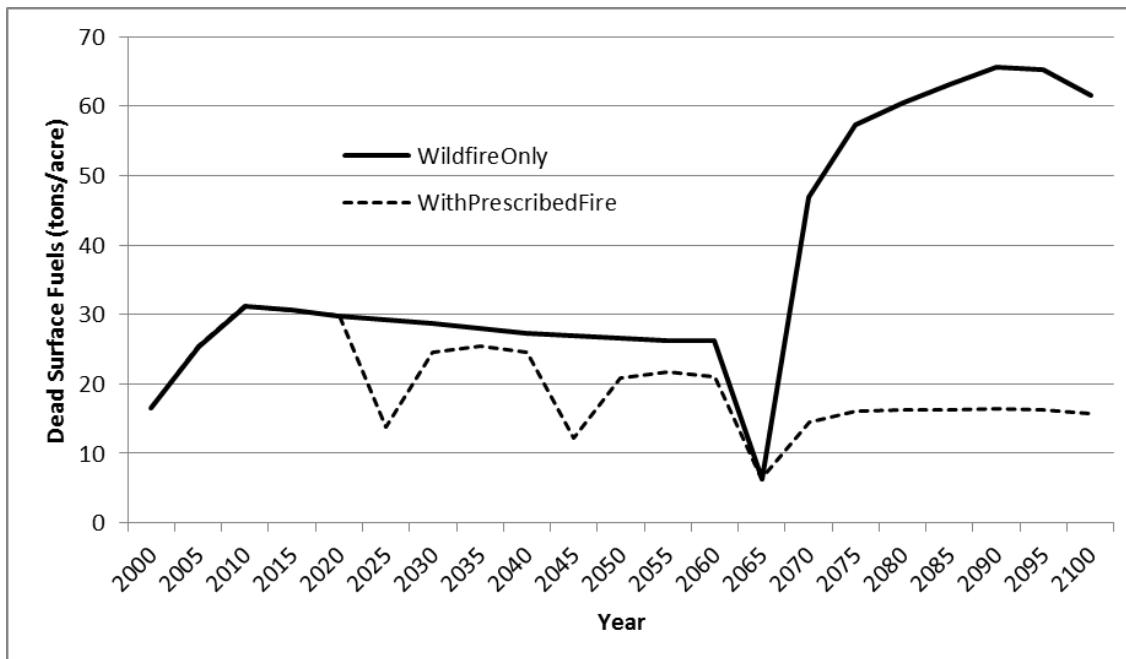


Figure 1.2.4 - Surface fuel loads are of interest to fuel managers. To wildlife and vegetation managers, this variable measures down woody debris. For the *Wildfire only* scenario, the model predicts surface fuel decomposition exceeds accumulation after the initial accumulation. A pulse of fuel accumulation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

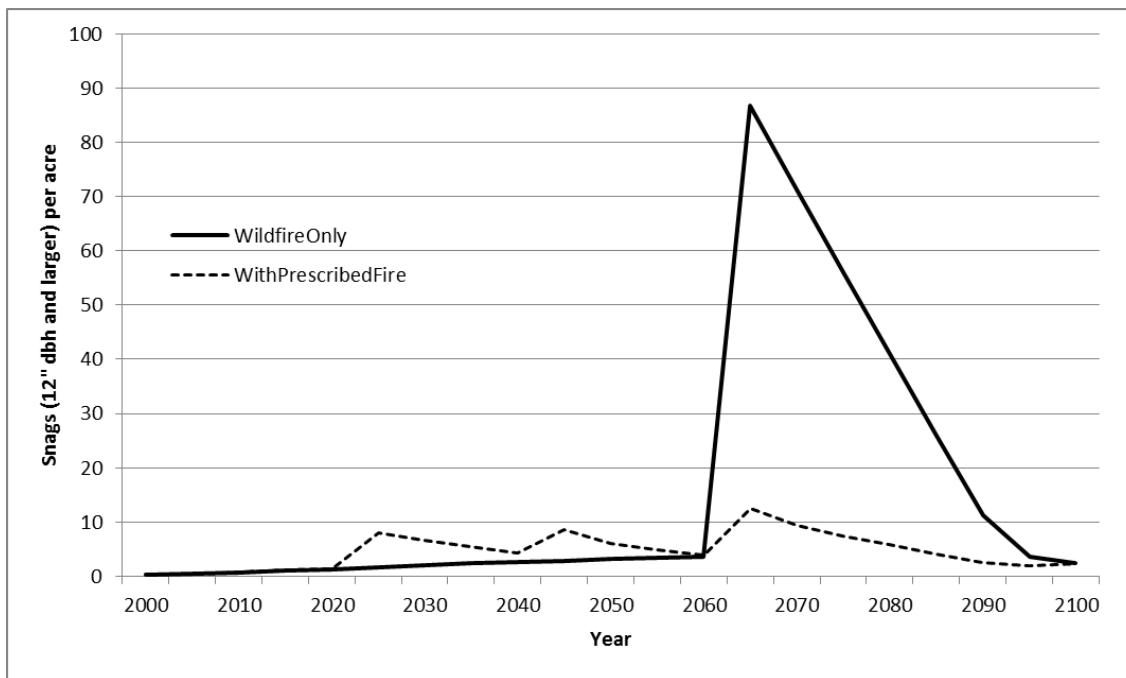


Figure 1.2.5 - The number of large snags per acre for the two scenarios.

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.

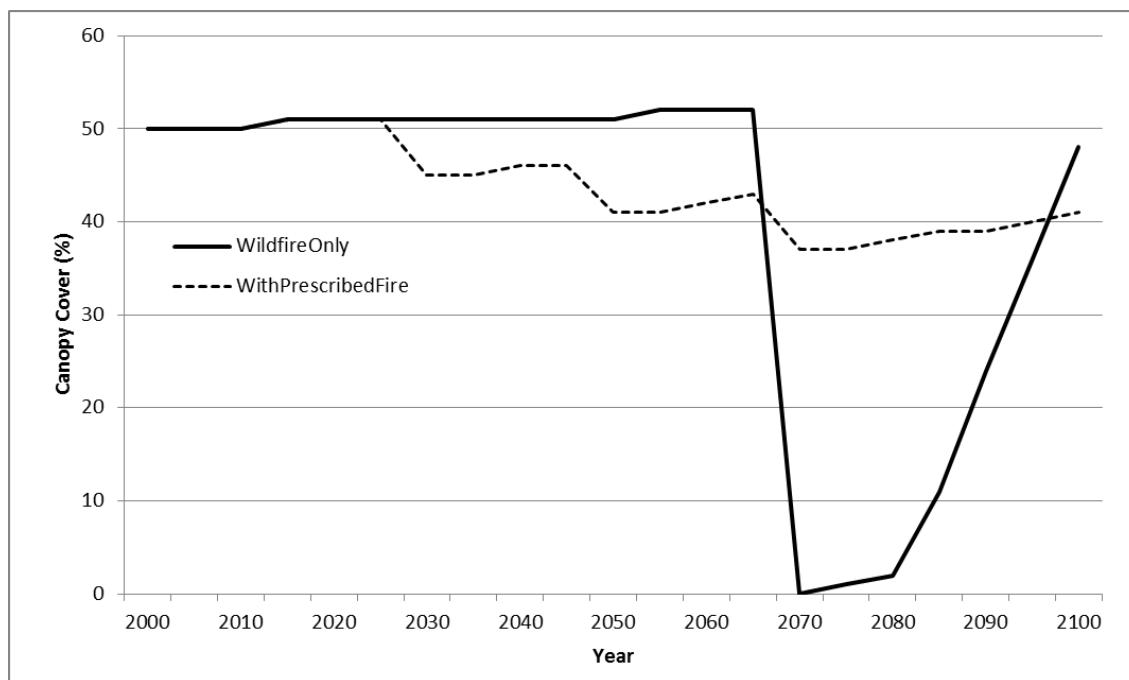


Figure 1.2.6 - Canopy cover is a key variable used in habitat assessments. The prescribed fires caused a steady reduction of this variable while the *Wildfire only* scenario provided significant cover until the wildfire of 2065.

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.

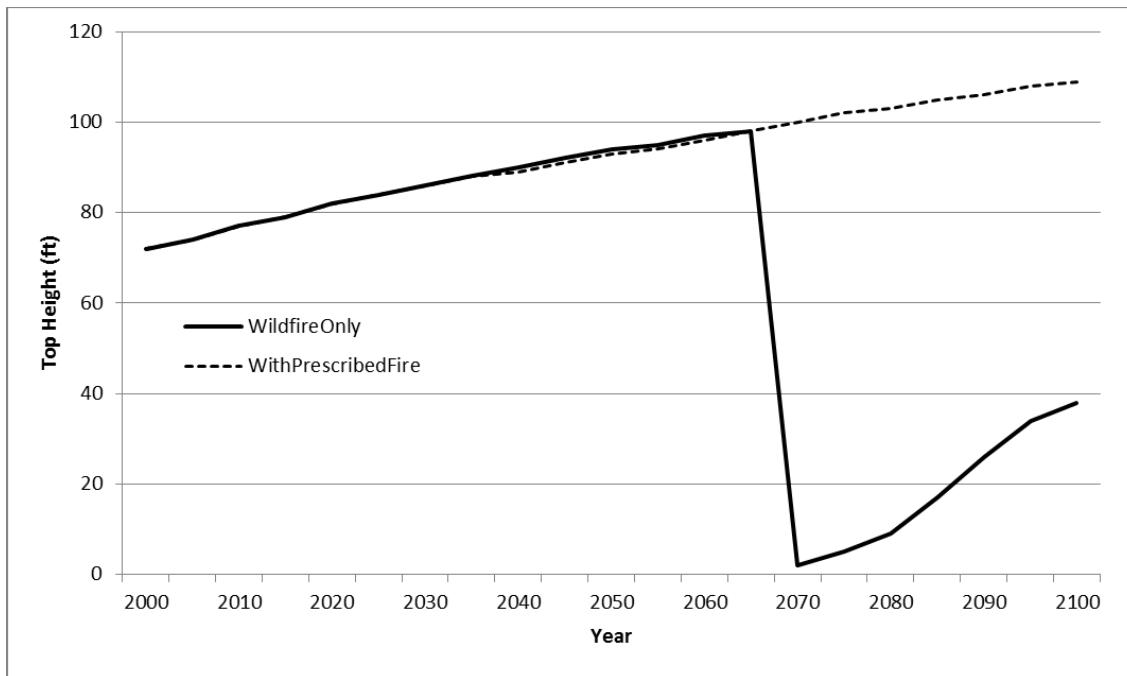


Figure 1.2.7 - Top height is the average height of the largest 40 trees per acres. The scenarios provide similar top heights until wildfire.

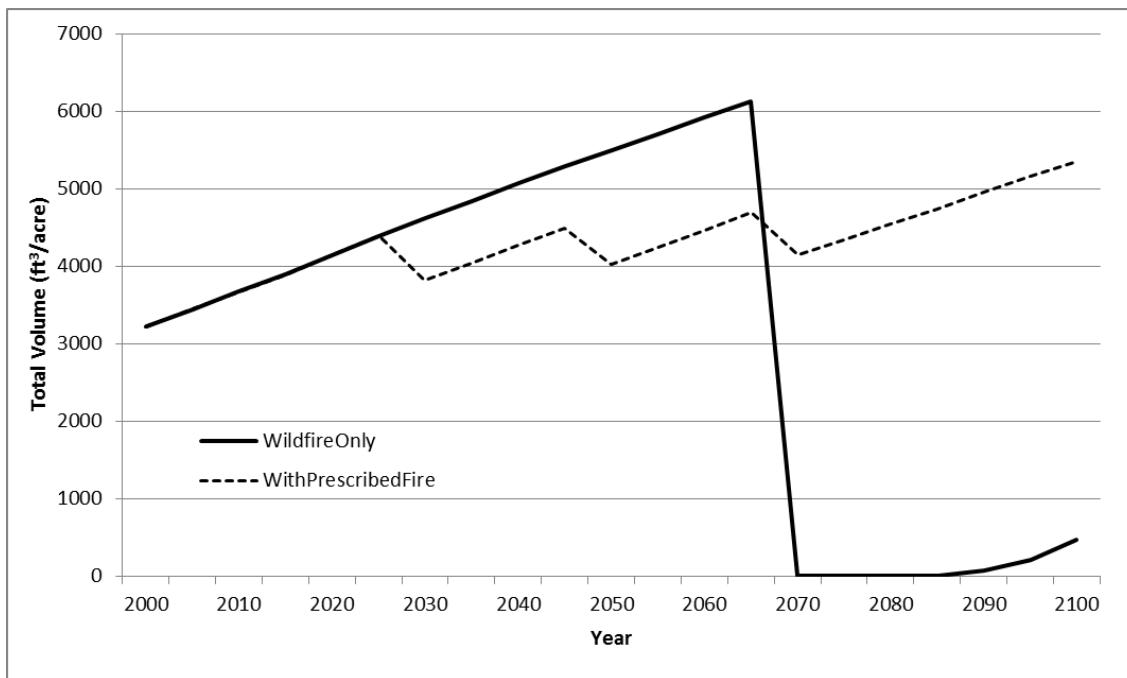


Figure 1.2.8 - The series of prescribed fires seriously reduced timber production as seen by this graph of cubic volume over time; this trend is similar when plotting board foot volume over time.

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 activities (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 be 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.

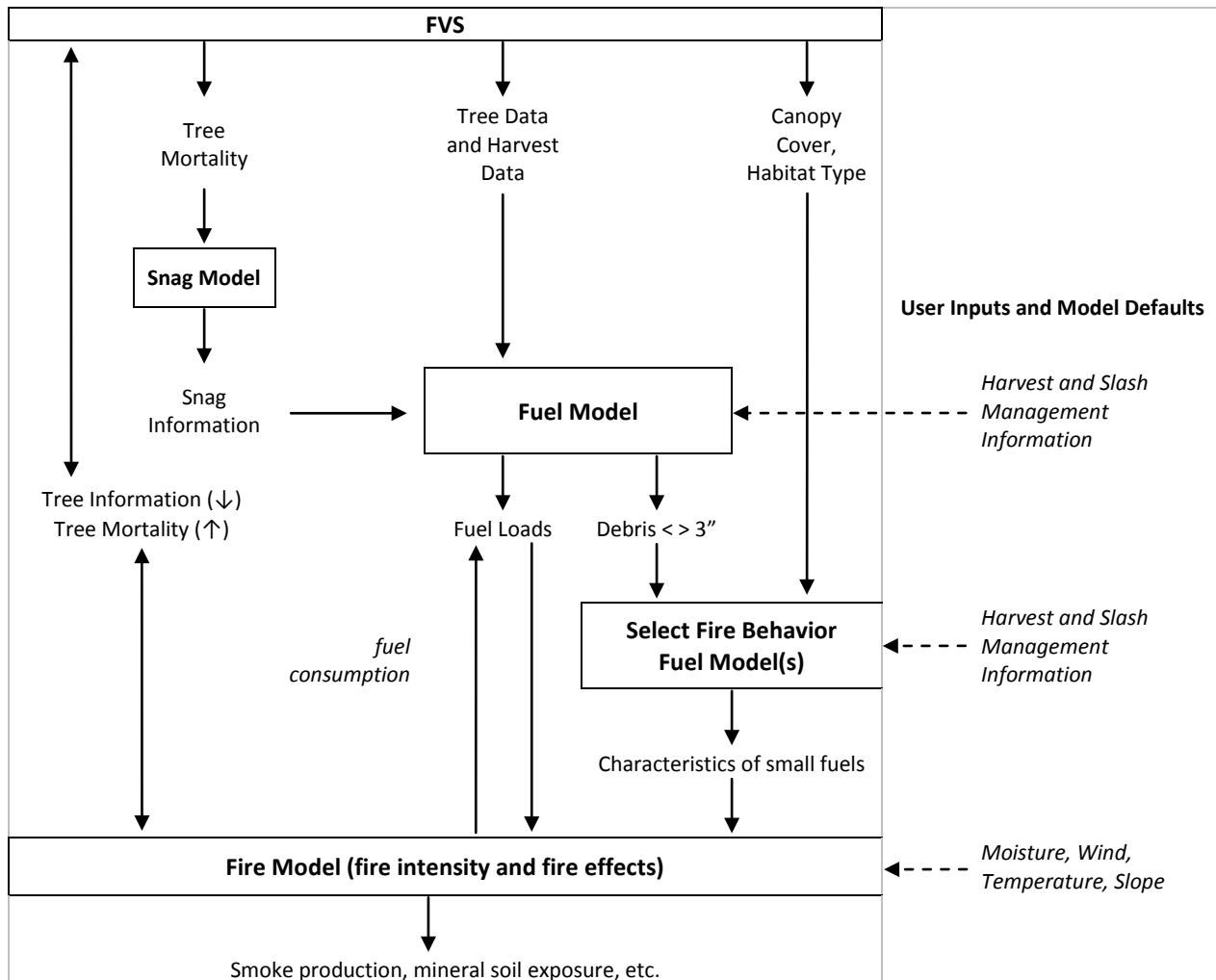


Figure 2.2.2 - Scheme of the FFE-FVS Model. The boxes in this figure show the major submodels of FFE. Arrows indicate the flow of information between submodels. See text for further explanation.

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:

$$HT_t = HT_0(1 - 0.0228mx)^t \quad \text{if } (1 - 0.0228mx)^t > 0.5$$

$$HT_t = 0.5 HT_0(1 - 0.01mx)^{t-y} \quad \text{if } (1 - 0.0228mx)^t \leq 0.5$$

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 .

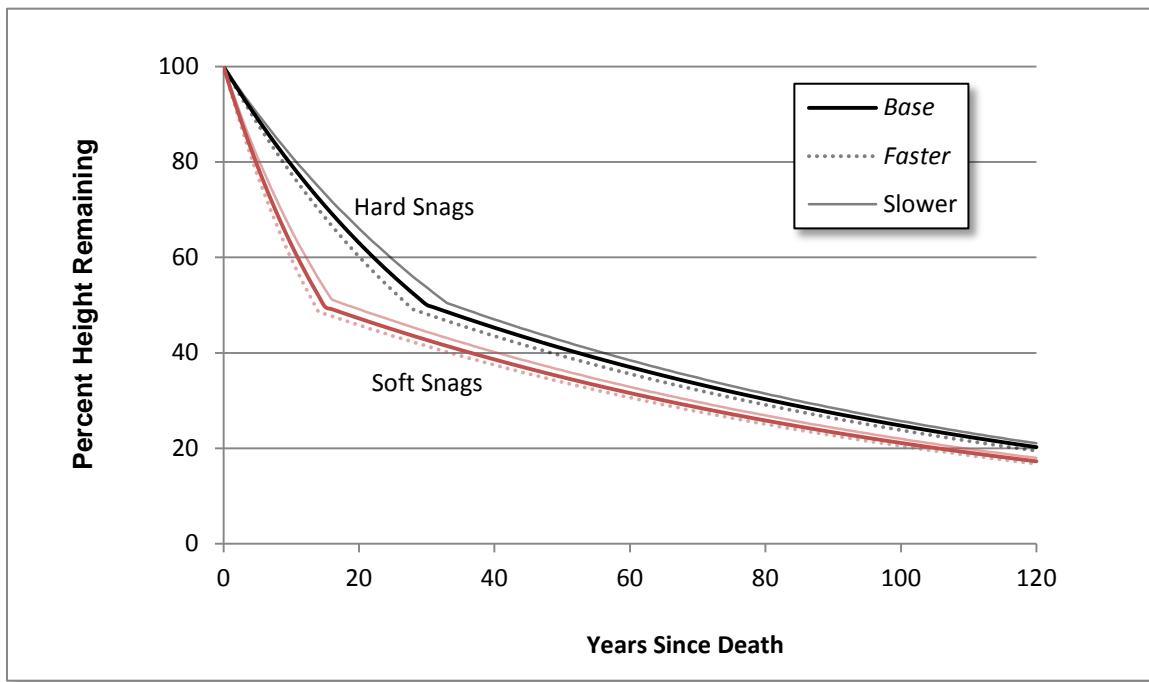


Figure 2.3.1 - Comparison between patterns of height loss for initially hard or soft snags with the three different sets of default rates.

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.

| Species | Multiplier | Years to 50% Height Loss | | % of Height After 100 Years | |
|--|------------|--------------------------|------|-----------------------------|------|
| | | 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:

$$\text{DecayTime} = m(1.24 \text{ dbh} + 13.82)$$

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.

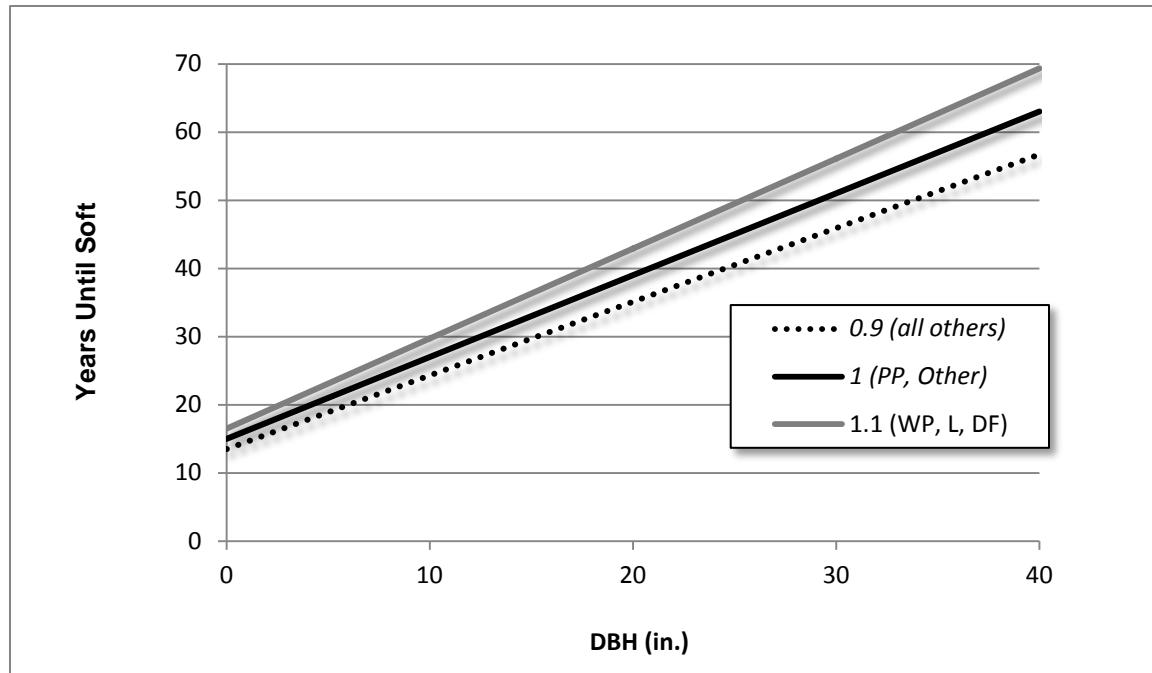


Figure 2.3.2 - Number of years until decay for the different default rates and a range of dbh. A multiplier less than 1 decreases the amount of time until decay (that is, the snag decays faster) while multipliers greater than 1 increase the amount of time before decay (that is, the snag decays slower).

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
- N_0 = 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
- N_0 = 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**.

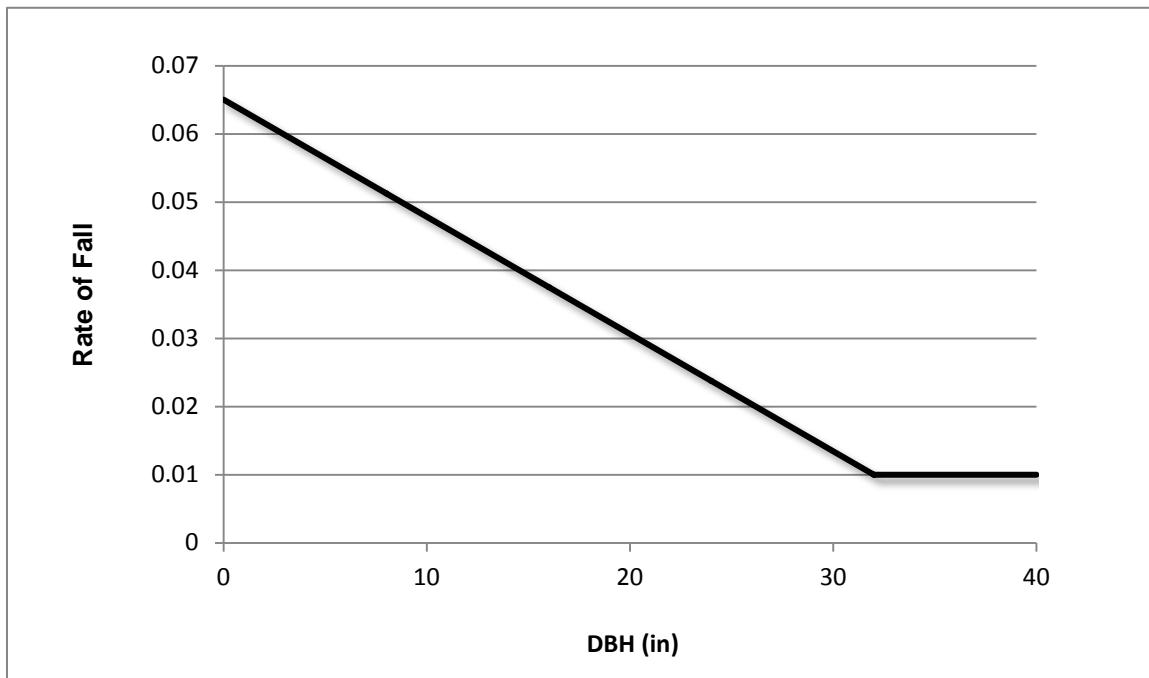


Figure 2.3.3 - The rate of fall of small snags and the first 95 percent of large snags.

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 |

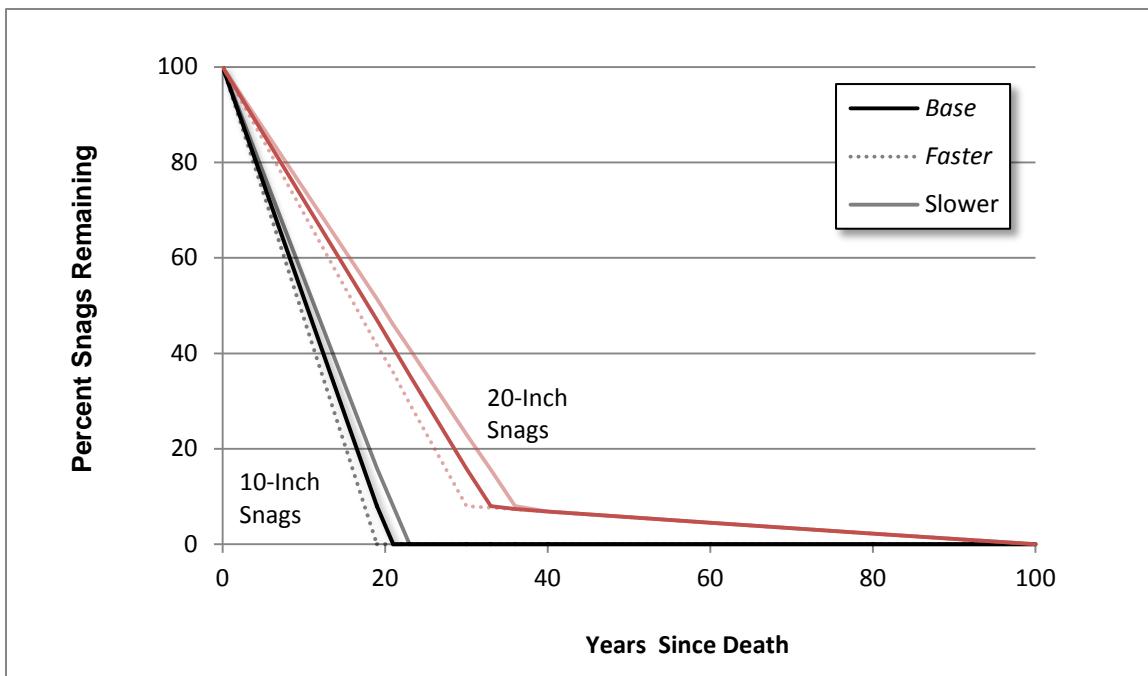


Figure 2.3.4 - Percent of large and small snags standing as a function of years since death. The last 5 percent of large snags, or those greater than 18" dbh, remain for a long period of time, while small snags fall at a consistent rate. Fall rates decrease with increasing dbh and differ between species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

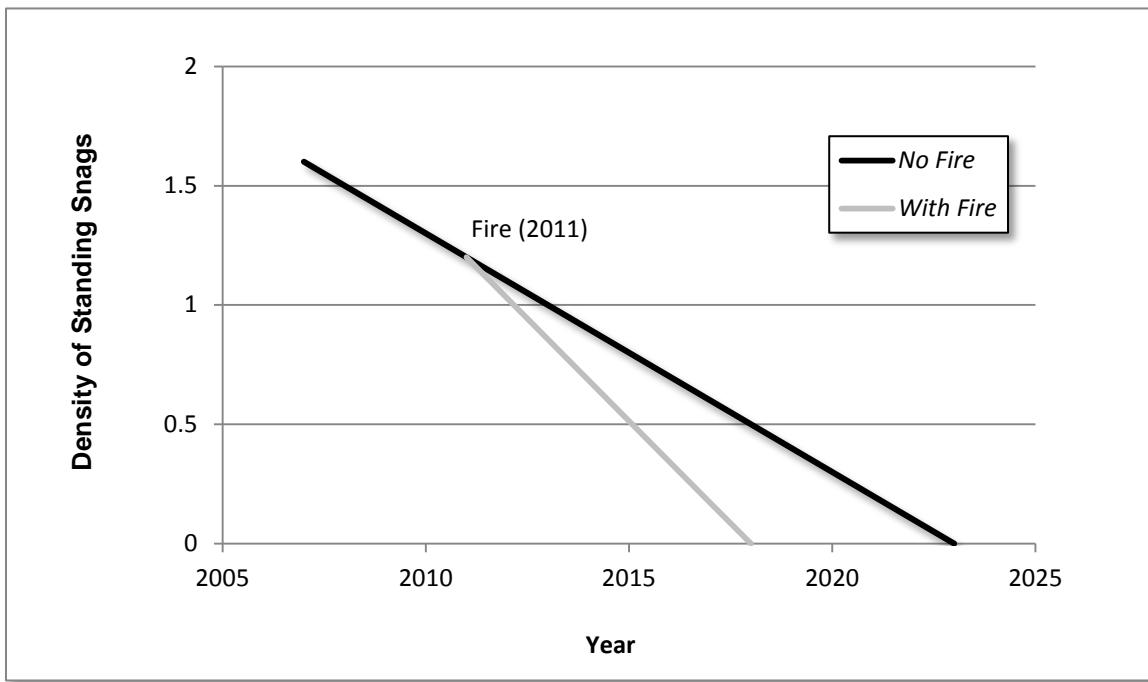


Figure 2.3.5 - Effect of fire on the fall rate of a sample snag record. The example record contains 6.8" GF snags that were created in 2006. The graph shows the density of the snags without a fire in 2011.

2.3.7 Management

Snags can be created by using the base FVS model keyword **FIXMORT** or by using **YARDLOSS** in conjunction 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 **CYCLET** 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

| YEAR | SP | CL | DBH (IN) | DEATH DBH | CURR HEIGHT ---(FT)--- | CURR VOLUME (FT ³) | DENSITY (#/ACRE) | | | | | |
|------|----|----|-------------|--------------|------------------------------|--------------------------------------|------------------|-----|------|------|------|-------|
| | | | | | | | DBH | DBH | YEAR | 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.

| Year | Sp | Dbh cls | Death dbh | Height | | Total Volume | | | Year Died | Density | | |
|------|----|------------|--------------|--------|------|--------------|------|-------|--------------|---------|------|-------|
| | | | | hard | soft | hard | soft | total | | 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 | | | | | | | | | | | | |
| YEAR | HARD SNAGS/ACRE | | | | | | SOFT SNAGS/ACRE | | | | | | GRAND TOTAL | |
| | >=00" | >=12" | >=18" | >=24" | >=30" | TOTAL | >=00" | >=12" | >=18" | >=24" | >=30" | TOTAL | GRAND TOTAL | |
| 2010 | 9.2 | 1.7 | 1.7 | 0.0 | 0.0 | 9.2 | 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 | 70.4 | 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 | 379.2 | 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 | 143.6 | 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 | 76.5 | 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 | 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 | 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 | 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 | 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 | 2.0 | |
| 2100 | 35.4 | 1.1 | 0.0 | 0.0 | 0.0 | 35.4 | 1.5 | 1.5 | 1.5 | 0.4 | 0.2 | 0.0 | 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).

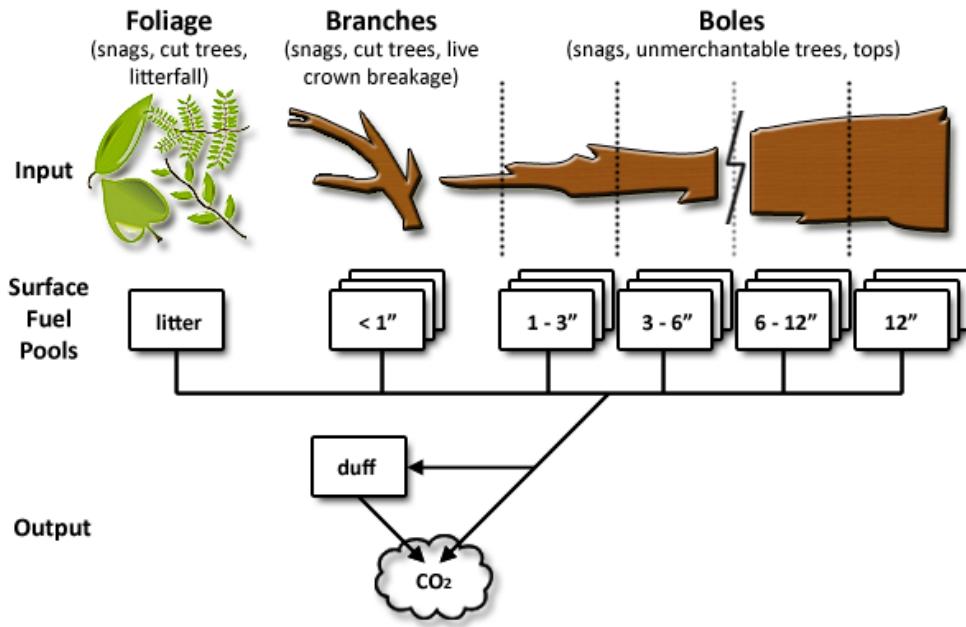


Figure 2.4.1 - Flow of material within the fuel model. Material enters the various size classes, decays and goes either to duff pool or to air (which is not tracked in this model). Not all size classes are shown in the figure. See Table 2.4.1 for additional information on each size class.

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 | 0.8 | 30.0 |
| | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 0.4 | 12.0 |
| western larch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 10.0 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 5.0 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 10.0 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 5.0 |
| grand fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 25.0 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 12.0 |
| western hemlock | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 35.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 12.0 |
| western redcedar | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 35.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 12.0 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 15.0 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 7.0 |
| Engelmann spruce | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 30.0 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 12.0 |
| subalpine fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 30.0 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 12.0 |
| ponderosa pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 5.0 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.8 |
| other | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 30.0 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 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/ft ³ |
|--------------------------|------------------|----------------------------|
| 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:

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

where:

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

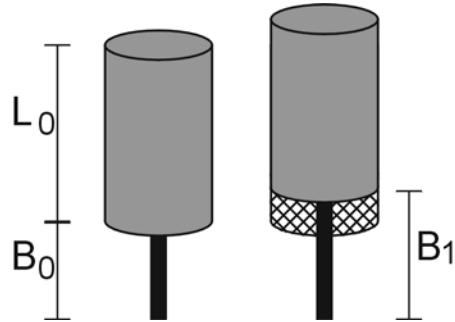


Figure 2.4.2 - Simulation of crown lifting. B_0 is the height of the base of the crown in the previous FVS cycle, B_1 is the height of the base of the crown in the current cycle, and L_0 is the length of the crown in the previous cycle. FFE assumes that all crown material in the space vacated by the 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:

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

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_{oi} = 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.

| Snag Species | Amount remaining 5 years after death (data) | | | | Estimated time to 100% loss (years) | | | |
|---------------------------|---|-------|----------|-----------------------|-------------------------------------|---------------|------------------|--------------------|
| | 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 is 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:

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

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" | | |
| 0.25" ≤ diam < 1" | 0.12 | |
| 1" ≤ diam < 3" | 0.09 | |
| 3" ≤ diam < 6" | | 0.02 |
| 6" ≤ diam < 12" | 0.015 | |
| 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**.

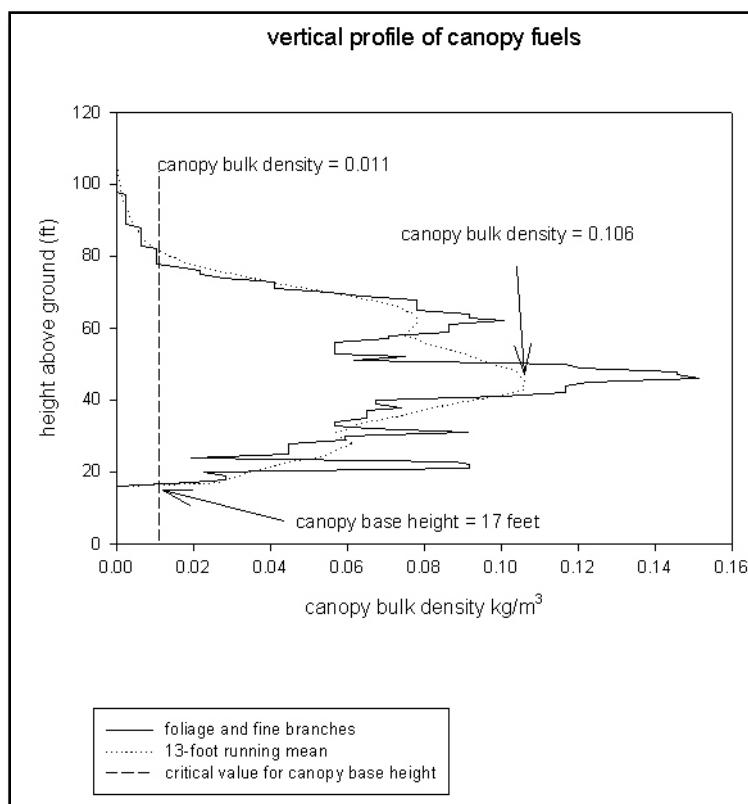


Figure 2.4.3 - Canopy fuel characteristics are determined by examining the vertical distribution of canopy fuels. Canopy bulk density is defined as the maximum of the 13-foot running mean of 1-foot deep layers. Canopy base height is defined as the lowest height at which the canopy bulk density exceeds 0.011 kg/m³.

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 model Code | Fuel model number | Name | Fuel Load (lbs/ft ²) | | | Fuel model type ^a | SAV Ratio (1/ft) ^b | | | Fuel bed depth (ft) | Dead fuel extinction moisture (percent) | Heat Content (BTU/lb) ^c | | |
|-----------------|-------------------|---|----------------------------------|--------|--------|------------------------------|-------------------------------|------------|------|---------------------|---|------------------------------------|------|------|
| | | | 1-hr | 10-hr | 100-hr | | Live herb | Live woody | 1-hr | | | | | |
| - | 1 | Short grass | 0.034 | 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.

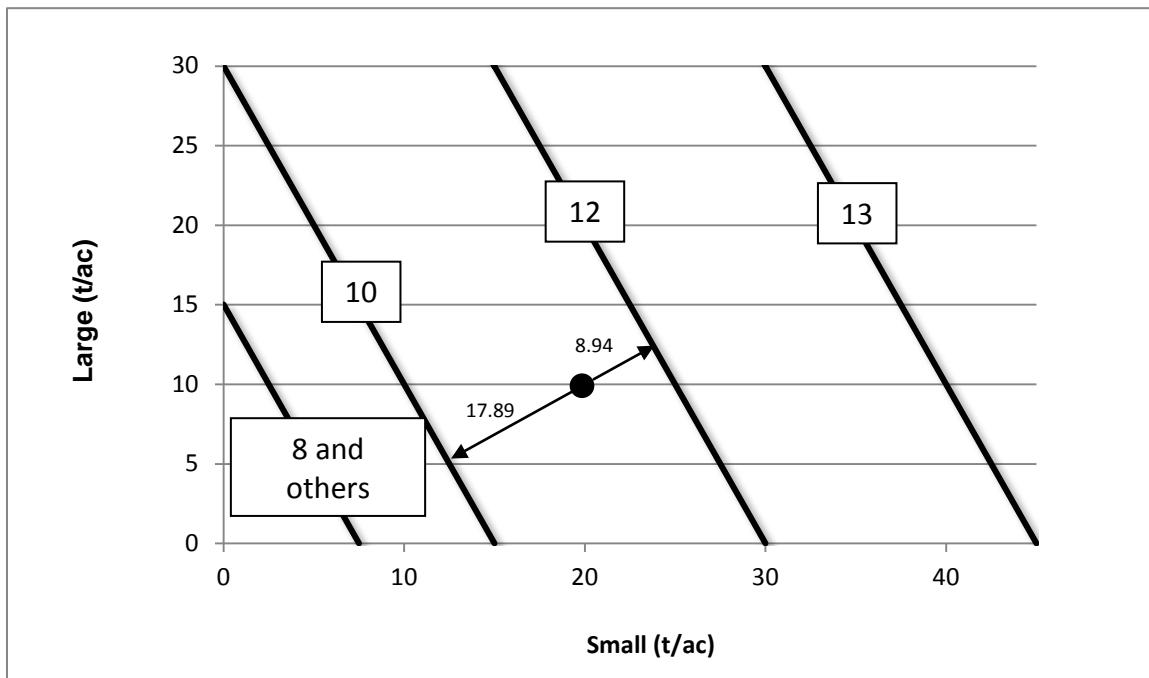


Figure 2.4.4 - An example of dynamic fuel modeling, based on large and small woody surface fuel. The lines here correspond to fuel models for natural fuel in closed stands for many habitat types, with the fuel model number shown on the line. The point shown below here will result in an interpolation 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, W_{10} and W_{12} can be calculated in this example as:

$$W_{10} = \frac{1/17.89}{(1/17.89) + (1/8.94)} = 0.33$$

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

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.

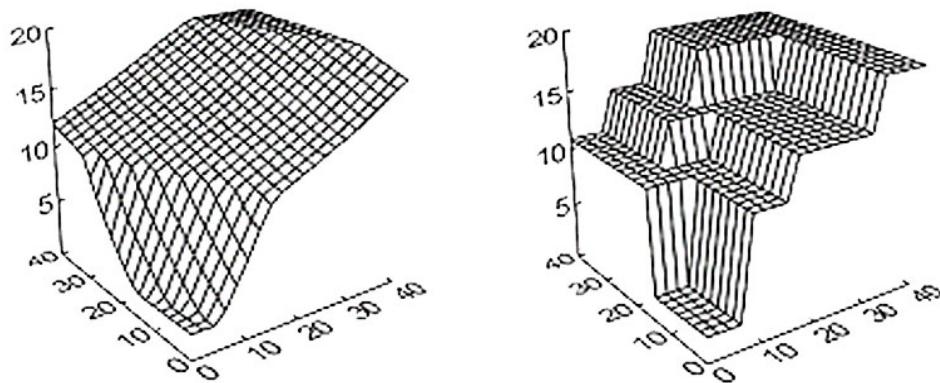


Figure 2.4.5 - Example of predicted flame length over a range of small and large woody fuels (tons/acre). Predictions using the dynamic option are on the left, and predictions using the static option are on the right.

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 **FUELRET** 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 **FUELRET**.

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

| Harvest Method | Slash Treatment Type | | |
|-----------------------|-----------------------------|----------------------|-----------------------|
| | 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 | | | | | | | | |
| YEAR | LITT. | DEAD FUEL | LIVE | DEAD | LIVE | SURF | 0-3" | >3" | FOL | 0-3" | >3" | TOTAL SURF | 0-3" | >3" | FOL | 0-3" | >3" | TOTAL BIOMASS | TOTAL BIOMASS CONS REMOVED | |
| YEAR | LITT. | DUFF | 0-3" | >3" | 3-6" | 6-12" | >12" | HERB | SHRUB | TOTAL | 0-3" | >3" | TOTAL | 0-3" | >3" | FOL | 0-3" | >3" | TOTAL BIOMASS | 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.

| ***** 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 | 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 | 0.0 | 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 | 0.0 | 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 | 0.0 | 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 | 0.0 | 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 | 0.0 | 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 | 0.0 | 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 | 0.0 | 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 | 0.0 | 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 | 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 * volume ^{0.8715} |
| 6-12" | % cover = 0.0092 * volume ^{0.8795} |
| 12-20" | % cover = 0.0063 * volume ^{0.8728} |
| 20-35" | % cover = 0.0069 * volume ^{0.8134} |
| 35-50" | % cover = 0.0033 * volume ^{0.8617} |
| >50" | % cover = 0.0949 * 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 |

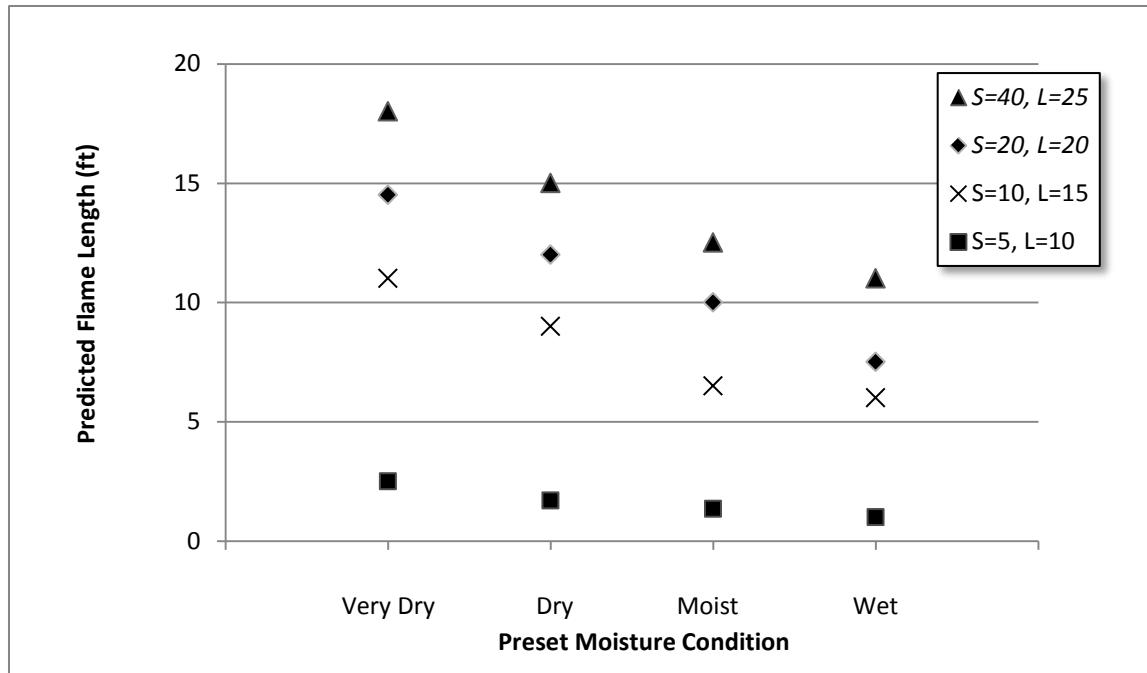


Figure 2.5.1 - Example flame lengths for each of the predefined moisture conditions for four different combinations of small ($S < 3"$) and large ($L > 3"$) fuel amounts (in tons/acre). Other factors being equal, the flame lengths decrease as moisture levels increase.

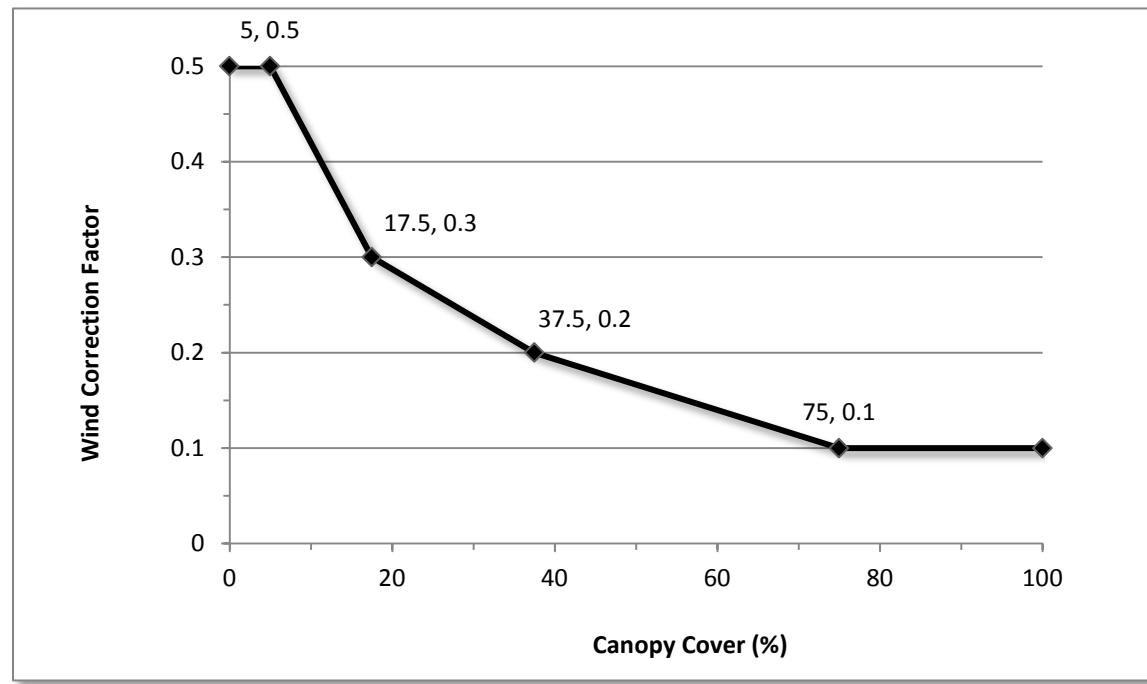


Figure 2.5.2 - The correction factors used to calculate mid-flame wind speed from wind at 20 feet above the vegetation

Air Temperature: The ambient air temperature ($^{\circ}\text{F}$) 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.

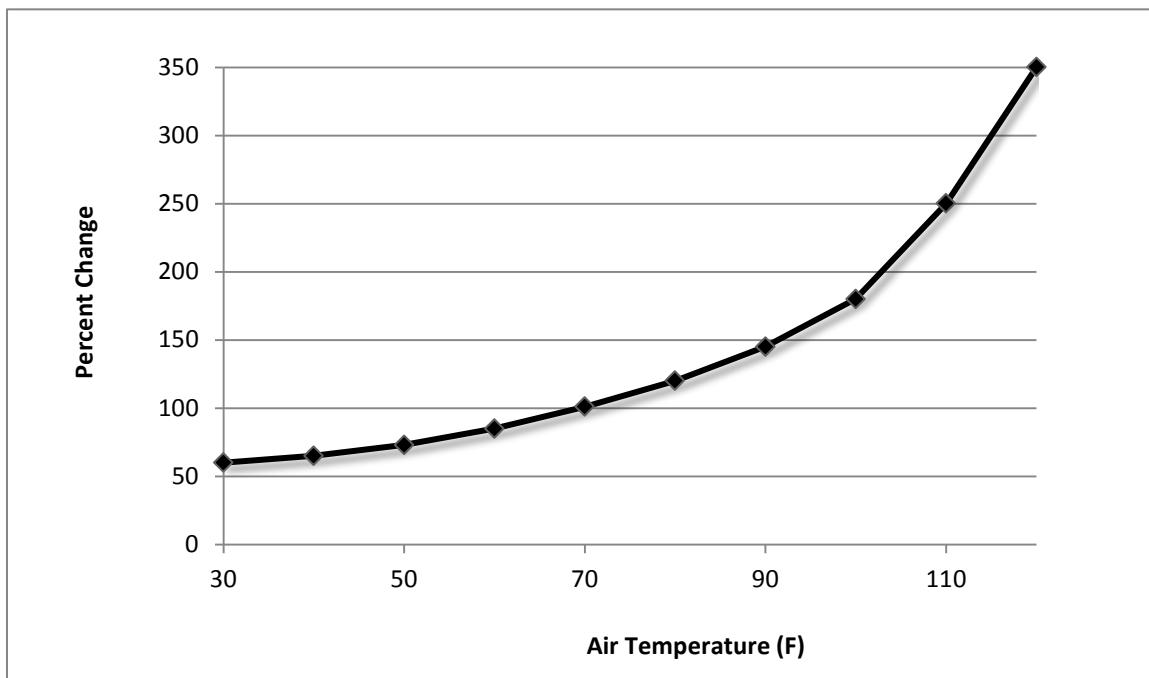


Figure 2.5.3 - The change in scorch height as temperature changes. In this figure, the scorch heights are relative to the scorch height at an air temperature of 70° (the default value). Thus, at 105° the scorch height would be about two times (200 percent) higher than at 70°.

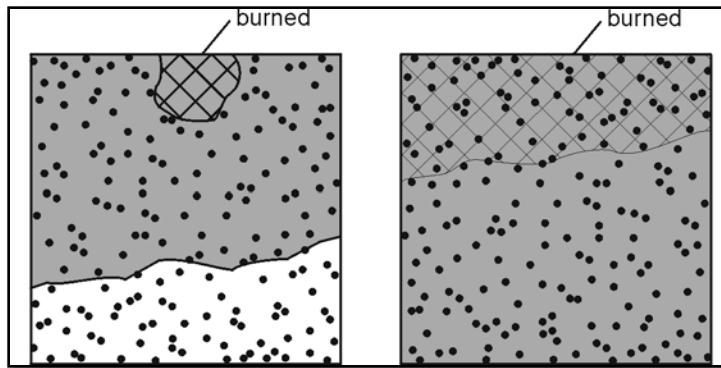


Figure 2.5.4 - Schematic diagram of the difference between pile burning (left) and jackpot burning (right). Each diagram represents a stand. The shaded areas are the areas from which fuel is concentrated. The hatched area represents the area that is then burned.

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.

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

$$b = v_{sp} d$$

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

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 |

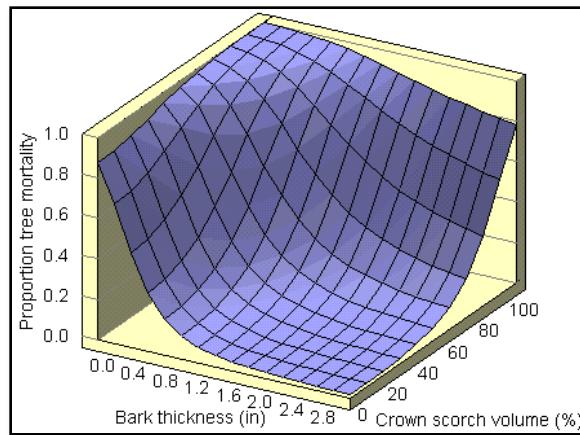


Figure 2.5.5 - Predicted tree mortality is based on bark thickness and the percent of the volume of the crown scorched.

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).

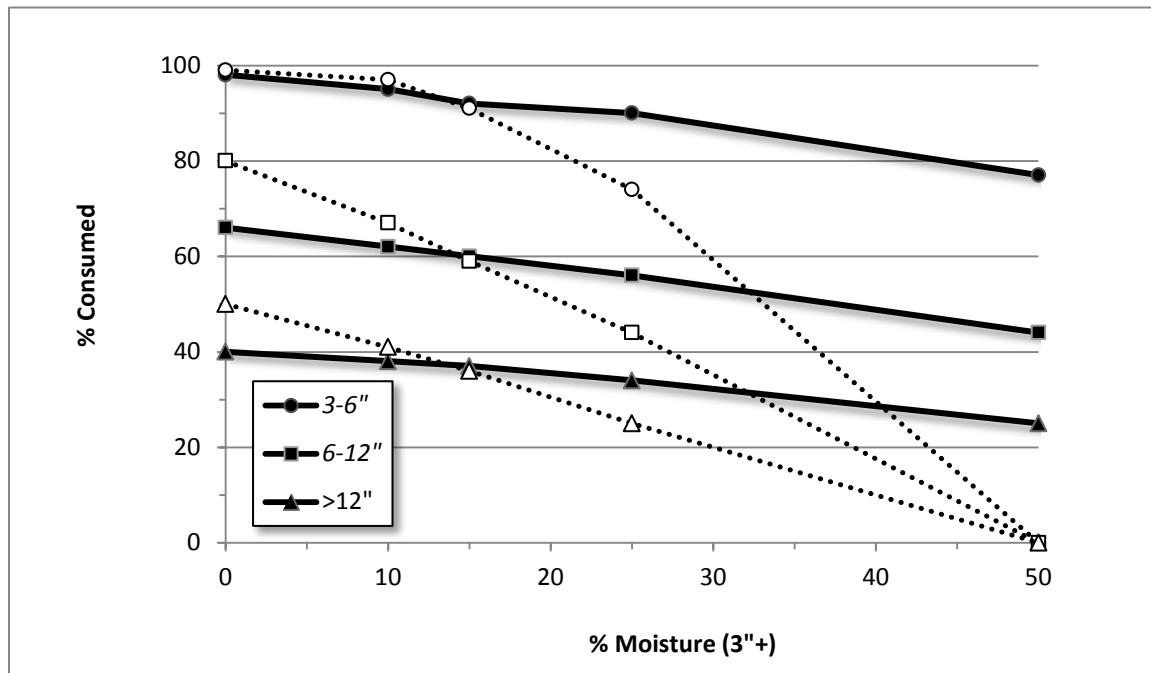


Figure 2.5.6 - Predicted fuel consumption for large woody fuel (>3") for different size classes and moisture contents. The points on the graph indicate the four default fuel moisture conditions. The solid lines and symbols are for the naturally occurring fuel, while the dotted lines and open symbols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

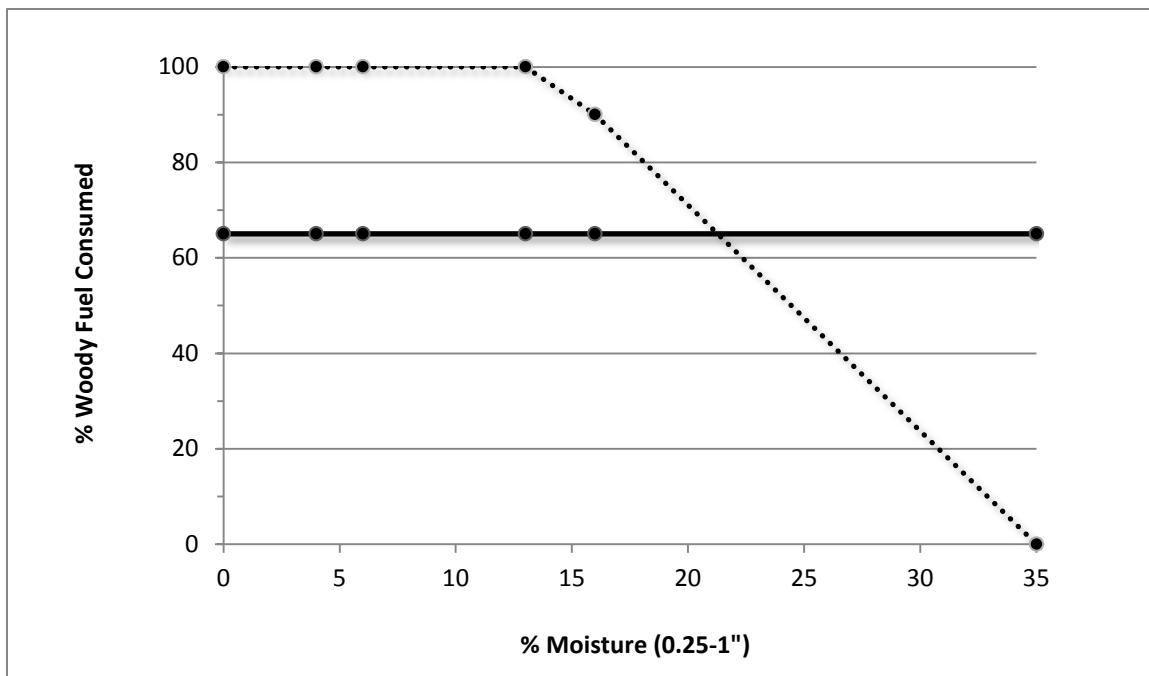


Figure 2.5.7 - Predicted fuel consumption for 1 to 3 inches woody fuel for different moisture levels. The points on the graph indicate the values at the four default fuel moisture conditions. The solid line is for the naturally occurring fuel, while the dotted line is for fuel resulting from management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

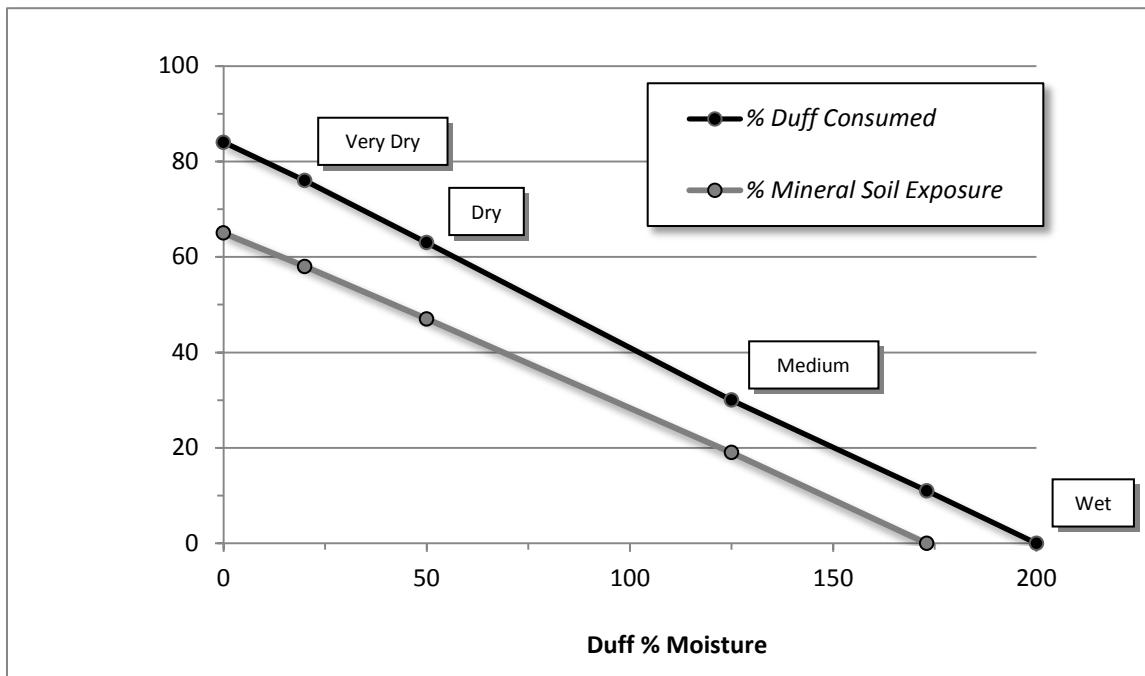


Figure 2.5.8 - Relationship between duff consumption, mineral soil exposure, and duff moisture levels. The points on the graph indicate the four default fuel moisture conditions. Duff consumption depends on duff moisture and mineral soil exposure is a function of duff consumption.

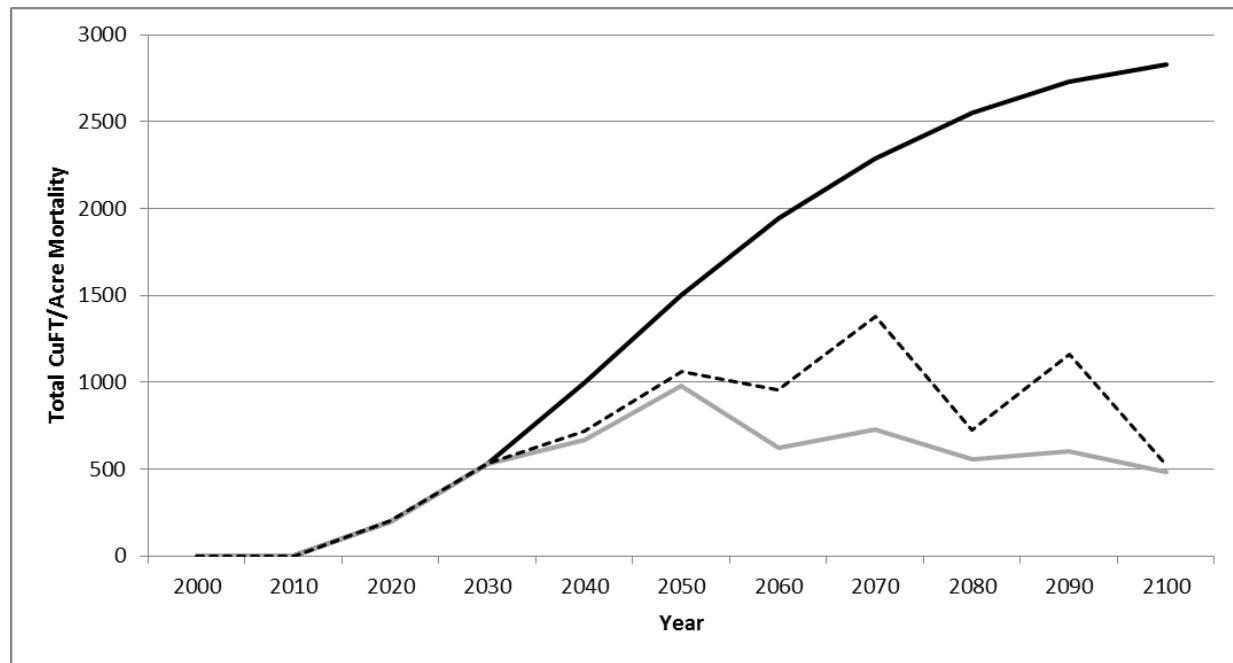
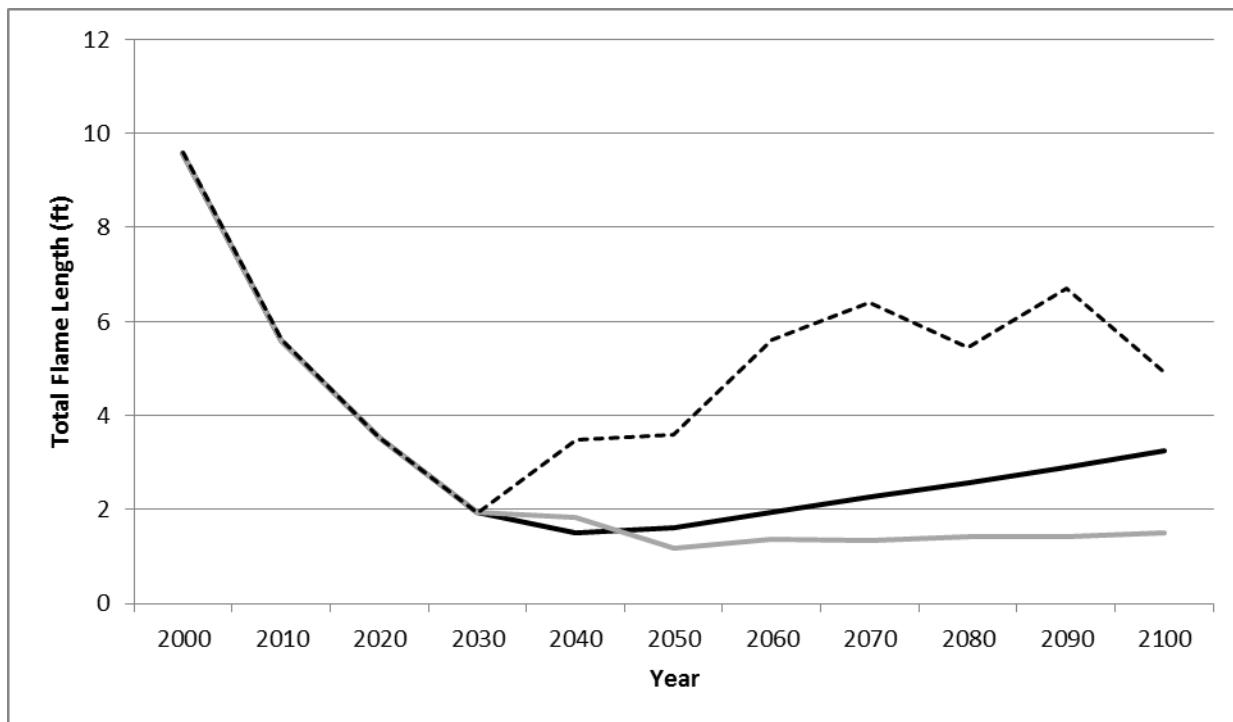


Figure 2.5.9 - Potential total flame length and cuft/acre mortality in a stand under three management scenarios. The stand is established at the beginning of the run. In one scenario no treatment was applied (dark line). In two scenarios the stand was thinned from below (in 2040, 2060, 2080, and 2100). 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.

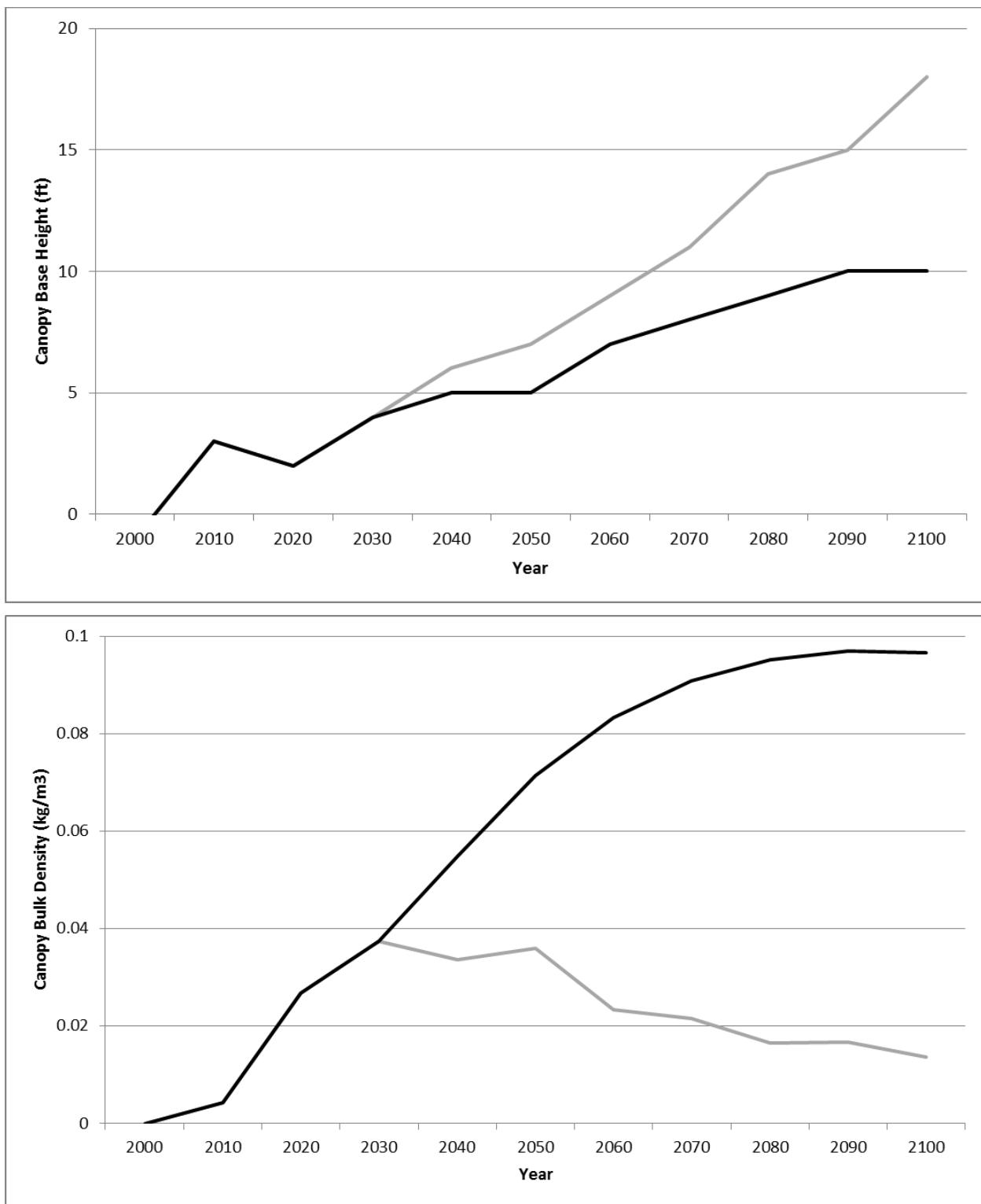


Figure 2.5.10 - Canopy base height and bulk density under different management scenarios. A mixed-conifer stand is established at the beginning of the simulation (dark line). In one scenario this stand is repeatedly thinned from below (light line). The canopy fuel is independent of whether the harvested 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 | | | | | | | | | | | | | | | |
| YEAR | MIDFLAME | | | FLAME | | | SCORCH | | | FUEL MODELS | | | | | |
| | % MOISTURE | 1HR | 10HR | 100HR | 3+ | DUFF | LIVE | W | LIVE | H (MPH) | (%) | (FT) | (FT) | FIRE TYPE | MOD %WT MOD %WT 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 | Percent of mineral soil exposure. |
| 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 Consumed | Percent of available fuel that was consumed. Divided into duff and fuels greater than 3 inches. |
| Percent Trees with Crown | 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 | | | | | | | | | | | | | | | | | |
|--|--------|----------------------------|---------------------------|------|------|------|------|-------|------|-------|-------|----------------|--------------------------|------------------------------------|-----|------|------|
| YEAR | EXPOSR | PERCENT MINERAL SOIL | FUEL CONSUMED (TONS/ACRE) | | | | | | | | | | % TREES WITH CRWNG | SMOKE PRODUCTION (TONS/ACRE) | | | |
| | | | LITR | DUFF | 0-3" | 3"+ | 3-6" | 6-12" | 12"+ | SHRUB | CRWNS | TOTAL CONS. | DUFF | 3"+ | | | |
| 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 report for fire-based mortality. In this simulation all trees were killed.

| ***** FIRE MODEL VERSION 1.0 ***** MORTALITY REPORT | | | | | | | | | | | | |
|--|-----|---|----------|-----------|-----------|-----------|-----------|--------|------------|-------------|--|--|
| YEAR | SP | NUMBER KILLED / NUMBER BEFORE (BY DIAMETER CLASS IN INCHES) | | | | | | >=50.0 | BASAL AREA | TOTAL CU FT | | |
| | | 0.0- 5.0 | 5.0-10.0 | 10.0-20.0 | 20.0-30.0 | 30.0-40.0 | 40.0-50.0 | | | | | |
| 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 | | | | | | | | | | | | | | | | |
|--|--|-----|-----|-----|-----|-----|-----|----|----|----|----|----|----|----|---|---|
| YEAR | DEPTH WHERE TEMP EXCEEDS | | | | | | | | | | | | | | | |
| | --TEMP IN CELCIUS AT THESE DEPTHS BELOW SURFACE (CM)-- | | | | | | | | | | | | | | | |
| 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 CONDITION | WIND (MPH) | TEMP (°F) | FUEL MOISTURE CONDITIONS (PERCENT) | | | | | | | | | | | | | | | POTENTIAL MORTALITY | | | |
| | | | 0-0.25" | 0.25-1" | 1-3" | 3+* | DUFF | LIVE WOODY | LIVE HERB | SEVERE | MOD. | SEV. | MOD. | SEV. | MOD. | SEV. | MOD. | | | | |
| SEVERE | 20.0 | 70 | 4. | 4. | 5. | 10. | 15. | 70. | 70. | | | | | | | | | | | | |
| Moderate | 6.0 | 70 | 12. | 12. | 14. | 25. | 125. | 150. | 150. | | | | | | | | | | | | |
| 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 | |
| 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. Merchantability 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 | | | f(sp,dbh) |
| Belowground, Dead | method always used | ✓ | | 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 negligible 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 | | | | | | | | | | | | |
| YEAR | Aboveground Live | | Belowground | | Forest | | | Total | | Total | | Carbon | | Stand | Removed | Released |
| | Total | Merch | Live | Dead | Stand | DDW | Floor | Shb/Hrb | Carbon | Stand | 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 | 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 | 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 | 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 | 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 | 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 | 0.0 | | | | |

| ESTIMATED FUEL LOADINGS | | | | | | | | | | | | | | | | | | | |
|--|-----------|--------|------|------|------|-------|------|------|------|------|-------|------|-----|------|------|-----|---------------|----|----|
| SURFACE FUEL (TONS/ACRE) STANDING WOOD (TONS/ACRE) | | | | | | | | | | | | | | | | | | | |
| YEAR | DEAD FUEL | | | | | | | | LIVE | | | | | | | | | | |
| | DEAD FUEL | LITTER | DUFF | >3" | 3-6" | 6-12" | >12" | HERB | SURF | SHRB | TOTAL | 0-3" | >3" | FOL | 0-3" | >3" | TOTAL BIOMASS | | |
| 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 | Emisssns | 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 fallowdown 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 |
| FUELRET | 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/ft².

- 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/ft²) for 0-0.25 inch fuel.
- field 8: Loading (lbs/ft²) for 0.25-1 inch fuel.
- field 9: Loading (lbs/ft²) for 1-3 inch fuel.
- field 10: Loading (lbs/ft²) 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/ft²) 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 conjunction 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.

FUELRET: 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 FUELRET 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.

| | | Fuel size class | | | | | |
|---------|----------|------------------------|--------------------------|------------------------|---------|------|------|
| Field 3 | moisture | 0-2.5 inch (1 hour) | 0.25-1 inch (10 hour) | 1-3 inch (100 hour) | ≥3 inch | Duff | Live |
| Value | level | | | | | | |
| 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 (usually 18 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 - usually 18 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 than 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 coarse 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/ft²/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 Southeast Alaska (AK)

4.2.1 Tree Species

The Southeast Alaska variant models the 11 tree species shown in Table 4.2.1. Two additional categories, ‘other hardwoods’ and ‘other softwoods’, are modeled using black cottonwood and Pacific silver fir, respectively.

Table 4.2.1 - Tree species simulated by the Southeast Alaska variant.

| Common Name | Scientific Name | Notes |
|--------------------|----------------------------------|----------------------|
| white spruce | <i>Picea glauca</i> | |
| western redcedar | <i>Thuja plicata</i> | |
| Pacific silver fir | <i>Abies amabilis</i> | |
| mountain hemlock | <i>Tsuga mertensiana</i> | |
| western hemlock | <i>Tsuga heterophylla</i> | |
| Alaska cedar | <i>Callitropsis nootkatensis</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Sitka spruce | <i>Picea sitchensis</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| red alder | <i>Alnus rubra</i> | |
| black cottonwood | <i>Populus trichocarpa</i> | |
| other hardwoods | | = black cottonwood |
| other softwoods | | = Pacific silver fir |

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) |
|--------------------|--------------------------------|
| white spruce | 23.1 |
| western redcedar | 19.3 |
| Pacific silver fir | 24.9 |
| mountain hemlock | 26.2 |
| western hemlock | 26.2 |
| Alaska cedar | 26.2 |
| lodgepole pine | 23.7 |
| Sitka spruce | 20.6 |
| subalpine fir | 19.3 |
| red alder | 23.1 |
| black cottonwood | 19.3 |
| other hardwoods | 19.3 |
| other softwoods | 24.9 |

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 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 |
|--------------------|--|
| white spruce | Engelmann spruce; Brown and Johnston (1976) |
| western redcedar | Brown and Johnston (1976) |
| Pacific silver fir | grand fir; Brown and Johnston (1976) |
| mountain hemlock | Brown and Johnston (1976) |
| western hemlock | Brown and Johnston (1976) |
| Alaska cedar | western redcedar; Brown and Johnston (1976) |
| lodgepole pine | Brown and Johnston (1976) |
| Sitka spruce | Engelmann spruce; Brown and Johnston (1976) |
| subalpine fir | Brown and Johnston (1976) |
| red alder | Snell and Little (1983) |
| black cottonwood | Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| other hardwoods | cottonwood; Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| other softwoods | grand fir; 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 4.2.4. 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.

| Species | Live | | Dead | | | |
|--|----------------|----------------|------------------|----------------|---------------|------------|
| | Foliage | Foliage | <0.25" | 0.25–1" | 1 – 3" | 3"+ |
| white spruce (mapped to Engelmann spruce) | 6 | 2 | 5 | 5 | 10 | 50 |
| western redcedar | 5 | 5 | 15 | 15 | 30 | 55 |
| Pacific silver fir | 7 | 2 | 5 | 5 | 15 | 50 |
| mountain hemlock | 4 | 1 | 5 | 5 | 15 | 50 |
| western hemlock | 5 | 1 | 5 | 5 | 15 | 50 |
| Alaska cedar | 5 | 5 | 15 | 15 | 30 | 55 |
| lodgepole pine | 3 | 2 | 5 | 5 | 15 | 50 |
| Sitka spruce | 5 | 2 | 5 | 5 | 15 | 50 |
| subalpine fir | 7 | 2 | 5 | 5 | 15 | 50 |
| red alder | 1 | 1 | 10 | 15 | 15 | 50 |
| black cottonwood | 1 | 1 | 10 | 15 | 15 | 50 |
| other hardwoods | 1 | 1 | 10 | 15 | 15 | 50 |
| other softwoods | 7 | 2 | 5 | 5 | 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 |
|--------------------|--------------|---------------|--|
| white spruce | E 0.30 | 0.20 | Use Engelmann spruce |
| | I 0.30 | 2.00 | |
| western redcedar | E 0.20 | 0.20 | |
| | I 0.40 | 2.00 | |
| Pacific silver fir | E 0.15 | 0.10 | |
| | I 0.30 | 2.00 | |
| mountain hemlock | E 0.15 | 0.20 | |
| | I 0.30 | 2.00 | |
| western hemlock | E 0.20 | 0.20 | |
| | I 0.40 | 2.00 | |
| Alaska cedar | E 0.20 | 0.20 | |
| | I 0.40 | 2.00 | |
| lodgepole pine | E 0.20 | 0.10 | |
| | I 0.40 | 1.00 | |
| Sitka spruce | E 0.30 | 0.20 | |
| | I 0.30 | 2.00 | |
| subalpine fir | E 0.15 | 0.10 | |
| | I 0.30 | 2.00 | |
| red alder | E 0.20 | 0.20 | |
| | I 0.40 | 2.00 | |
| black cottonwood | E 0.25 | 0.25 | Use quaking aspen - Ottmar and others 2000b |
| | I 0.18 | 1.32 | |
| other hardwoods | E 0.25 | 0.25 | Use quaking aspen - Ottmar and others 2000b |
| | I 0.18 | 1.32 | |
| other softwoods | E 0.15 | 0.10 | use Pacific silver fir |
| | I 0.30 | 2.00 | |

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 | Litter | Duff |
| mountain hemlock (270) | 0.12 | 0.24 | 0.56 | 0.27 | 1.00 | 2.61 | 2.95 | 39.20 |
| Alaska yellow cedar (271) | 0.12 | 0.24 | 0.42 | 0.46 | 1.54 | 5.81 | 3.23 | 62.46 |
| western hemlock (301) | 0.23 | 0.46 | 1.14 | 0.66 | 2.01 | 22.47 | 4.53 | 50.75 |
| Sitka spruce (305) | 0.41 | 0.72 | 2.23 | 1.44 | 5.14 | 15.79 | 4.94 | 30.62 |
| cottonwood (703) | 0.22 | 0.56 | 1.25 | 0.07 | 0.11 | 0.02 | 3.01 | 8.61 |
| 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}) |
|--------------------|-------------------------|
| white spruce | 0.025 |
| western redcedar | 0.035 |
| Pacific silver fir | 0.047 |
| mountain hemlock | 0.040 |
| western hemlock | 0.040 |
| Alaska cedar | 0.022 |
| lodgepole pine | 0.028 |
| Sitka spruce | 0.027 |
| subalpine fir | 0.041 |
| red alder | 0.026 |
| black cottonwood | 0.044 |
| other hardwoods | 0.044 |
| other softwoods | 0.047 |

4.2.5 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 (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 | | | | |
| 0.25 – 1 | 0.052 | 0.061 | 0.073 | 0.098 |
| 1 – 3 | | | | |
| 3 – 6 | 0.012 | 0.025 | 0.041 | 0.077 |
| 6 – 12 | | | | 0.02 |
| > 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 | 0.0 |

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 **FUELDECAY** 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 |
|--------------------|---------------------|
| white spruce | 2 |
| western redcedar | 1 |
| Pacific silver fir | 3 |
| mountain hemlock | 2 |
| western hemlock | 2 |
| Alaska cedar | 1 |
| lodgepole pine | 2 |
| Sitka spruce | 2 |
| subalpine fir | 3 |
| red alder | 4 |
| black cottonwood | 4 |
| other hardwoods | 4 |
| other softwoods | 3 |

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.

| Size Class | Moisture Group | | | |
|------------------------|----------------|-----|-------|-----|
| | 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.

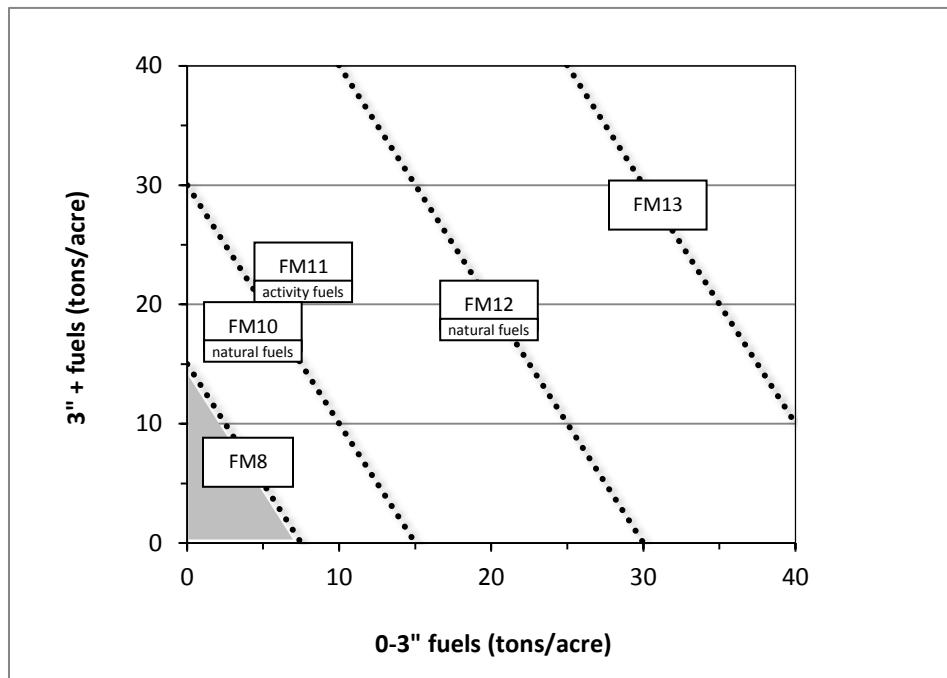


Figure 4.2.1 - At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. At low fuel loads, fuel model 8 is selected.

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 softwoods’ and ‘other hardwoods’, 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 | <i>Pinus monticola</i> | |
| western larch | <i>Larix occidentalis</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| grand fir | <i>Abies grandis</i> | |
| mountain hemlock | <i>Tsuga mertensiana</i> | |
| western juniper | <i>Juniperus occidentalis</i> | = SO & UT western juniper |
| lodgepole pine | <i>Pinus contorta</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| whitebark pine | <i>Pinus albicaulis</i> | = SO & TT whitebark pine |
| limber pine | <i>Pinus flexilis</i> | = UT limber pine |
| Pacific yew | <i>Taxus brevifolia</i> | = SO & WC Pacific yew |
| Alaska cedar | <i>Callitropsis nootkatensis</i> | = WC Alaska cedar |
| quaking aspen | <i>Populus tremuloides</i> | = SO & UT quaking aspen |
| black cottonwood | <i>Populus balsamifera</i> | = SO & WC black cottonwood |
| other softwoods | | = ponderosa pine |
| other hardwoods | | = 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/fmfc/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 softwoods | 23.7 |
| other hardwoods | 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 softwoods | Use ponderosa pine |
| other hardwoods | 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.

| Species | Live | Dead | | | |
|--------------------|---------|---------|--------|---------|----|
| | Foliage | Foliage | <0.25" | 0.25–1" | |
| 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 softwoods | 4 | 3 | 10 | 10 | 10 |
| other hardwoods | 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 |
| | I | 0.40 | 2.00 | |
| western juniper | E | 0.14 | 0.35 | Ottmar and others (1998) |
| | I | 0.10 | 2.06 | |

| Species | | Herbs | Shrubs | Notes |
|------------------|---|--------------|---------------|---|
| 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 | |
| | I | 0.40 | 1.00 | Use BM lodgepole pine |
| limber pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | Use BM lodgepole pine |
| Pacific yew | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use BM Douglas-fir |
| Alaska cedar | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use WC redcedar |
| quaking aspen | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Use UT quaking aspen; Ottmar and others 2000b |
| black cottonwood | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Use UT quaking aspen; Ottmar and others 2000b |
| other softwoods | E | 0.20 | 0.25 | |
| | I | 0.25 | 0.10 | Use ponderosa pine |
| other hardwoods | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Use UT quaking aspen; 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 4.3.6). 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.

| 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 | 0.8 | 30.0 |
| | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 0.4 | 12.0 |
| western larch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 10.0 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 5.0 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 10.0 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 5.0 |
| grand fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 25.0 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 12.0 |
| mountain hemlock | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| western juniper | E | 0.1 | 0.2 | 0.4 | 0.5 | 0.8 | 1.0 | 0.1 |
| | I | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |

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

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 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 |
| 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 softwoods | 0.063 |
| other hardwoods | 0.044 |

4.3.5 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 (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 **FUELDECAY** 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 | | | | |
| | 0.25 – 1 | 0.113 | 0.121 | 0.134 | 0.168 |
| | 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 | | | | |
| | 0.25 – 1 | 0.057 | 0.061 | 0.068 | 0.085 |
| | 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 | | | | |
| | 0.25 – 1 | 0.103 | 0.109 | 0.122 | 0.153 |
| | 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 | | | | |
| | 0.25 – 1 | 0.076 | 0.081 | 0.090 | 0.113 |
| | 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 | | | | |
| | 0.25 – 1 | 0.067 | 0.071 | 0.079 | 0.099 |
| | 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 | | | | |
| | 0.25 – 1 | 0.092 | 0.098 | 0.109 | 0.137 |
| | 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 | | | | |
| | 0.25 – 1 | 0.087 | 0.092 | 0.103 | 0.129 |
| | 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 | | | | |
| | 0.25 – 1 | 0.057 | 0.061 | 0.068 | 0.085 |
| | 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 | 0.02 |
| | Duff | 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 | CLS55 | 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 | moderate | 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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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.

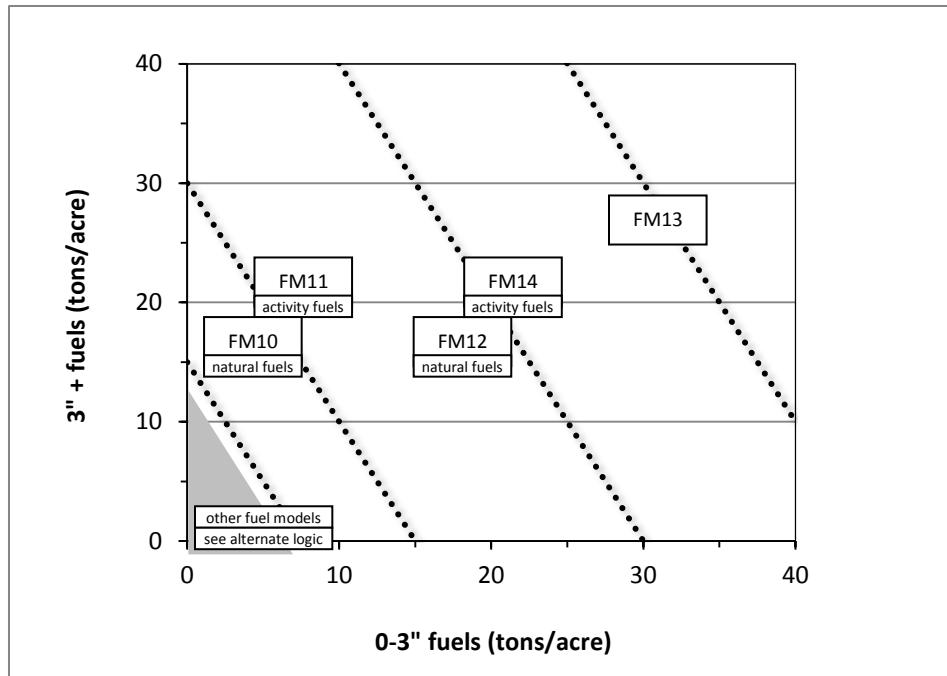


Figure 4.3.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.3.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further 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 $\pm 20\%$ 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.

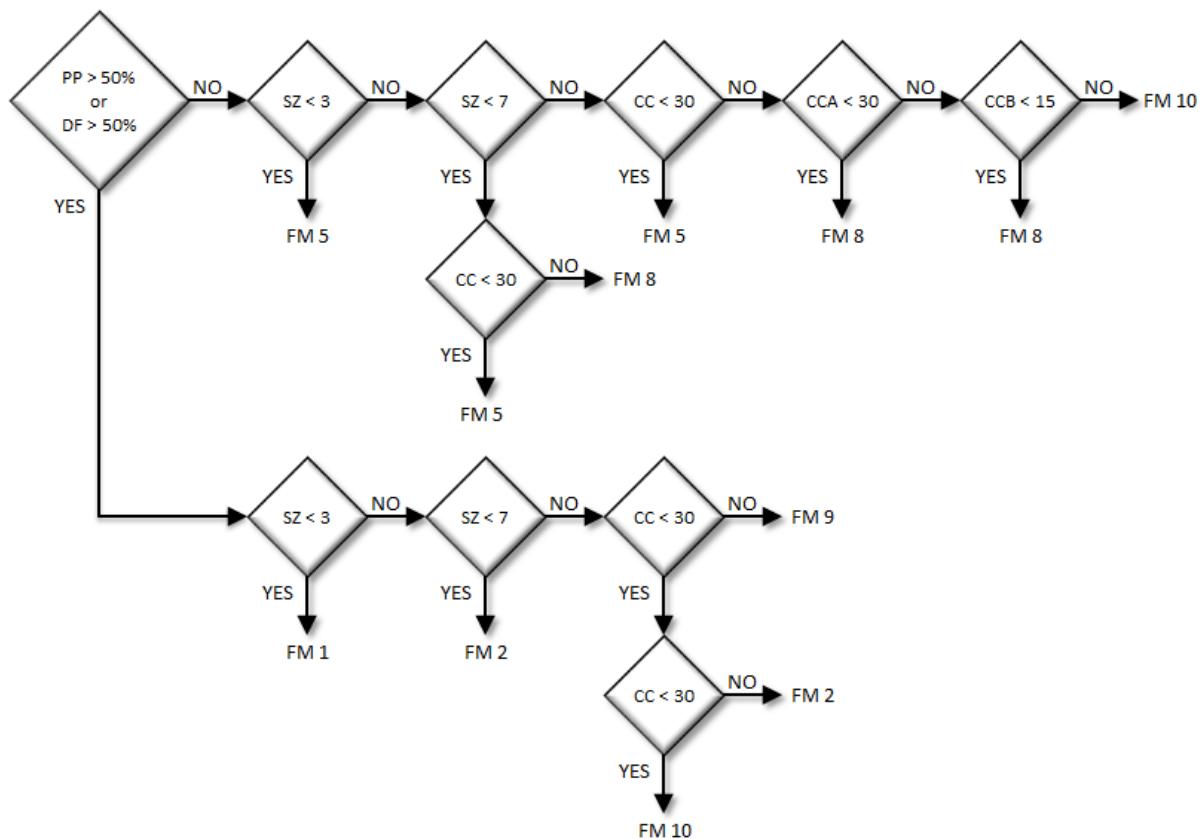


Figure 4.3.2 - Logic for modeling fire at "low" fuel loads in the BM-FFE variant.

4.4 Inland California and Southern Cascades (CA)

4.4.1 Tree Species

The Inland California and Southern Cascades variant models the 47 tree species shown in Table 4.4.1. Two additional categories, ‘other hardwoods’ and ‘other softwoods’ 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 | <i>Chamaecyparis lawsonia</i> | |
| incense-cedar | <i>Libocedrus decurrens</i> | |
| western redcedar | <i>Thuja plicata</i> | |
| white fir | <i>Abies concolor</i> | |
| California red fir | <i>Abies magnifica magnifica</i> | |
| Shasta red fir | <i>Abies magnifica shastensis</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| western hemlock | <i>Tsuga heterophylla</i> | |
| mountain hemlock | <i>Tsuga mertensiana</i> | |
| whitebark pine | <i>Pinus albicaulis</i> | |
| knobcone pine | <i>Pinus attenuata</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Coulter pine | <i>Pinus coulteri</i> | |
| limber pine | <i>Pinus flexilis flexilis</i> | |
| Jeffrey pine | <i>Pinus jeffreyi</i> | |
| sugar pine | <i>Pinus lambertiana</i> | |
| western white pine | <i>Pinus monticola</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| Monterey pine | <i>Pinus radiata</i> | |
| gray pine | <i>Pinus sabiniana</i> | |
| western juniper | <i>Juniperus occidentalis</i> | |
| Brewer spruce | <i>Picea breweriana</i> | |
| giant sequoia | <i>Sequoiadendron giganteum</i> | |
| Pacific yew | <i>Taxus brevifolia</i> | |
| coast live oak | <i>Quercus agrifolia</i> | |
| canyon live oak | <i>Quercus chrysolepis</i> | |
| blue oak | <i>Quercus douglasii</i> | |
| Engelmann oak | <i>Quercus engelmanni</i> | |
| Oregon white oak | <i>Quercus garryana</i> | |
| California black oak | <i>Quercus kelloggii</i> | |
| valley white oak | <i>Quercus lobata</i> | |
| interior live oak | <i>Quercus wislizenii</i> | |
| bigleaf maple | <i>Acer macrophyllum</i> | |
| California buckeye | <i>Aesculus californica</i> | |
| red alder | <i>Alnus rubra</i> | |
| Pacific madrone | <i>Arbutus menziesii</i> | |
| giant chinquapin | <i>Chrysolepis chrysophylla</i> | |
| Pacific dogwood | <i>Cornus nuttallii</i> | |
| Oregon ash | <i>Fraxinus latifolia</i> | |
| walnut | <i>Juglans spp.</i> | |
| tanoak | <i>Lithocarpus densiflorus</i> | |
| California sycamore | <i>Platanus racemosa</i> | |
| quaking aspen | <i>Populus tremuloides</i> | |
| black cottonwood | <i>Populus trichocarpa</i> | |

| Common Name | Scientific Name | Notes |
|-------------------|---------------------------------|-------------------------------|
| willow | <i>Salix spp.</i> | |
| California nutmeg | <i>Torreya californica</i> | |
| California laurel | <i>Umbellularia californica</i> | |
| other softwoods | | = <i>ponderosa pine</i> |
| other hardwoods | | = <i>California black oak</i> |

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 | - |
| gray pine | 25 | 100 | 20 | - |
| western juniper | 45 | 150 | 20 | - |

| Species | 95% Fallen | All Down | 50% Height | Hard-to-Soft |
|----------------------|-------------------|-----------------|-------------------|---------------------|
| Brewer spruce | 25 | 100 | 20 | — |
| giant sequoia | 45 | 150 | 20 | — |
| Pacific yew | 45 | 100 | 20 | — |
| coast live oak | 20 | 50 | 20 | — |
| 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 white 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 | — |
| other softwoods | 25 | 100 | 20 | — |
| other hardwoods | 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 | — |
| gray 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 | — |
| Coast live oak | 1.55 | 1.0 | — |

| Species | Snag Fall | Height loss | Hard-to-Soft |
|----------------------|------------------|--------------------|---------------------|
| canyon live oak | 1.55 | 1.0 | — |
| blue oak | 1.55 | 1.0 | — |
| Engelmann oak | 1.55 | 1.0 | — |
| Oregon white oak | 1.55 | 1.0 | — |
| California black oak | 1.55 | 1.0 | — |
| valley white 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 | — |
| other softwoods | 1.24 | 1.0 | — |
| other hardwoods | 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 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 oven-dry 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 (overdry lb/ft³) used in the CA-FFE variant.

| Species | Density (lb/ft³) | Species | Density (lb/ft³) |
|--------------------|------------------------------------|----------------------|------------------------------------|
| 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 |
| gray 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 | other softwoods | 34.9 |
| Pacific yew | 26.2 | other hardwoods | 34.9 |
| Coast live oak | 49.9 | | |

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) |

| Species | Species Mapping and Equation Source |
|----------------------|---|
| 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) |
| 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 white 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) |
| other softwoods | ponderosa pine (Brown and Johnston 1976) |
| other hardwoods | 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.

| Species | Live | | Dead | | |
|--------------------|----------------|----------------|------------------|----------------|----------------|
| | 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 |
| gray pine | 3 | 3 | 10 | 15 | 15 |
| western juniper | 4 | 3 | 10 | 15 | 20 |
| Brewer spruce | 8 | 3 | 10 | 15 | 15 |

| Species | Live | | Dead | | |
|----------------------|---------|---------|--------|---------|------|
| | Foliage | Foliage | <0.25" | 0.25–1" | > 1" |
| giant sequoia | 5 | 3 | 10 | 15 | 20 |
| Pacific yew | 7 | 3 | 10 | 15 | 15 |
| Coast live oak | 1 | 1 | 10 | 15 | 15 |
| 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 white 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 |
| other softwoods | 3 | 3 | 10 | 10 | 10 |
| other hardwoods | 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 |

| Species | | Herbs | Shrubs | Notes |
|----------------------|---|--------------|---------------|--|
| | I | 0.40 | 2.00 | |
| white fir | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | grand fir, NI-FFE |
| California red fir | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | grand fir, NI-FFE |
| Shasta red fir | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | grand fir, NI-FFE |
| Douglas-fir | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | NI-FFE |
| western hemlock | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | NI-FFE |
| mountain hemlock | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | subalpine fir, NI-FFE |
| whitebark pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | lodgepole pine, NI-FFE |
| knobcone pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | lodgepole pine, NI-FFE |
| lodgepole pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | NI-FFE |
| Coulter pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | lodgepole pine, NI-FFE |
| limber pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | lodgepole pine, NI-FFE |
| Jeffrey pine | E | 0.20 | 0.25 | |
| | I | 0.25 | 1.00 | ponderosa pine, NI-FFE |
| sugar pine | E | 0.20 | 0.25 | |
| | I | 0.25 | 1.00 | ponderosa pine, NI-FFE |
| western white pine | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | NI-FFE |
| ponderosa pine | E | 0.20 | 0.25 | |
| | I | 0.25 | 1.00 | NI-FFE |
| Monterey pine | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Douglas-fir, NI-FFE |
| gray 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 | |
| | I | 0.10 | 2.06 | Ottmar and others (1998) |
| Brewer spruce | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | Engelmann spruce, NI-FFE |
| giant sequoia | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Douglas-fir, NI-FFE |
| Pacific yew | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Douglas-fir, NI-FFE |
| coast 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 white 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 | |

| Species | | Herbs | Shrubs | Notes |
|---------------------|---|--------------|---------------|--|
| bigleaf maple | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | I | 0.40 | 2.00 | |
| California buckeye | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | I | 0.40 | 2.00 | |
| red alder | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | I | 0.40 | 2.00 | |
| Pacific madrone | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | 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 | Douglas-fir, NI-FFE |
| | I | 0.40 | 2.00 | |
| Oregon ash | E | 0.20 | 0.25 | ponderosa pine, NI-FFE |
| | I | 0.25 | 1.00 | |
| walnut | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | I | 0.40 | 2.00 | |
| tanoak | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and others 2000b (modified) |
| | I | 0.18 | 2.00 | |
| California sycamore | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | 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 | |
| willow | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and others 2000b |
| | I | 0.18 | 1.32 | |
| California nutmeg | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | I | 0.40 | 2.00 | |
| California laurel | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | I | 0.40 | 2.00 | |
| other softwoods | E | 0.20 | 0.20 | ponderosa pine, NI-FFE |
| | I | 0.25 | 1.00 | |
| other hardwoods | E | 0.23 | 0.22 | Gambel oak, CR-FFE, 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 4.4.8). 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.

| Species | Size Class (in) | | | | | | | |
|-------------------|------------------------|----------|-------|-------|--------|------|--------|------|
| | < 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 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| incense-cedar | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |

| Species | Size Class (in) | | | | | | | |
|----------------------|-----------------|----------|-------|-------|--------|------|--------|------|
| | < 0.25 | 0.25 – 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 | Litter | Duff |
| western redcedar | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| white fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| California red fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| Shasta red fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| western hemlock | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| mountain hemlock | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| whitebark pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| knobcone pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| lodgepole pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| Coulter pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| limber pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| Jeffrey pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| sugar pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| western white pine | E | 1.0 | 1.0 | 1.6 | 10.0 | 10.0 | 10.0 | 0.8 |
| | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 6.0 | 0.4 |
| ponderosa pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Monterey pine | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| gray pine | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| western juniper | E | 0.1 | 0.2 | 0.4 | 0.5 | 0.8 | 1.0 | 0.1 |
| | I | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 |
| Brewer spruce | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| giant sequoia | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Pacific yew | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| coast live oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| canyon live oak | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| blue oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| Engelmann oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| Oregon white oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| California black oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| valley white oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |

| Species | Size Class (in) | | | | | | | |
|---------------------|-----------------|----------|-------|-------|--------|------|--------|------|
| | < 0.25 | 0.25 – 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 | Litter | Duff |
| interior live oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 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 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| California buckeye | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| red alder | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Pacific madrone | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| giant chinquapin | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| Pacific dogwood | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Oregon ash | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| walnut | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| tanoak | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| California sycamore | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| quaking aspen | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| black cottonwood | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| willow | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| California nutmeg | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| California laurel | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| other softwoods | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| other hardwoods | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |

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 white oak | 0.043 |
| Douglas-fir | 0.063 | interior live oak | 0.034 |
| 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 |

| Species | Multiplier (V_{sp}) | Species | Multiplier (V_{sp}) |
|--------------------|---|---------------------|---|
| 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 |
| gray 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 | other softwoods | 0.063 |
| Pacific yew | 0.025 | other hardwoods | 0.030 |
| coast live oak | 0.050 | | |

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 shown 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 | | |
| 0.25 – 1 | 0.025 | |
| 1 – 3 | | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.0125 | |
| > 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 | | | | |
| | 0.25 – 1 | 0.113 | 0.121 | 0.134 | 0.168 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | 0.02 |
| | 6 – 12 | 0.036 | 0.048 | 0.063 | 0.111 |
| | > 12 | 0.028 | 0.037 | 0.049 | 0.086 |
| hot, dry | < 0.25 | | | | |
| | 0.25 – 1 | 0.057 | 0.061 | 0.068 | 0.085 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | 0.02 |
| | 6 – 12 | 0.016 | 0.021 | 0.028 | 0.049 |
| | > 12 | 0.014 | 0.019 | 0.025 | 0.044 |
| moderate, wet | < 0.25 | | | | |
| | 0.25 – 1 | 0.103 | 0.109 | 0.122 | 0.153 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | 0.02 |
| | 6 – 12 | 0.035 | 0.046 | 0.061 | 0.107 |
| | > 12 | 0.026 | 0.034 | 0.045 | 0.078 |
| moderate, mesic | < 0.25 | | | | |
| | 0.25 – 1 | 0.076 | 0.081 | 0.090 | 0.113 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | 0.02 |
| | 6 – 12 | 0.032 | 0.043 | 0.056 | 0.099 |
| | > 12 | 0.019 | 0.025 | 0.033 | 0.058 |
| moderate, dry | < 0.25 | | | | |
| | 0.25 – 1 | 0.067 | 0.071 | 0.079 | 0.099 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | 0.02 |
| | 6 – 12 | 0.023 | 0.030 | 0.040 | 0.070 |
| | > 12 | 0.017 | 0.022 | 0.029 | 0.051 |
| cold, wet | < 0.25 | | | | |
| | 0.25 – 1 | 0.092 | 0.098 | 0.109 | 0.137 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | 0.02 |
| | 6 – 12 | 0.034 | 0.045 | 0.059 | 0.104 |
| | > 12 | 0.023 | 0.030 | 0.040 | 0.070 |
| cold, mesic | < 0.25 | | | | |
| | 0.25 – 1 | 0.087 | 0.092 | 0.103 | 0.129 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | 0.02 |
| | 6 – 12 | 0.033 | 0.044 | 0.058 | 0.102 |
| | > 12 | 0.022 | 0.029 | 0.038 | 0.066 |
| cold, dry | < 0.25 | | | | |
| | 0.25 – 1 | 0.057 | 0.061 | 0.068 | 0.085 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | 0.02 |
| | 6 – 12 | 0.016 | 0.021 | 0.028 | 0.049 |
| | > 12 | 0.014 | 0.019 | 0.025 | 0.044 |
| All | Litter | 0.50 | 0.50 | 0.50 | 0.02 |
| | Duff | 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 white 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 |
| gray pine | 3 | willow | 4 |
| western juniper | 1 | California nutmeg | 4 |
| Brewer spruce | 2 | California laurel | 4 |
| giant sequoia | 1 | other softwoods | 3 |
| Pacific yew | 1 | other hardwoods | 3 |
| coast live oak | 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.

| Size Class | Moisture Group | | | |
|-------------------------|----------------|-----|-------|-----|
| | 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 (CWRH) 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 CWRH size class and CWRH density class 1 (the third and fourth columns). Mayer and Laudenslayer's class definitions were modified to

¹ A BASIC-language function named 'CWRHSizeDensity' 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.

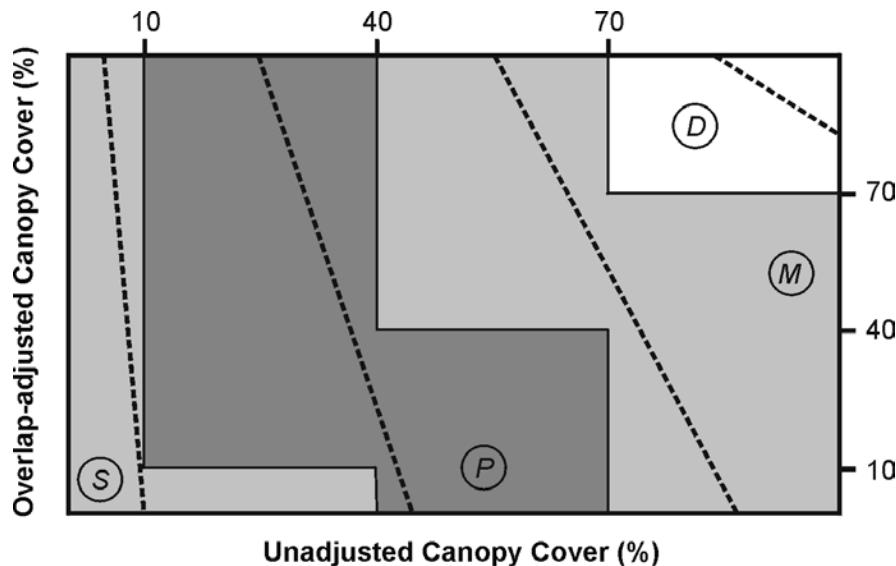


Figure 4.4.1 - Two measures of canopy cover, unadjusted and overlap-adjusted percent canopy cover, are used to derive weighted estimates of the four CWHR density classes. (S = sparse, P = open, M = moderate and D = dense)

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 | |
| Forest Type | | | | | | | | | | | | | | |
| Pine | 5 | 6 | 6 | 6 | 6 | 2 | 2 | 9 | 9 | 2 | 2 | 2 | 9 | 10 |
| Red fir | 5 | 5 | 5 | 8 | 8 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 8 | 10 |
| White fir – east side | 5 | 5 | 5 | 8 | 8 | 11 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 10 |
| White fir – west side | 5 | 5 | 5 | 8 | 8 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 8 | 10 |
| Douglas-fir | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 8 | 8 | 11 | 11 | 9 | 8 | 10 |
| Hardwoods | 5 | 5 | 5 | 6 | 6 | 11 | 11 | 11 | 9 | 9 | 9 | 9 | 9 | 10 |
| Pine mixed – conifer | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 9 | 9 | 9 | 8 | 8 | 10 |
| Fir mixed – conifer | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 8 | 6 | 6 | 8 | 8 | 10 |
| Other softwood | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 8 | 6 | 6 | 8 | 8 | 10 |

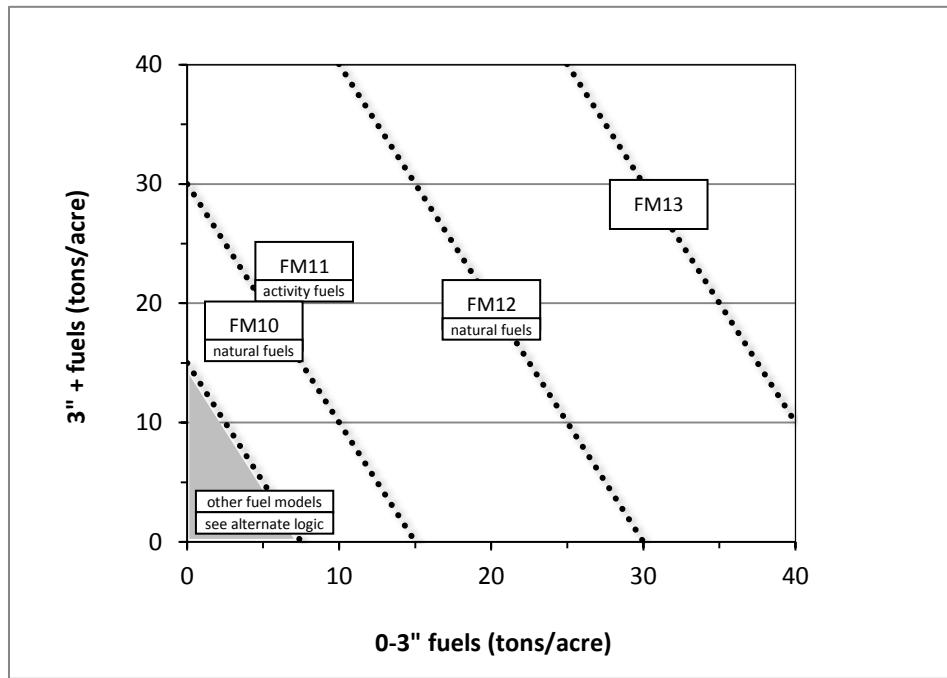


Figure 4.4.2 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.4.17. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further 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 softwoods’ and ‘other hardwoods’ 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 | <i>Pinus monticola</i> | |
| western larch | <i>Larix occidentalis</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| grand fir | <i>Abies grandis</i> | |
| western hemlock | <i>Tsuga heterophylla</i> | |
| western redcedar | <i>Thuja plicata</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| whitebark pine | <i>Pinus albicaulis</i> | |
| Pacific yew | <i>Taxus brevifolia</i> | |
| quaking aspen | <i>Populus tremuloides</i> | |
| western juniper | <i>Juniperus occidentalis</i> | |
| curlleaf mountain-mahogany | <i>Cercocarpus ledifolius</i> | |
| limber pine | <i>Pinus flexilis</i> | |
| black cottonwood | <i>Populus balsamifera</i> var. <i>trichocarpa</i> | |
| other softwoods | | = mountain hemlock |
| other hardwoods | | = 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 |
| curlleaf mountain-mahogany | 31 | 90 | — | 39 |
| limber pine | 75 | 90 | 30 | 35 |
| black cottonwood | 8 | 5 | — | 35 |
| other softwoods | 34 | 30 | 20 | 35 |
| other hardwoods | 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 |
| curlleaf mountain-mahogany | 1.0 | 1.0 | 1.0 |
| limber pine | 1.0 | 1.0 | 1.0 |
| black cottonwood | 4.0 | — | 0.9 |
| other softwoods | 0.9 | 1.5 | 0.9 |
| other hardwoods | 4.0 | — | 0.9 |

§ This value applies 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 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 oven-dry 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/ft³) 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 |
| curlleaf mountain-mahogany | 21.8 |
| limber pine | 22.5 |
| black cottonwood | 19.3 |
| other softwoods | 26.2 |
| other hardwoods | 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) |
| curlleaf 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 softwoods | Gholz and others (1979); Brown and Johnston (1976) |
| other hardwoods | 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.

| Species | Live | | Dead | | |
|----------------------------|---------|---------|--------|---------|------|
| | 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 |
| curlleaf mountain-mahogany | 1 | 1 | 5 | 5 | 15 |
| limber pine | 3 | 2 | 5 | 5 | 15 |
| black cottonwood | 1 | 1 | 5 | 5 | 10 |
| other softwoods | 4 | 2 | 5 | 5 | 15 |
| other hardwoods | 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 | Use Douglas-fir |
| | I 0.30 | 2.00 | |
| western larch | E 0.20 | 0.20 | Use Douglas-fir |
| | I 0.40 | 2.00 | |
| Douglas-fir | E 0.20 | 0.20 | Use Douglas-fir |
| | I 0.40 | 2.00 | |
| grand fir | E 0.15 | 0.10 | Use Douglas-fir |
| | 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 | Use Douglas-fir |
| | I 0.40 | 1.00 | |
| Engelmann spruce | E 0.15 | 0.20 | Use Douglas-fir |
| | I 0.30 | 2.00 | |
| subalpine fir | E 0.15 | 0.20 | Use Douglas-fir |
| | I 0.30 | 2.00 | |
| ponderosa pine | E 0.20 | 0.25 | |

| Species | | Herbs | Shrubs | Notes |
|----------------------------|---|--------------|---------------|--------------------------|
| whitebark pine | I | 0.25 | 0.10 | |
| | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | Use lodgepole pine |
| Pacific yew | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| quaking aspen | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Ottmar et. al. 2000b |
| western juniper | E | 0.04 | 0.05 | |
| | I | 0.13 | 1.63 | Ottmar et. al. 2000a |
| curlleaf mountain-mahogany | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | |
| limber pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | Use lodgepole pine |
| black cottonwood | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Use quaking aspen |
| other softwoods | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | Use spruce-subalpine fir |
| other hardwoods | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Use quaking aspen |

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.

| 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 |
| | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 6.0 | 0.4 |
| western larch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| grand fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| western hemlock | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| western redcedar | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Engelmann spruce | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| subalpine fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| 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 |
| whitebark pine | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| Pacific yew | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| quaking aspen | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| western juniper | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| curlleaf mountain-mahogany | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| limber pine | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| black cottonwood | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| other softwoods | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| other hardwoods | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |

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 |
| curlleaf mountain-mahogany | 0.044 |
| limber pine | 0.030 |
| black cottonwood | 0.038 |
| other softwoods | 0.040 |
| other hardwoods | 0.038 |

4.5.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.5.10). 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 | | |
| 0.25 – 1 | 0.12 | |
| 1 – 3 | 0.09 | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.015 | |
| > 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 |
| curlleaf mountain-mahogany | 4 |
| limber pine | 4 |
| black cottonwood | 4 |
| other softwoods | 4 |
| other hardwoods | 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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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 |
|--------------|-----|--------------|-----|--------------|-----|--------------|-----|
| 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.

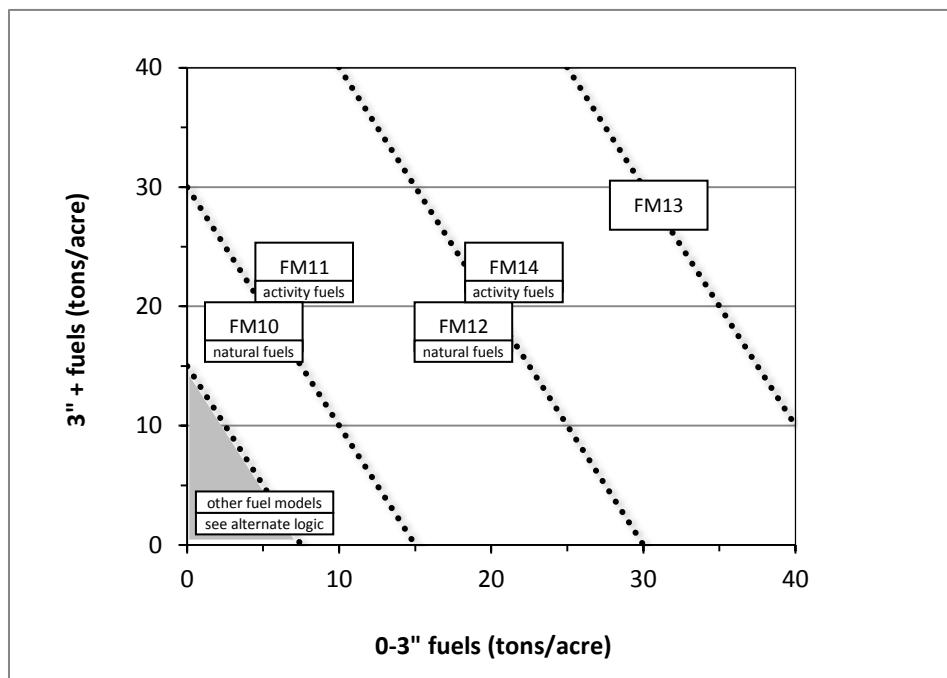


Figure 4.5.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.5.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

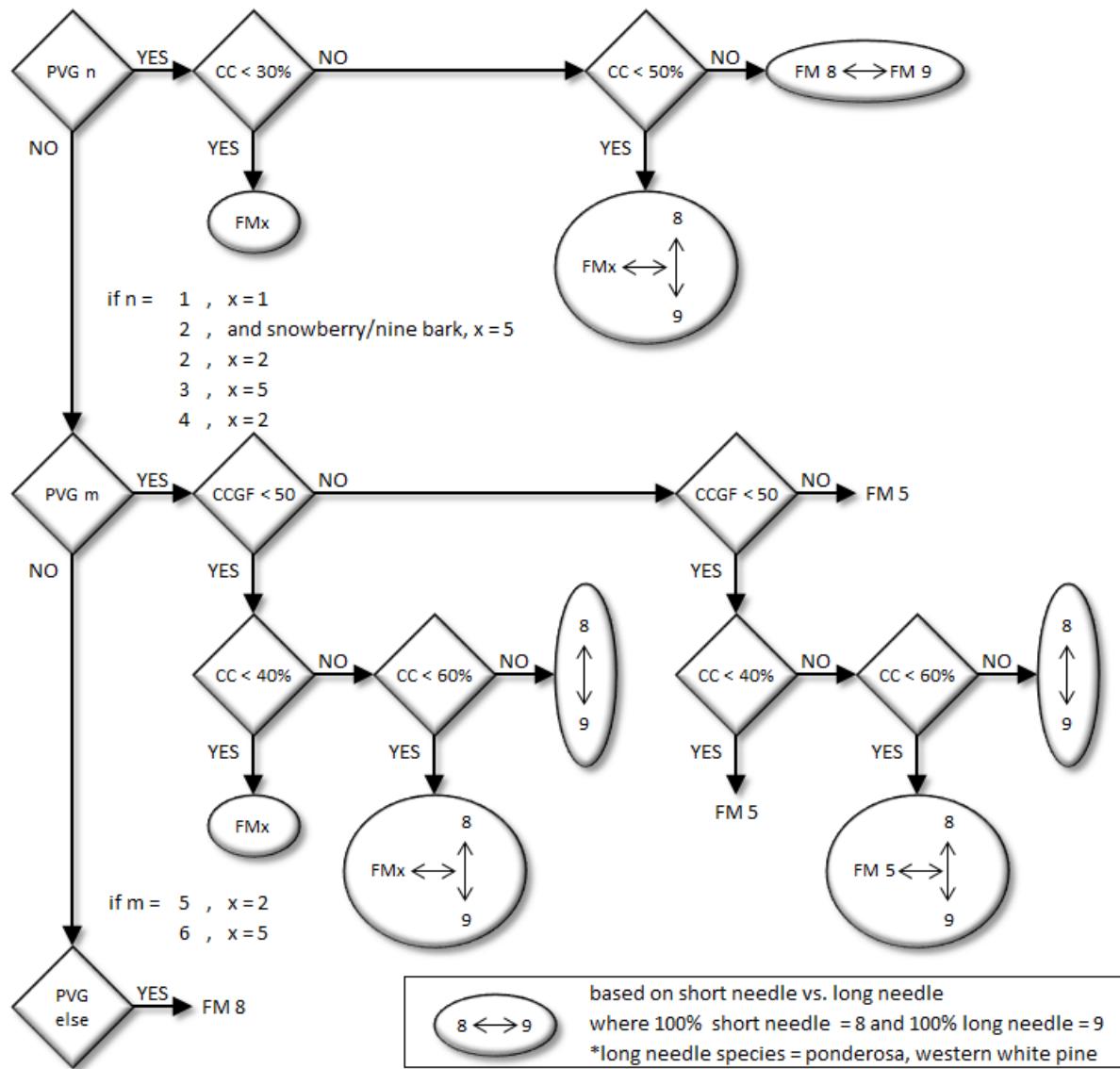


Figure 4.5.2 - Fuel models for the CI-FFE variant. The *n* and *m* indices are the PVG groups defined in Table 4.5.14.

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 | <i>Abies lasiocarpa</i> | |
| corkbark fir | <i>Abies lasiocarpa arizonica</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| grand fir | <i>Abies grandis</i> | |
| white fir | <i>Abies concolor</i> | |
| mountain hemlock | <i>Tsuga mertensiana</i> | |
| western redcedar | <i>Thuja plicata</i> | |
| western larch | <i>Larix occidentalis</i> | |
| bristlecone pine | <i>Pinus aristata</i> | |
| limber pine | <i>Pinus flexilis</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| common pinyon | <i>Pinus edulis</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| whitebark pine | <i>Pinus albicaulis</i> | |
| southwestern white pine | <i>Pinus strobiformis</i> | |
| Utah juniper | <i>Juniperus osteosperma</i> | |
| blue spruce | <i>Picea pungens</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| white spruce | <i>Picea glauca</i> | |
| quaking aspen | <i>Populus tremuloides</i> | |
| narrowleaf cottonwood | <i>Populus angustifolia</i> | |
| plains cottonwood | <i>Populus deltoids</i> var. <i>monilifera</i> | Use narrowleaf cottonwood |
| Gambel oak | <i>Quercus gambelii</i> | |
| Arizona white oak | <i>Quercus arizonica</i> | |
| Emory oak | <i>Quercus emoryi</i> | |
| bur oak | <i>Quercus macrocarpa</i> | |
| silverleaf oak | <i>Quercus hypoleucoides</i> | |
| paper birch | <i>Betula papyrifera</i> | |
| alligator juniper | <i>Juniperus deppeana</i> | |
| Rocky Mountain juniper | <i>Juniperus scopulorum</i> | |
| oneseed juniper | <i>Juniperus monosperma</i> | |
| eastern redcedar | <i>Juniperus virginiana</i> | |
| singleleaf pinyon | <i>Pinus monophylla</i> | |
| border pinyon | <i>Pinus discolor</i> | |
| Arizona pinyon pine | <i>Pinus monophylla</i> var. <i>fallax</i> | |
| Chihuahua pine | <i>Pinus leiophylla</i> var. <i>chihuahuana</i> | |
| other softwoods | | Use ponderosa pine = pines |
| other hardwoods | | = 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 |
| common 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 pinyon pine | 31 | 150 | 310 | 35 |
| Chihuahua pine | 31 | 150 | 310 | 39 |
| other softwoods | 31 | 150 | 660 | 35 |
| other hardwoods | 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 |
| common 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 pinyon pine | 1.0 | 0.098 | 0.9 |
| Chihuahua pine | 1.0 | 0.098 | 1.0 |
| other softwoods | 1.0 | 0.046 | 0.9 |
| other hardwoods | 4.0 | — | 0.9 |

| Species | Snag Fall | Height loss | Hard-to-Soft |
|--|-----------|-------------|--------------|
| § This value applies 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 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/ft³) used in the CR-FFE variant.

| Species | Density (lb/ft ³) | Species | Density (lb/ft ³) |
|-------------------------|-------------------------------|------------------------|-------------------------------|
| 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 |
| common 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 pinyon pine | 31.8 |
| blue spruce | 20.6 | Chihuahua pine | 23.7 |
| Engelmann spruce | 20.6 | other softwoods | 23.7 |
| white spruce | 23.1 | other hardwoods | 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) |
| common 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 pinyon pine | Use common pinyon |
| Chihuahua pine | Use ponderosa pine |
| other softwoods | lodgepole pine: Brown and Johnston (1976) |
| other hardwoods | 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.

| Species | Live | | Dead | | |
|----------------|----------------|----------------|------------------|----------------|----------------|
| | 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 |

| Species | Live | | Dead | | |
|-------------------------|---------|---------|--------|---------|------|
| | 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 |
| common 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 pinyon pine | 3 | 2 | 10 | 15 | 15 |
| Chihuahua pine | 4 | 2 | 10 | 10 | 10 |
| other softwoods | 3 | 2 | 10 | 15 | 15 |
| other hardwoods | 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 | |
| | I | 0.30 | 2.00 | Use subalpine fir |
| 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 | |
| | I | 0.13 | 1.63 | Use pinyon pine |
| limber pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | Use lodgepole pine |
| lodgepole pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | |
| common pinyon | E | 0.04 | 0.05 | |
| | I | 0.13 | 1.63 | Ottmar and others (2000a) |
| ponderosa pine | E | 0.20 | 0.25 | |
| | I | 0.25 | 0.10 | |
| whitebark pine | E | 0.20 | 0.10 | |
| | I | 0.40 | 1.00 | Use lodgepole pine |
| southwestern white pine | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | Use western white pine |
| Utah juniper | E | 0.04 | 0.05 | |
| | I | 0.13 | 1.63 | Ottmar and others (2000a) |
| blue spruce | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | Use Engelmann spruce |
| Engelmann spruce | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | |
| white spruce | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | Use Engelmann spruce |
| quaking aspen | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Ottmar and others (2000b) |
| narrowleaf cottonwood | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Ottmar and others (2000b) |
| plains cottonwood | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Use narrowleaf cottonwood |
| Gambel oak | E | 0.23 | 0.22 | |
| | I | 0.55 | 0.35 | Ottmar and others (2000b) |
| Arizona white oak | E | 0.23 | 0.22 | |
| | I | 0.55 | 0.35 | Use Gambel oak |
| Emory oak | E | 0.23 | 0.22 | |
| | I | 0.55 | 0.35 | Use Gambel oak |
| bur oak | E | 0.23 | 0.22 | |
| | I | 0.55 | 0.35 | Use Gambel oak |
| silverleaf oak | E | 0.23 | 0.22 | |
| | I | 0.55 | 0.35 | Use Gambel oak |
| paper birch | E | 0.25 | 0.25 | |
| | I | 0.18 | 1.32 | Use quaking aspen |
| alligator juniper | E | 0.04 | 0.05 | |
| | I | 0.13 | 1.63 | Use Utah juniper |
| Rocky Mountain juniper | E | 0.04 | 0.05 | |
| | I | 0.13 | 1.63 | Use Utah juniper |
| oneseed juniper | E | 0.04 | 0.05 | |
| | I | 0.13 | 1.63 | Use Utah juniper |
| eastern redcedar | E | 0.04 | 0.05 | Use Utah juniper |

| Species | | Herbs | Shrubs | Comments |
|---------------------|---|--------------|---------------|--------------------|
| singleleaf pinyon | I | 0.13 | 1.63 | |
| | E | 0.04 | 0.05 | Use common pinyon |
| border pinyon | I | 0.13 | 1.63 | |
| | E | 0.04 | 0.05 | Use common pinyon |
| Arizona pinyon pine | I | 0.13 | 1.63 | |
| | E | 0.04 | 0.05 | Use common pinyon |
| Chihuahua pine | I | 0.25 | 0.10 | Use ponderosa pine |
| | E | 0.20 | 0.25 | |
| other softwoods | I | 0.40 | 1.00 | Use lodgepole pine |
| | E | 0.20 | 0.10 | |
| other hardwoods | I | 0.18 | 1.32 | Use quaking aspen |
| | E | 0.25 | 0.25 | |

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 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| corkbark fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| grand fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| white fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| mountain hemlock | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| western redcedar | E | 1.6 | 1.6 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| western larch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| bristlecone pine | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| limber pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| common pinyon | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 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 |
| whitebark pine | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| southwestern white pine | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| | E | 1.0 | 1.0 | 1.6 | 10.0 | 10.0 | 10.0 | 0.8 |
| Utah juniper | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 6.0 | 0.4 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| blue spruce | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| Engelmann spruce | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| white spruce | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| quaking aspen | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| narrowleaf cottonwood | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| plains cottonwood | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| Gambel oak | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| Arizona white oak | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| Emory oak | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| bur oak | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| silverleaf oak | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| paper birch | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| alligator juniper | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| Rocky Mountain juniper | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| oneseed juniper | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| eastern redcedar | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| singleleaf pinyon | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| border pinyon | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| Arizona pinyon pine | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| Chihuahua pine | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 5.0 |
| other softwoods | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| other hardwoods | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |

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 |
| common 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 pinyon pine | 0.030 |
| Chihuahua pine | 0.063 |
| other softwoods | 0.030 |
| other hardwoods | 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 | |
| 0.25 – 1 | | |
| 1 – 3 | 0.0405 | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.00675 | |
| > 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 **FUELDECAY** 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 |
| common 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 pinyon pine | 4 |
| blue spruce | 4 | Chihuahua pine | 4 |
| Engelmann spruce | 4 | other softwoods | 4 |
| white spruce | 4 | other hardwoods | 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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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:

| | |
|--|-------------------------------------|
| <i>% of tree ht. that must be exceeded for a gap in the ht. distribution</i> | <i>= 20</i> |
| <i>diam breakpoint between seedlings/saplings and pole-sized trees</i> | <i>= 5</i> |
| <i>diam breakpoint between pole-sized trees and large older trees</i> | <i>= 18 (12 for lodgepole pine)</i> |
| <i>min cover % needed to qualify as a stratum</i> | <i>= 5</i> |
| <i>min trees/acre needed to classify as stand initiation</i> | <i>= 200</i> |
| <i>min % of maximum sdi to classify as stem exclusion</i> | <i>= 30</i> |

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.

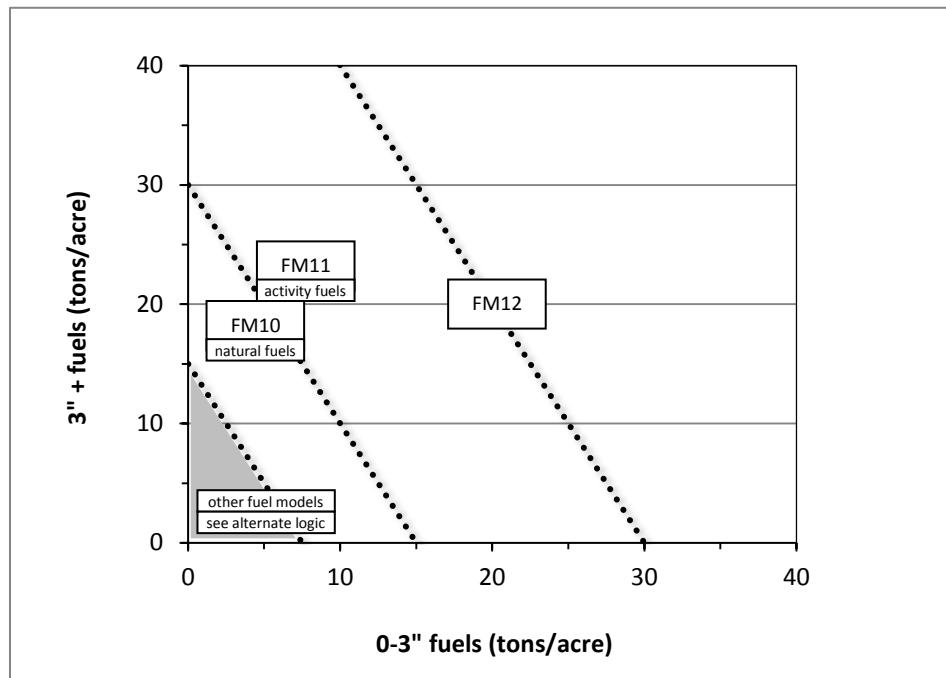
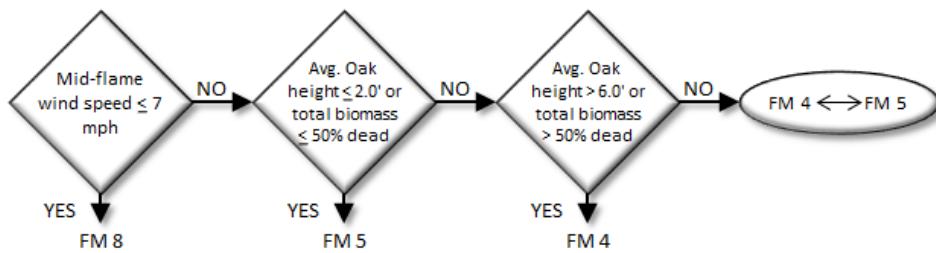
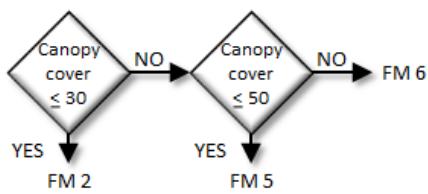


Figure 4.6.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.6.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

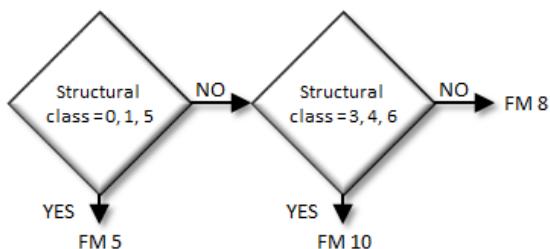
Oak Brush Cover Type



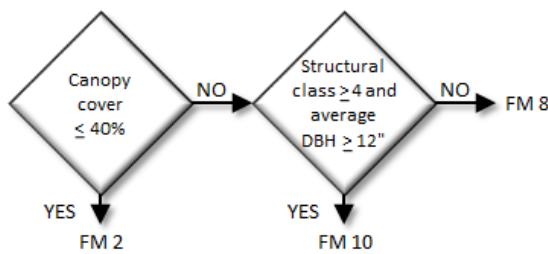
Pinyon Juniper Cover Type



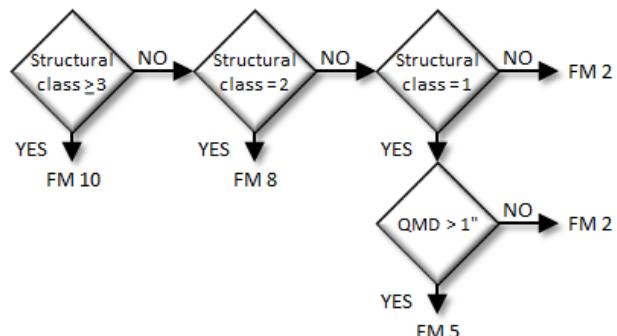
Lodgepole Pine Cover Type



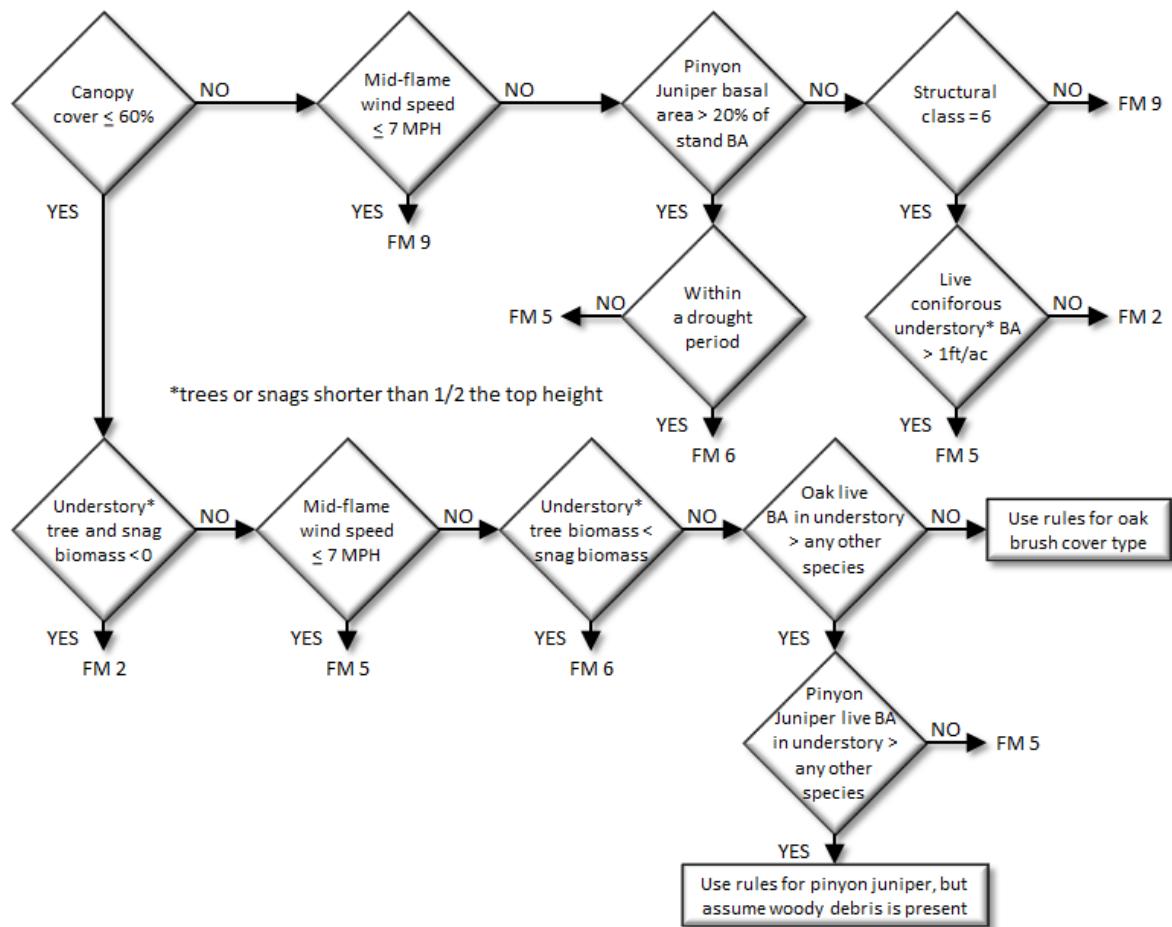
White Spruce Cover Type

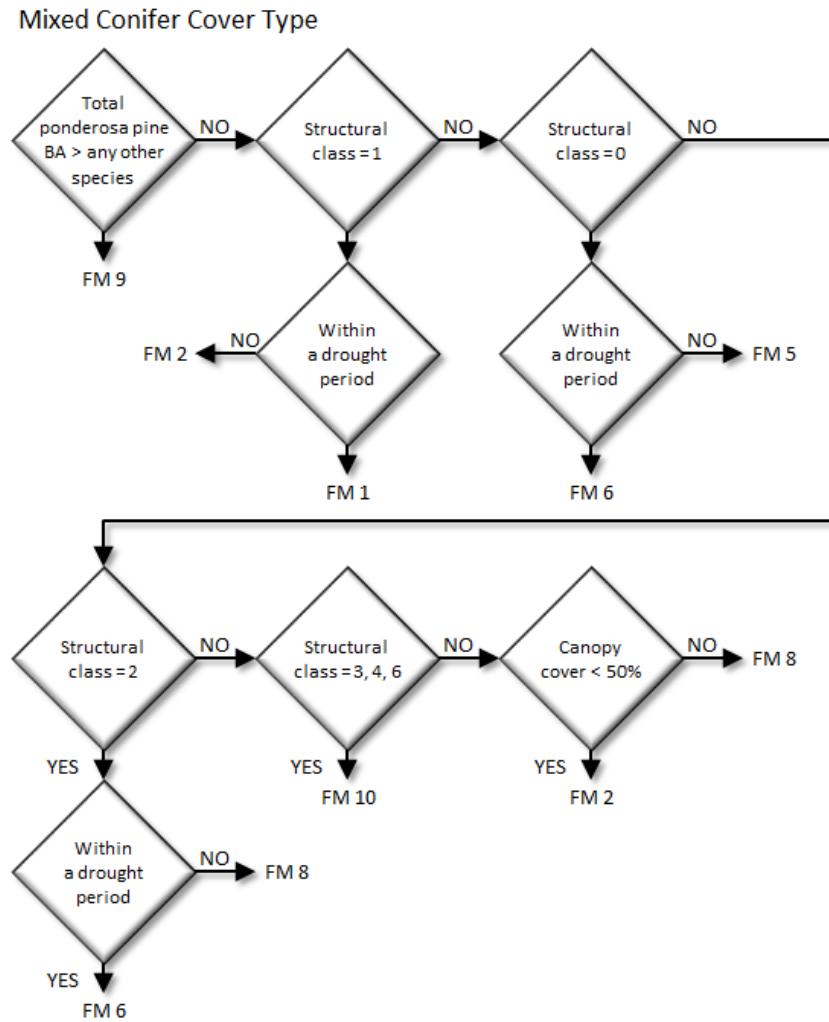


Spruce Fir Cover Type



Ponderosa Pine Cover Type





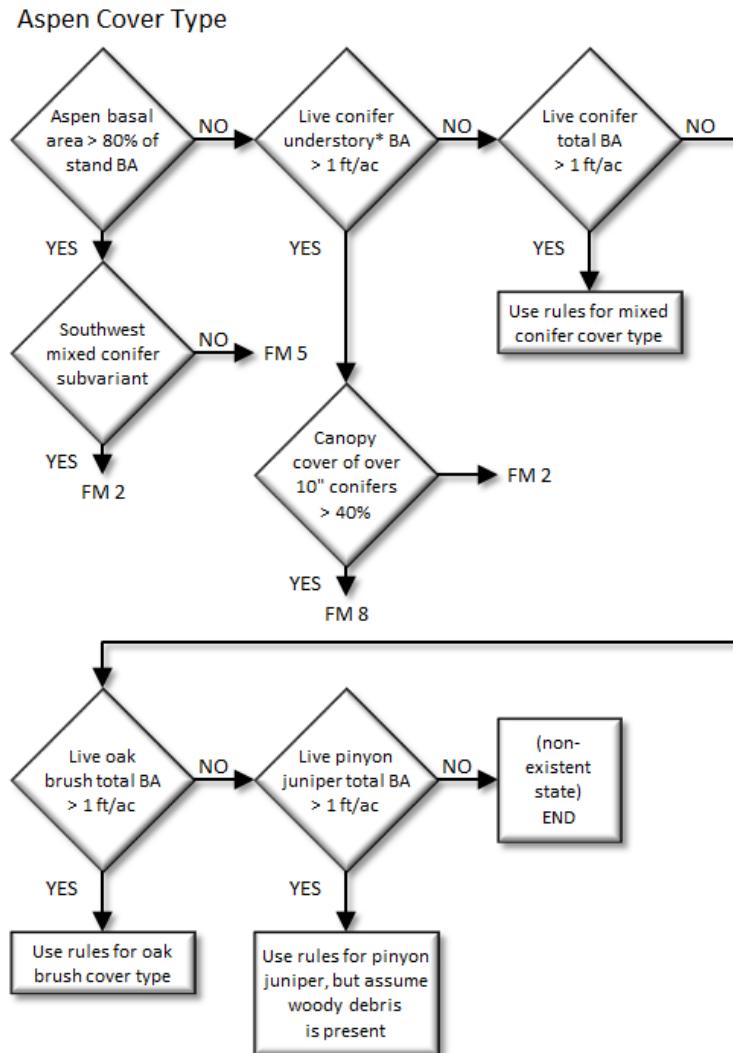


Figure 4.6.2 - Logic for modeling fire at “low” fuel load in the CR-FFE variant.

4.7 Central States (CS)

4.7.1 Tree Species

The Central States variant models the 96 tree species categories shown in Table 4.7.1. The “other softwood” category is modeled as eastern white pine, the “other upland hardwoods” category is modeled as honeylocust, the “other lowland hardwoods” category is modeled as sycamore and the “non-commercial hardwoods” category is modeled as flowering dogwood.

Table 4.7.1 - Tree species simulated by the Central States variant.

| Common name | Scientific name | Common name | Scientific name |
|------------------------|--------------------------------|--------------------------|---|
| eastern redcedar | <i>Juniperus virginiana</i> | southern red oak | <i>Quercus falcata</i> |
| juniper species | <i>Juniperus sp.</i> | black oak | <i>Quercus velutina</i> |
| shortleaf pine | <i>Pinus echinata</i> | scarlet oak | <i>Quercus coccinea</i> |
| Virginia pine | <i>Pinus virginiana</i> | blackjack oak | <i>Quercus marilandica</i> |
| loblolly pine | <i>Pinus taeda</i> | chinkapin oak | <i>Quercus muehlenbergii</i> |
| other softwood species | | swamp white oak | <i>Quercus bicolor</i> |
| eastern white pine | <i>Pinus strobus</i> | bur oak | <i>Quercus macrocarpa</i> |
| black walnut | <i>Juglans nigra</i> | swamp chestnut oak | <i>Quercus michauxii</i> |
| butternut | <i>Juglans cinerea</i> | post oak | <i>Quercus stellata</i> |
| | | | <i>Quercus stellata</i> var. <i>mississippiensis</i> |
| tupelo species | <i>Nyssa sp.</i> | Delta post oak | <i>Quercus prinus</i> |
| swamp tupelo | <i>Nyssa biflora</i> | chestnut oak | <i>Quercus palustris</i> |
| water tupelo | <i>Nyssa aquatica</i> | pin oak | <i>Quercus pagoda</i> |
| blackgum, black tupelo | <i>Nyssa sylvatica</i> | cherrybark oak | <i>Quercus imbricaria</i> |
| select hickory | <i>Carya sp.</i> | shingle oak | <i>Quercus lyrata</i> |
| shagbark hickory | <i>Carya ovata</i> | overcup oak | <i>Quercus nigra</i> |
| shellbark hickory | <i>Carya laciniosa</i> | water oak | <i>Quercus nutallii</i> |
| mockernut hickory | <i>Carya alba</i> | Nuttall oak | <i>Quercus phellos</i> |
| pignut hickory | <i>Carya glabra</i> | willow oak | <i>Quercus shumardii</i> |
| hickory species | <i>Carya sp.</i> | Shumard oak | |
| water hickory | <i>Carya aquatica</i> | other upland hardwoods | |
| bitternut hickory | <i>Carya cordiformis</i> | sassafras | <i>Sassafras albidum</i> |
| pecan | <i>Carya illinoensis</i> | Ohio buckeye | <i>Aesculus glabra</i> |
| black hickory | <i>Carya texana</i> | catalpa | <i>Catalpa sp.</i> |
| American beech | <i>Fagus grandifolia</i> | common persimmon | <i>Diospyros virginiana</i> |
| black ash | <i>Fraxinus nigra</i> | honeylocust | <i>Gleditsia triacanthos</i> |
| pumpkin ash | <i>Fraxinus profunda</i> | balsam poplar | <i>Populus balsamifera</i> |
| blue ash | <i>Fraxinus quadrangulata</i> | bigtooth aspen | <i>Populus grandidentata</i> |
| eastern cottonwood | <i>Populus deltoides</i> | quaking aspen | <i>Populus tremuloides</i> |
| red maple | <i>Acer rubrum</i> | black locust | <i>Robinia pseudoacacia</i> |
| boxelder | <i>Acer negundo</i> | other lowland species | |
| silver maple | <i>Acer saccharinum</i> | sycamore | <i>Platanus occidentalis</i> |
| black cherry | <i>Prunus serotina</i> | baldcypress | <i>Taxodium distichum</i> |
| American elm | <i>Ulmus americana</i> | river birch | <i>Betula nigra</i> |
| sugarberry | <i>Celtis laevigata</i> | sweetgum | <i>Liquidamber styraciflua</i> |
| hackberry | <i>Celtis occidentalis</i> | willow species | <i>Salix sp.</i> |
| winged elm | <i>Ulmus alata</i> | black willow | <i>Salix nigra</i> |
| elm species | <i>Ulmus sp.</i> | non-commercial hardwoods | |
| Siberian elm | <i>Ulmus pumila</i> | American hornbeam | <i>Carpinus caroliniana</i> |
| slippery (red) elm | <i>Ulmus rubra</i> | eastern redbud | <i>Cercis canadensis</i> |
| rock elm | <i>Ulmus thomasii</i> | flowering dogwood | <i>Cornus florida</i> |
| yellow-poplar | <i>Liriodendron tulipifera</i> | hawthorn species | <i>Crataegus sp.</i> |
| American basswood | <i>Tilia americana</i> | Kentucky coffeetree | <i>Gymnocladus dioicus</i> |
| sugar maple | <i>Acer saccharum</i> | osage-orange | <i>Maclura pomifera</i> |
| ash species | <i>Fraxinus sp.</i> | cucumbertree | <i>Magnolia acuminata</i> |
| white ash | <i>Fraxinus americana</i> | sweetbay | <i>Magnolia virginiana</i> |
| green ash | <i>Fraxinus pennsylvanica</i> | mulberry species | <i>Morus sp.</i> |
| white oak | <i>Quercus alba</i> | eastern hop hornbeam | <i>Ostrya virginiana</i> |
| northern red oak | <i>Quercus rubra</i> | sourwood | <i>Oxydendrum arboreum</i> |

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 species | 3 | black oak | 2 |
| shortleaf pine | 1 | scarlet oak | 2 |
| Virginia pine | 1 | blackjack oak | 3 |
| loblolly pine | 1 | chinkapin oak | 3 |
| other softwood species | 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 species | 3 | Delta post oak | 3 |
| swamp tupelo | 3 | chestnut oak | 2 |
| water tupelo | 3 | pin oak | 2 |
| blackgum, black tupelo | 3 | cherrybark oak | 2 |
| select hickory | 3 | shingle oak | 2 |
| shagbark hickory | 3 | overcup oak | 2 |
| shellbark hickory | 3 | water oak | 3 |
| mockernut hickory | 3 | Nuttall oak | 2 |
| pignut hickory | 3 | willow oak | 2 |
| hickory species | 3 | Shumard oak | 2 |
| water hickory | 3 | other upland hardwoods | 3 |
| 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 |

| Species | Snag class | Species | Snag class |
|--------------------|-------------------|--------------------------|-------------------|
| eastern cottonwood | 1 | quaking aspen | 1 |
| red maple | 2 | black locust | 3 |
| boxelder | 2 | other lowland species | 2 |
| silver maple | 2 | sycamore | 2 |
| black cherry | 2 | baldcypress | 3 |
| American elm | 1 | river birch | 1 |
| sugarberry | 2 | sweetgum | 2 |
| hackberry | 2 | willow species | 1 |
| winged elm | 1 | black willow | 1 |
| elm species | 1 | non-commercial hardwoods | 2 |
| Siberian elm | 1 | American hornbeam | 2 |
| slippery (red) elm | 1 | eastern redbud | 2 |
| rock elm | 1 | flowering dogwood | 2 |
| yellow-poplar | 2 | hawthorn species | 2 |
| American basswood | 1 | Kentucky coffeetree | 2 |
| sugar maple | 2 | osage-orange | 2 |
| ash species | 2 | cucumbertree | 2 |
| white ash | 2 | sweetbay | 2 |
| green ash | 2 | mulberry species | 2 |
| white oak | 3 | eastern hophornbeam | 2 |
| northern red oak | 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.

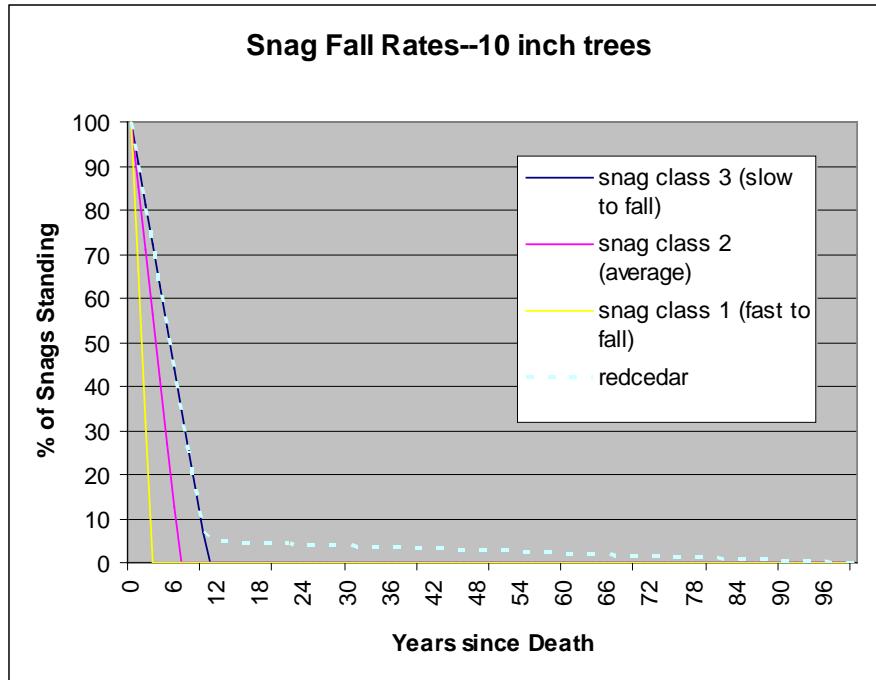


Figure 4.7.1 - Snag fall rates for 10 inch trees.

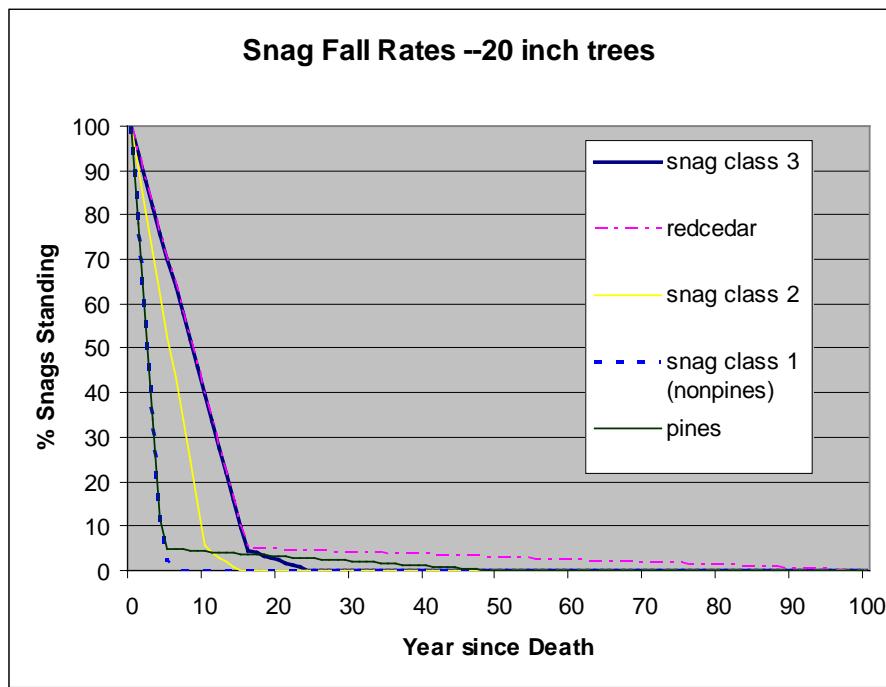


Figure 4.7.2 - Snag fall rates for 20 inch trees.

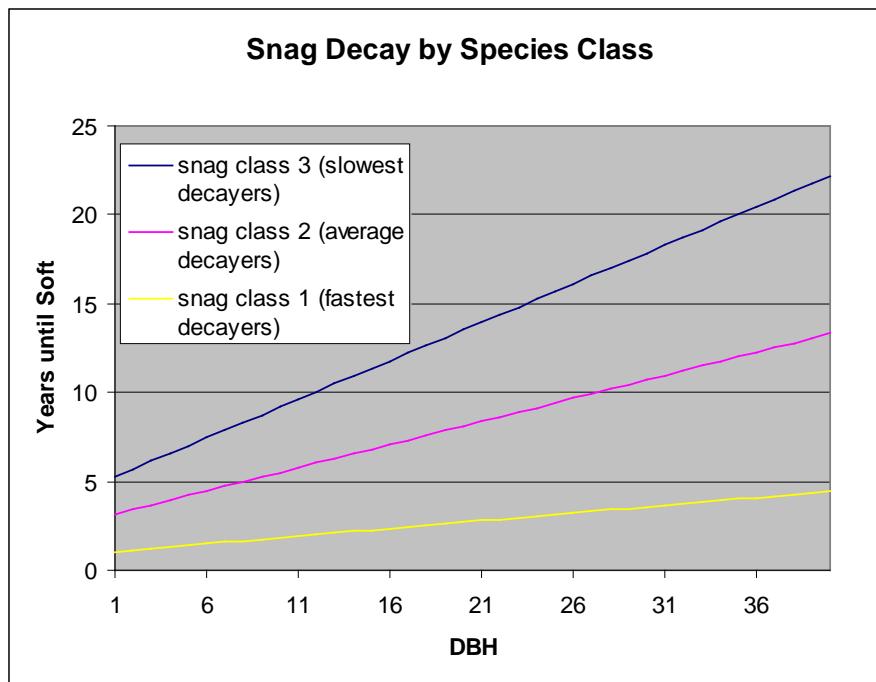


Figure 4.7.3 - The number of years until soft for various diameter snags.

4.7.3 Fuels

Fuels are divided into 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 | Ibs/cuft | Species used | Species | Ibs/cuft | Species used |
|------------------------|----------|------------------|------------------------|----------|-------------------|
| eastern redcedar | 27.4 | | southern red oak | 32.4 | |
| juniper species | 27.4 | eastern redcedar | black oak | 34.9 | |
| shortleaf pine | 29.3 | | scarlet oak | 37.4 | |
| Virginia pine | 28.1 | | blackjack oak | 34.9 | black oak |
| loblolly pine | 29.3 | | chinkapin oak | 37.4 | white oak |
| other softwood species | 21.2 | | swamp white oak | 39.9 | |
| eastern white pine | 21.2 | e. white pine | bur oak | 36.2 | |
| black walnut | 31.8 | | swamp chestnut oak | 37.4 | |
| butternut | 22.5 | | post oak | 37.4 | |
| tupelo species | 28.7 | black tupelo | Delta post oak | 37.4 | post oak |
| swamp tupelo | 28.7 | black tupelo | chestnut oak | 35.6 | |
| water tupelo | 28.7 | | pin oak | 36.2 | |
| blackgum, black tupelo | 28.7 | | cherrybark oak | 38.0 | |
| select hickory | 39.9 | shagbark hickory | shingle oak | 34.9 | northern red oak |
| shagbark hickory | 39.9 | | overcup oak | 35.6 | |
| shellbark hickory | 38.7 | | water oak | 34.9 | |
| mockernut hickory | 39.9 | | Nuttall oak | 34.9 | black oak |
| pignut hickory | 41.2 | | willow oak | 34.9 | |
| hickory species | 39.9 | shagbark hickory | Shumard oak | 34.9 | black oak |
| water hickory | 38.0 | | other upland hardwoods | 37.4 | honeylocust |
| bitternut hickory | 37.4 | | sassafras | 26.2 | |
| pecan | 37.4 | | Ohio buckeye | 20.6 | yellow buckeye |
| black hickory | 39.9 | shagbark hickory | catalpa | 23.7 | |
| American beech | 34.9 | | common persimmon | 39.9 | |
| black ash | 28.1 | | honeylocust | 37.4 | |
| pumpkin ash | 29.9 | | balsam poplar | 19.3 | |
| blue ash | 33.1 | | bigtooth aspen | 22.5 | |
| eastern cottonwood | 23.1 | | quaking aspen | 21.8 | |
| red maple | 30.6 | | black locust | 41.2 | |
| boxelder | 25.9 | | other lowland species | 28.7 | sycamore |
| silver maple | 27.4 | | sycamore | 28.7 | |
| black cherry | 29.3 | | baldcypress | 26.2 | |
| American elm | 28.7 | | river birch | 30.6 | |
| sugarberry | 30.6 | hackberry | sweetgum | 28.7 | |
| hackberry | 30.6 | | willow species | 22.5 | black willow |
| winged elm | 37.4 | | black willow | 22.5 | |
| elm species | 28.7 | American elm | non-commercial | | flowering dogwood |
| Siberian elm | 28.7 | American elm | hardwoods | 39.9 | |
| slippery (red) elm | 29.9 | | American hornbeam | 36.2 | |
| rock elm | 35.6 | | eastern redbud | 36.2 | |
| yellow-poplar | 24.9 | | flowering dogwood | 39.9 | |
| American basswood | 20.0 | | hawthorn species | 38.7 | |
| sugar maple | 34.9 | | Kentucky coffeetree | 33.1 | |
| ash species | 33.1 | green ash | osage-orange | 47.4 | |
| white ash | 34.3 | | cucumbertree | 27.4 | |
| green ash | 33.1 | | sweetbay | 26.2 | |
| white oak | 37.4 | | mulberry species | 36.8 | |
| northern red oak | 34.9 | | eastern hop hornbeam | 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 ($\text{Vol} = 0.0015*D*D*H$) 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 | Species | Leaf Life (years) | Crown Fall Class |
|------------------------|----------------------|---------------------|--------------------|----------------------|---------------------|
| eastern redcedar | 5 | 1 | southern red oak | 1 | 4 |
| juniper species | 5 | 1 | black oak | 1 | 4 |
| shortleaf pine | 4 | 6 | scarlet oak | 1 | 4 |
| Virginia pine | 3 | 6 | blackjack oak | 1 | 2 |
| loblolly pine | 3 | 6 | chinkapin oak | 1 | 3 |
| other softwood species | 2 | 6 | swamp white oak | 1 | 3 |
| eastern white pine | 2 | 6 | bur oak | 1 | 3 |
| black walnut | 1 | 4 | swamp chestnut oak | 1 | 3 |
| butternut | 1 | 4 | post oak | 1 | 3 |
| tupelo species | 1 | 3 | Delta post oak | 1 | 3 |
| swamp tupelo | 1 | 3 | chestnut oak | 1 | 3 |
| water tupelo | 1 | 3 | pin oak | 1 | 4 |
| blackgum, black tupelo | 1 | 3 | cherrybark oak | 1 | 4 |
| select hickory | 1 | 2 | shingle oak | 1 | 4 |
| shagbark hickory | 1 | 2 | overcup oak | 1 | 3 |
| shellbark hickory | 1 | 2 | water oak | 1 | 3 |
| mockernut hickory | 1 | 2 | Nuttall oak | 1 | 4 |
| pignut hickory | 1 | 2 | willow oak | 1 | 4 |

| Species | Leaf Life (years) | Crown Fall Class | Species | Leaf Life (years) | Crown Fall Class |
|--------------------|------------------------------|-----------------------------|-----------------------------|------------------------------|-----------------------------|
| hickory species | 1 | 2 | Shumard oak | 1 | 4 |
| water hickory | 1 | 2 | other upland hardwoods | 1 | 2 |
| bitternut hickory | 1 | 2 | sassafras | 1 | 4 |
| pecan | 1 | 2 | Ohio buckeye | 1 | 5 |
| black hickory | 1 | 2 | catalpa | 1 | 4 |
| American beech | 1 | 4 | common persimmon | 1 | 4 |
| black ash | 1 | 5 | honeylocust | 1 | 2 |
| pumpkin ash | 1 | 5 | balsam poplar | 1 | 5 |
| blue ash | 1 | 5 | bigtooth aspen | 1 | 5 |
| eastern cottonwood | 1 | 5 | quaking aspen | 1 | 5 |
| red maple | 1 | 5 | black locust | 1 | 2 |
| boxelder | 1 | 5 | other lowland species | 1 | 5 |
| silver maple | 1 | 5 | sycamore | 1 | 5 |
| black cherry | 1 | 4 | baldcypress | 1 | 1 |
| American elm | 1 | 5 | river birch | 1 | 5 |
| sugarberry | 1 | 4 | sweetgum | 1 | 5 |
| hackberry | 1 | 4 | willow species | 1 | 6 |
| winged elm | 1 | 5 | black willow | 1 | 6 |
| | 1 | 5 | non-commercial hardwoods | 1 | 5 |
| elm species | | | American hornbeam | 1 | 4 |
| Siberian elm | 1 | 5 | eastern redbud | 1 | 5 |
| slippery (red) elm | 1 | 5 | flowering dogwood | 1 | 5 |
| rock elm | 1 | 5 | hawthorn species | 1 | 5 |
| yellow-poplar | 1 | 5 | Kentucky coffeetree | 1 | 5 |
| American basswood | 1 | 5 | osage-orange | 1 | 4 |
| sugar maple | 1 | 5 | cucumbertree | 1 | 4 |
| ash species | 1 | 5 | sweetbay | 1 | 4 |
| white ash | 1 | 5 | mulberry species | 1 | 5 |
| green ash | 1 | 5 | eastern hop hornbeam | 1 | 4 |
| white oak | 1 | 3 | sourwood | 1 | 5 |
| northern red oak | 1 | 4 | | | |

Table 4.7.7 - Years until all snag crown material of certain sizes has fallen by crown fall class

| Crown fall class | Foliage | Snag Crown Material Time to 100% Fallen (years) | | | | |
|-----------------------------|----------------|--|----------------|-------------|-------------|--------------|
| | | <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 |
| Pines | 100s | 0.18 | 0.93 | 1.77 | 0.27 | 0.75 | 8.38 | 4.10 |
| Redcedar | 181, 402 | 0.19 | 0.86 | 1.58 | 0.11 | 0.31 | 0.67 | 4.89 |
| Pine-hardwood | 400s | 0.18 | 0.75 | 2.42 | 0.59 | 0.67 | 1.34 | 5.37 |
| Oak-hickory | 500s | 0.15 | 0.74 | 1.70 | 0.38 | 0.97 | 2.68 | 5.17 |
| Elm-ash-cottonwood | 700s | 0.20 | 0.92 | 2.19 | 0.41 | 1.46 | 3.80 | 2.49 |
| Maple-beech-birch | 800s | 0.19 | 0.88 | 1.95 | 0.56 | 1.62 | 1.82 | 3.88 |
| 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 | Species | Multiplier (V_{sp}) | Species used |
|------------------------|-------------------------|--------------|------------------------|-------------------------|--------------|
| eastern redcedar | 0.038 | | southern red oak | 0.044 | |
| juniper species | 0.033 | | black oak | 0.045 | |
| shortleaf pine | *** | | scarlet oak | 0.04 | |
| Virginia pine | 0.033 | | blackjack oak | 0.037 | |
| loblolly pine | 0.052 | | chinkapin oak | 0.042 | |
| other softwood species | 0.045 | | swamp white oak | 0.045 | |
| eastern white pine | 0.045 | | bur oak | 0.042 | |
| black walnut | 0.041 | | swamp chestnut oak | 0.046 | |
| butternut | 0.041 | | post oak | 0.044 | |
| tupelo species | 0.025 | | Delta post oak | 0.044 | post oak |
| swamp tupelo | 0.037 | | chestnut oak | 0.049 | |
| water tupelo | 0.03 | | pin oak | 0.041 | |
| blackgum, black tupelo | 0.039 | | cherrybark oak | 0.044 | s. red oak |
| select hickory | 0.044 | hickory spp | shingle oak | 0.041 | |
| shagbark hickory | 0.04 | | overcup oak | 0.039 | |
| shellbark hickory | 0.043 | | water oak | 0.036 | |
| mockernut hickory | 0.043 | | Nuttall oak | 0.03 | |
| pignut hickory | 0.037 | | willow oak | 0.041 | |
| hickory species | 0.044 | | Shumard oak | 0.037 | |
| water hickory | 0.044 | hickory spp | other upland hardwoods | 0.038 | honeylocust |
| bitternut hickory | 0.037 | | sassafras | 0.035 | |
| pecan | 0.036 | | Ohio buckeye | 0.036 | |
| black hickory | 0.04 | | catalpa | 0.037 | |
| American beech | 0.025 | | common persimmon | 0.041 | |
| black ash | 0.035 | | honeylocust | 0.038 | |
| pumpkin ash | 0.037 | | balsam poplar | 0.04 | |
| blue ash | 0.03 | | bigtooth aspen | 0.039 | |
| eastern cottonwood | 0.04 | | quaking aspen | 0.044 | |
| red maple | 0.028 | | black locust | 0.049 | |
| boxelder | 0.034 | | other lowland species | 0.033 | sycamore |
| silver maple | 0.031 | | sycamore | 0.033 | |
| black cherry | 0.03 | | baldcypress | 0.025 | |

| Species | Multiplier (V_{sp}) | Species used | Species | Multiplier (V_{sp}) | Species used |
|--------------------|--|---------------------|--------------------------|--|---------------------|
| American elm | 0.031 | | river birch | 0.029 | |
| sugarberry | 0.036 | | sweetgum | 0.036 | |
| hackberry | 0.036 | sugarberry | willow species | 0.041 | |
| winged elm | 0.031 | | black willow | 0.04 | |
| elm species | 0.039 | | non-commercial hardwoods | 0.041 | dogwood |
| Siberian elm | 0.038 | | American hornbeam | 0.03 | |
| slippery (red) elm | 0.032 | | eastern redbud | 0.035 | |
| rock elm | 0.033 | | flowering dogwood | 0.041 | |
| yellow-poplar | 0.041 | | hawthorn species | 0.038 | |
| American basswood | 0.038 | | Kentucky coffeetree | 0.031 | |
| sugar maple | 0.033 | | osage-orange | 0.037 | |
| ash species | 0.042 | | cucumbertree | 0.036 | |
| white ash | 0.042 | | sweetbay | 0.04 | |
| green ash | 0.039 | | mulberry species | 0.033 | |
| white oak | 0.04 | | eastern hophornbeam | 0.037 | |
| northern red oak | 0.042 | | sourwood | 0.036 | |

4.7.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.7.11). 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 | | |
| 0.25 – 1 | 0.11 | |
| 1 – 3 | 0.09 | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.07 | |
| > 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 **FUELDECAY** 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 | Species | Decay Rate Class |
|------------------------|-----------------------------|--------------------|-----------------------------|
| eastern redcedar | 2 | southern red oak | 3 |
| juniper species | 2 | black oak | 3 |
| shortleaf pine | 4 | scarlet oak | 3 |
| Virginia pine | 4 | blackjack oak | 2 |
| loblolly pine | 4 | chinkapin oak | 2 |
| other softwood species | 4 | swamp white oak | 2 |
| eastern white pine | 4 | bur oak | 2 |
| black walnut | 2 | swamp chestnut oak | 3 |

| Species | Decay Rate Class | Species | Decay Rate Class |
|------------------------|------------------|--------------------------|------------------|
| butternut | 4 | post oak | 2 |
| tupelo species | 2 | Delta post oak | 2 |
| swamp tupelo | 2 | chestnut oak | 3 |
| water tupelo | 2 | pin oak | 3 |
| blackgum, black tupelo | 2 | cherrybark oak | 3 |
| select hickory | 4 | shingle oak | 2 |
| shagbark hickory | 4 | overcup oak | 3 |
| shellbark hickory | 4 | water oak | 2 |
| mockernut hickory | 4 | Nuttall oak | 3 |
| pignut hickory | 4 | willow oak | 2 |
| hickory species | 4 | Shumard oak | 3 |
| water hickory | 4 | other upland hardwoods | 2 |
| bitternut hickory | 4 | sassafras | 2 |
| pecan | 4 | Ohio buckeye | 4 |
| black hickory | 4 | catalpa | 2 |
| American beech | 4 | common persimmon | 2 |
| black ash | 4 | honeylocust | 2 |
| pumpkin ash | 4 | balsam poplar | 4 |
| blue ash | 4 | bigtooth aspen | 4 |
| eastern cottonwood | 4 | quaking aspen | 4 |
| red maple | 4 | black locust | 1 |
| boxelder | 4 | other lowland species | 4 |
| silver maple | 4 | sycamore | 4 |
| black cherry | 2 | baldcypress | 3 |
| American elm | 4 | river birch | 4 |
| sugarberry | 4 | sweetgum | 4 |
| hackberry | 4 | willow species | 4 |
| winged elm | 4 | black willow | 4 |
| elm species | 4 | non-commercial hardwoods | 3 |
| Siberian elm | 4 | American hornbeam | 3 |
| slippery (red) elm | 4 | eastern redbud | 3 |
| rock elm | 4 | flowering dogwood | 3 |
| yellow-poplar | 4 | hawthorn species | 4 |
| American basswood | 4 | Kentucky coffeetree | 4 |
| sugar maple | 4 | osage-orange | 1 |
| ash species | 4 | cucumbertree | 4 |
| white ash | 4 | sweetbay | 4 |
| green ash | 4 | mulberry species | 1 |
| white oak | 2 | eastern hophornbeam | 3 |
| northern red oak | 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.

| Size Class | Moisture Group | | | |
|------------------------|----------------|-----|-------|-----|
| | 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.

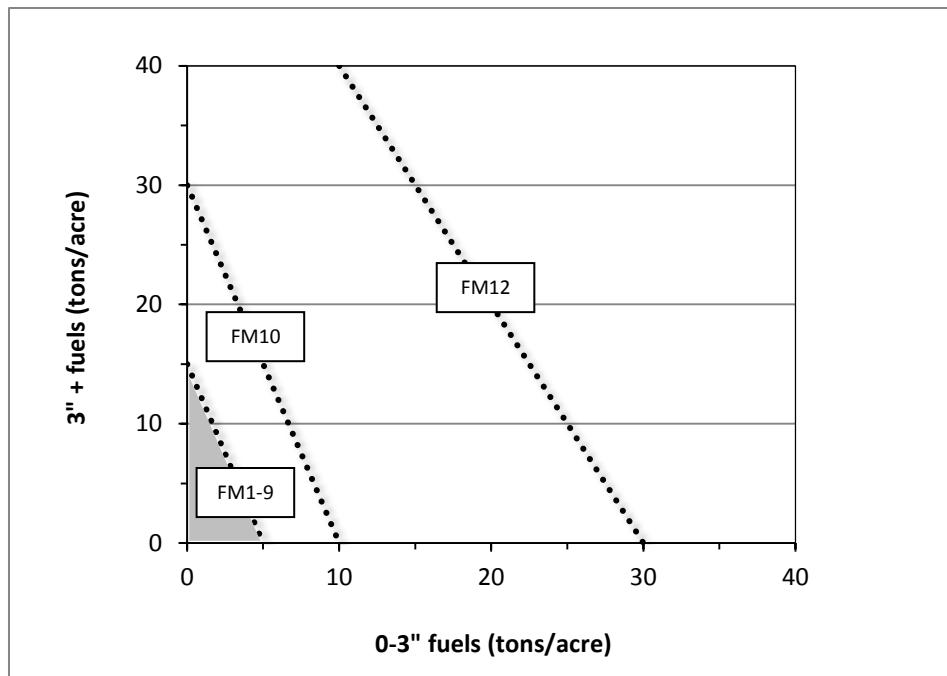


Figure 4.7.4 - If large and small fuels map to fuel models 1 - 9, candidate fuel models are determined using the logic shown in Table 4.7.14 and Table 4.7.15. Otherwise, fire behavior is based on the distance to the closest fuel models, identified by the dashed lines.

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 0-3" fuel <= 5 tons and 3"+ moisture >20% 0-3" fuel <= 5 tons and 3"+ moisture <= 20% | 5 8 9 |
| Pine and Bottomland | 3"+ moisture >20% | 8 |
| Hardwoods | 3"+ moisture <= 20% | 9 |
| Pine-Bluestem | | 2 |
| Oak Savannah | | 2 |
| Eastern Redcedar | Avg. ht. of redcedar > 6 ft. Avg. ht. of redcedar <= 6 ft. | 4 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. It also includes two additional categories; ‘other softwoods’ is modeled using mountain hemlock, and ‘other hardwoods’ 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 | <i>Pinus monticola</i> | |
| western larch | <i>Larix occidentalis</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| Pacific silver fir | <i>Abies amabilis</i> | |
| western redcedar | <i>Thuja plicata</i> | |
| grand fir | <i>Abies grandis</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| western hemlock | <i>Tsuga heterophylla</i> | = WC western hemlock |
| mountain hemlock | <i>Tsuga mertensiana</i> | = EC mountain hemlock |
| Pacific yew | <i>Taxus brevifolia</i> | = WC Pacific yew |
| whitebark pine | <i>Pinus albicaulis</i> | = WC whitebark pine |
| noble fir | <i>Abies procera</i> | = WC noble fir |
| white fir | <i>Abies concolor</i> | = EC grand fir |
| subalpine larch | <i>Larix lyallii</i> | = WC subalpine larch |
| Alaska cedar | <i>Callitropsis nootkatensis</i> | = WC Alaska cedar |
| western juniper | <i>Juniperus occidentalis</i> | = WC western juniper |
| bigleaf maple | <i>Acer macrophyllum</i> | = WC bigleaf maple |
| vine maple | <i>Acer circinatum</i> | = WC bigleaf maple |
| red alder | <i>Alnus rubra</i> | = WC red alder |
| paper birch | <i>Betula papyrifera</i> | = WC paper birch |
| giant chinquapin | <i>Chrysolepis chrysophylla</i> | = WC giant chinquapin |
| Pacific dogwood | <i>Cornus nuttallii</i> | = WC Pacific dogwood |
| quaking aspen | <i>Populus tremuloides</i> | = WC quaking aspen |
| black cottonwood | <i>Populus balsamifera</i> ssp. <i>trichocarpa</i> | = WC black cottonwood |
| Oregon white oak | <i>Quercus garryana</i> | = WC Oregon white oak |
| cherry and plum species | <i>Prunus</i> spp. | = WC bitter cherry |
| willow species | <i>Salix</i> spp. | = WC willow species |
| other softwoods | | = EC mountain hemlock |
| other hardwoods | | = 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/fmfc/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 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/ft³) 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 | cherry and plum species | 29.3 |
| whitebark pine | 22.5 | willow species | 22.5 |
| noble fir | 23.1 | other softwoods | 26.2 |
| white fir | 21.8 | other hardwoods | 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) |
| cherry and plum species | Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| willow species | Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| other softwoods | Gholz and others (1979); Brown and Johnston (1976) |
| other hardwoods | 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.

| Species | Live | | Dead | | |
|-------------------------|---------|---------|--------|---------|------|
| | 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 |
| cherry and plum species | 1 | 1 | 10 | 15 | 15 |
| willow species | 1 | 1 | 10 | 15 | 15 |
| other softwoods | 4 | 2 | 5 | 5 | 10 |
| other hardwoods | 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 | |
| | I | 0.30 | 2.00 | Use grand fir |
| 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 |
| | I | 0.18 | 2.00 | others 2000b (modified) |
| 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 |
| | I | 0.18 | 1.32 | others 2000b |
| Oregon white oak | E | 0.23 | 0.22 | |
| | I | 0.55 | 0.35 | |
| cherry and plum species | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and |
| | I | 0.18 | 1.32 | others 2000b |
| willow species | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and |
| | I | 0.18 | 1.32 | others 2000b |
| other softwoods | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | Use spruce-subalpine fir |

| Species | | Herbs | Shrubs | Notes |
|-----------------|---|--------------|---------------|--------------------------------|
| other hardwoods | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and |
| | I | 0.18 | 1.32 | 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 4.8.6). 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.

| 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 |
| | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 6.0 | 0.4 |
| western larch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Pacific silver fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| western redcedar | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| grand fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Engelmann spruce | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| subalpine fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| ponderosa pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| western hemlock | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 10.0 | 1.0 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 6.0 | 0.5 |
| mountain hemlock | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| Pacific yew | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.1 | 1.1 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| whitebark pine | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| noble fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| white fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| subalpine larch | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Alaska cedar | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.1 | 1.1 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| western juniper | E | 0.1 | 0.2 | 0.4 | 0.5 | 0.8 | 1.0 | 0.1 |
| | I | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 |

| Species | Size Class (in) | | | | | | | | |
|-------------------------|-----------------|----------|-------|-------|--------|------|--------|------|------|
| | < 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 |
| cherry and plum species | 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 species | 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 softwoods | 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 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 |

4.8.4 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 | cherry and plum species | 0.062 |
| whitebark pine | 0.030 | willow species | 0.041 |
| noble fir | 0.045 | other softwoods | 0.040 |
| white fir | 0.046 | other hardwoods | 0.044 |

4.8.5 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 (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 | | | | |
| | 0.25 – 1 | 0.113 | 0.121 | 0.134 | 0.168 |
| | 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 | | | | |
| | 0.25 – 1 | 0.057 | 0.061 | 0.068 | 0.085 |
| | 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 | | | | |
| | 0.25 – 1 | 0.103 | 0.109 | 0.122 | 0.153 |
| | 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 | | | | |
| | 0.25 – 1 | 0.076 | 0.081 | 0.090 | 0.113 |
| | 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 | | | | |
| | 0.25 – 1 | 0.067 | 0.071 | 0.079 | 0.099 |
| | 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 | | | | |
| | 0.25 – 1 | 0.092 | 0.098 | 0.109 | 0.137 |
| | 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 | | | | |
| | 0.25 – 1 | 0.087 | 0.092 | 0.103 | 0.129 |
| | 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 | | | | |
| | 0.25 – 1 | 0.057 | 0.061 | 0.068 | 0.085 |
| | 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 | 0.02 |
| | Duff | 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 | cherry and plum species | 4 |
| whitebark pine | 1 | willow species | 4 |
| noble fir | 3 | other softwoods | 2 |
| white fir | 3 | other hardwoods | 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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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.

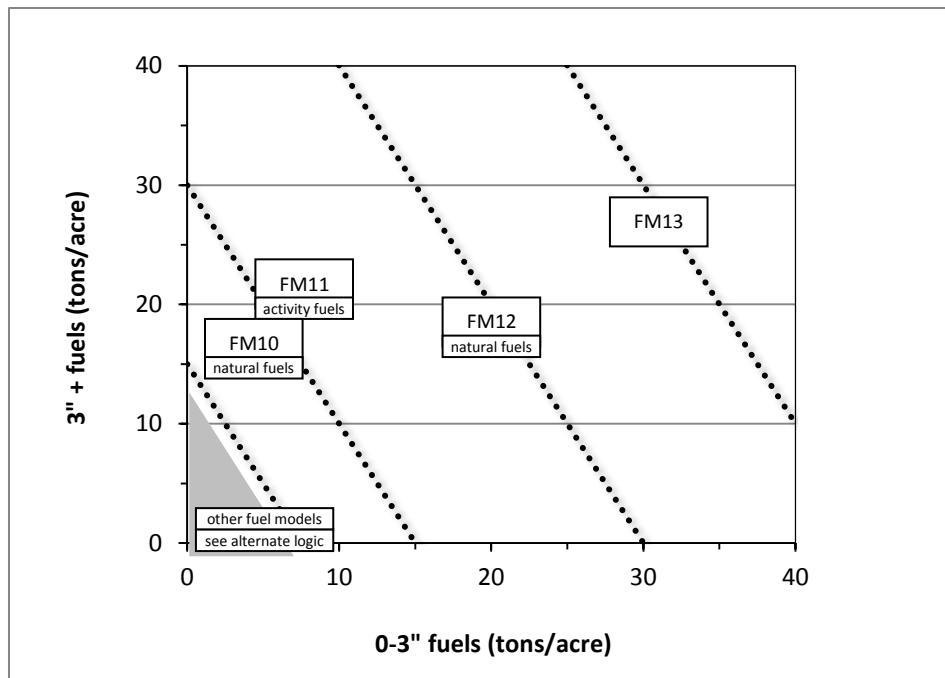
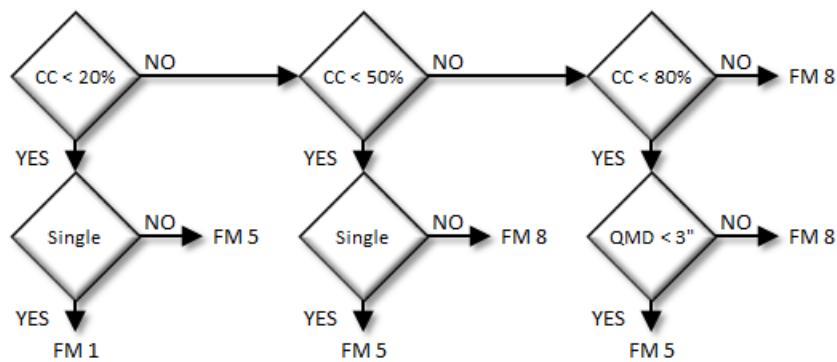
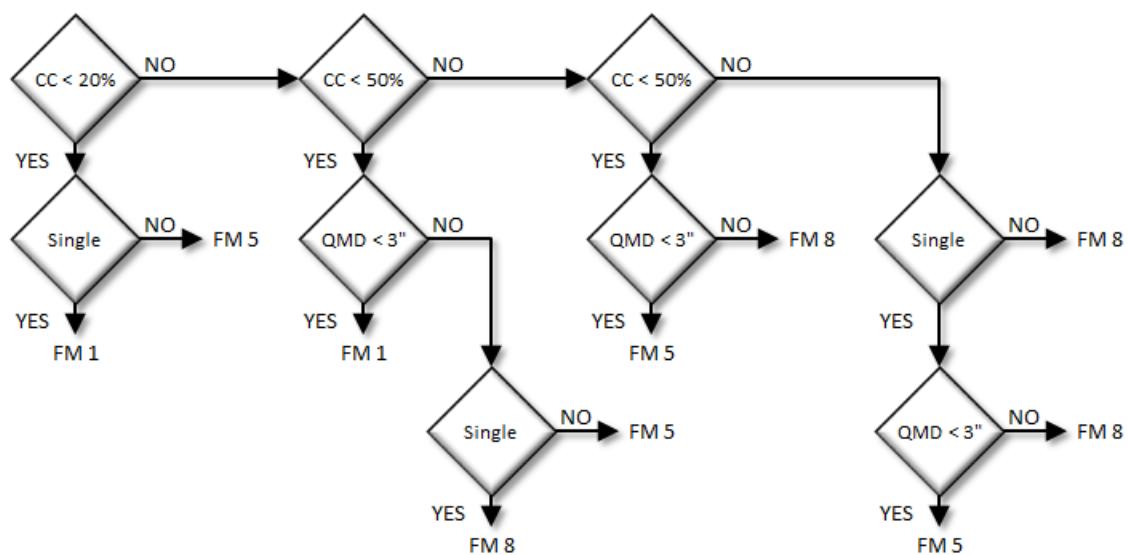


Figure 4.8.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in the figures below. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

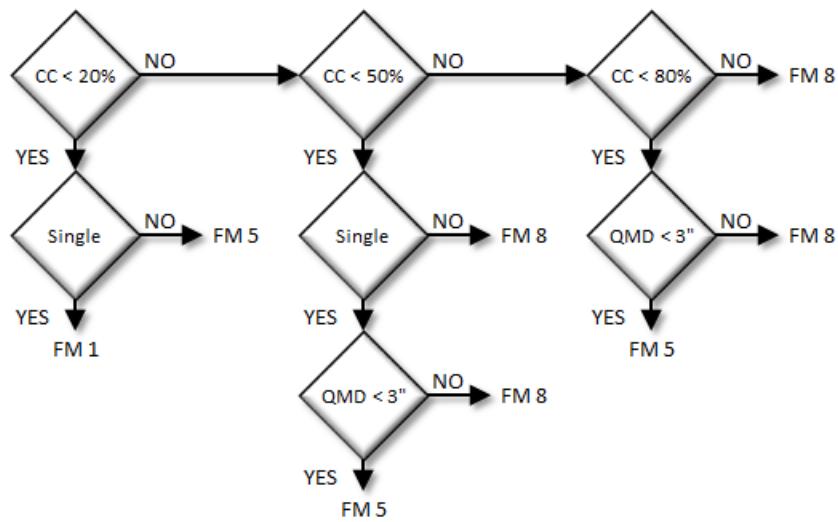
Douglas fir



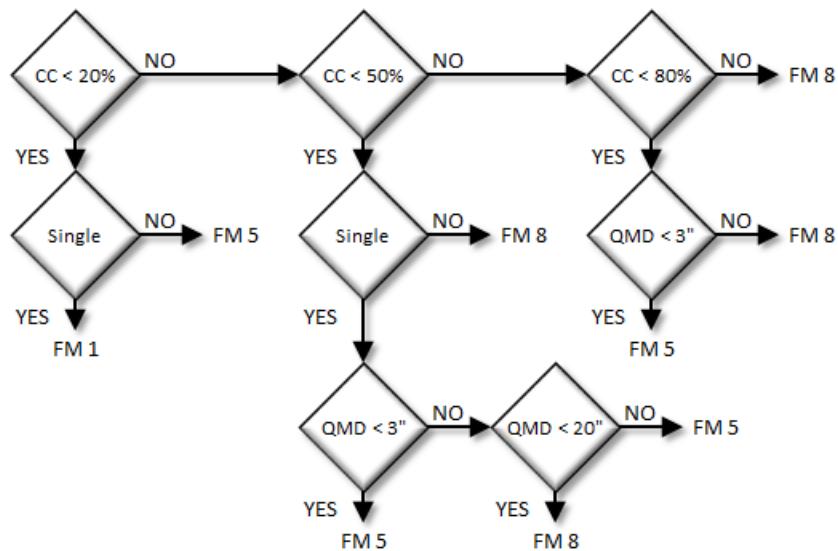
Lodgepole Pine, White Pine



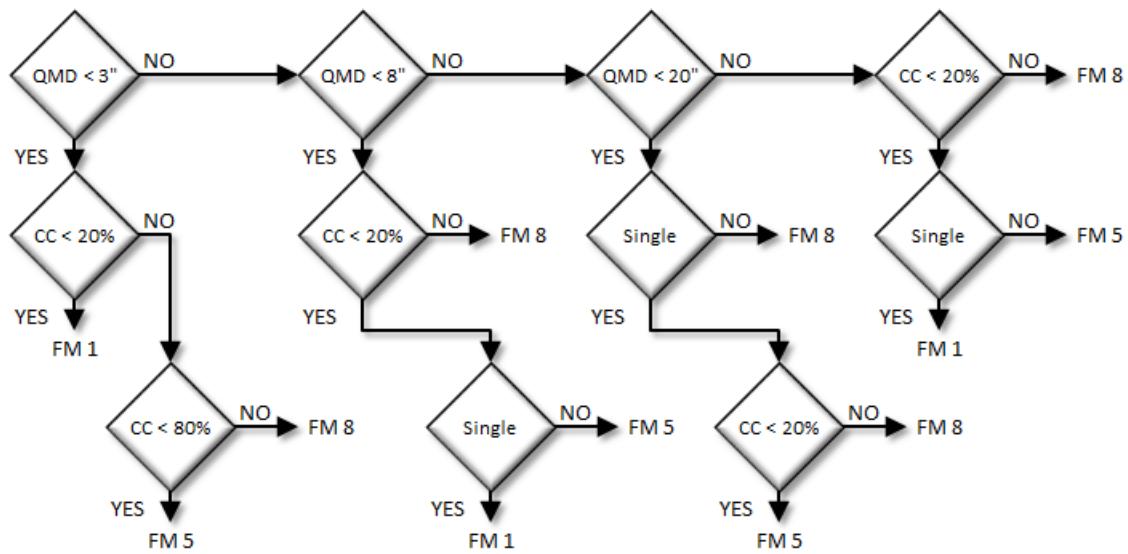
Subalpine fir, subalpine fir mixture



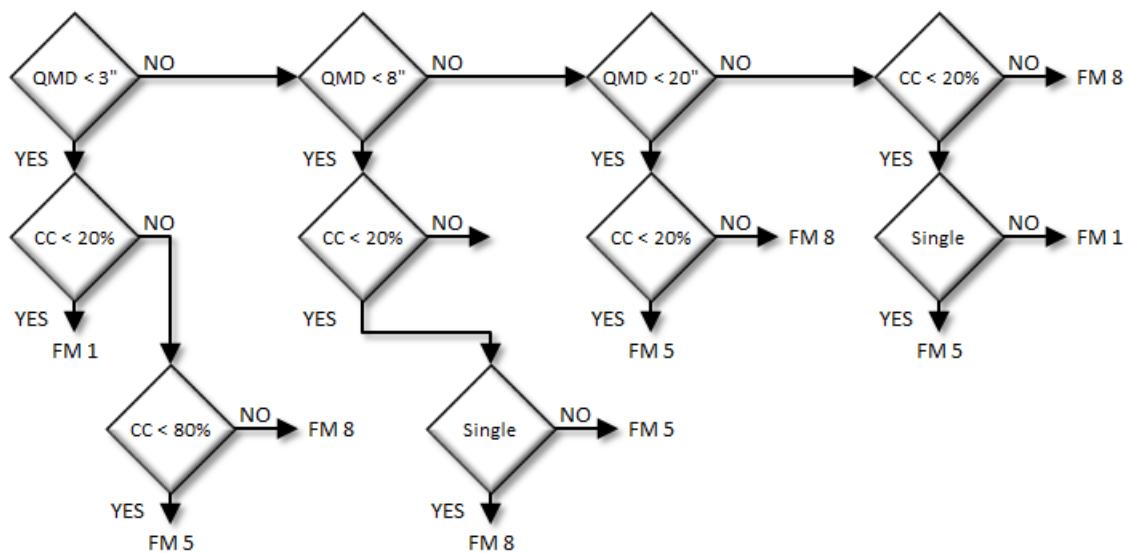
Mountain hemlock, pacific silver fir, Douglas fir/grand fir



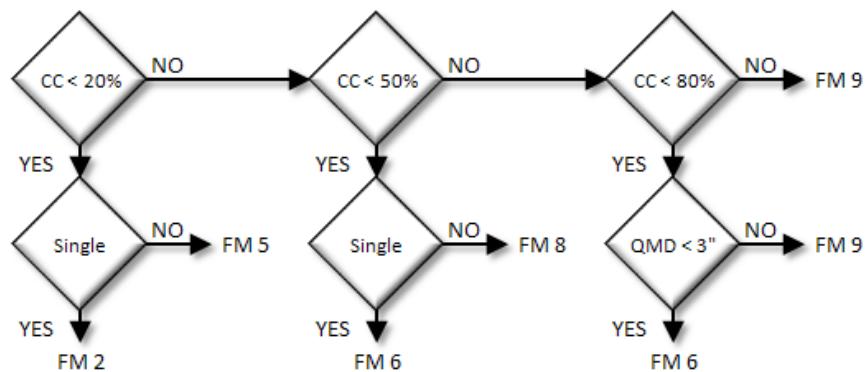
Engelmann spruce



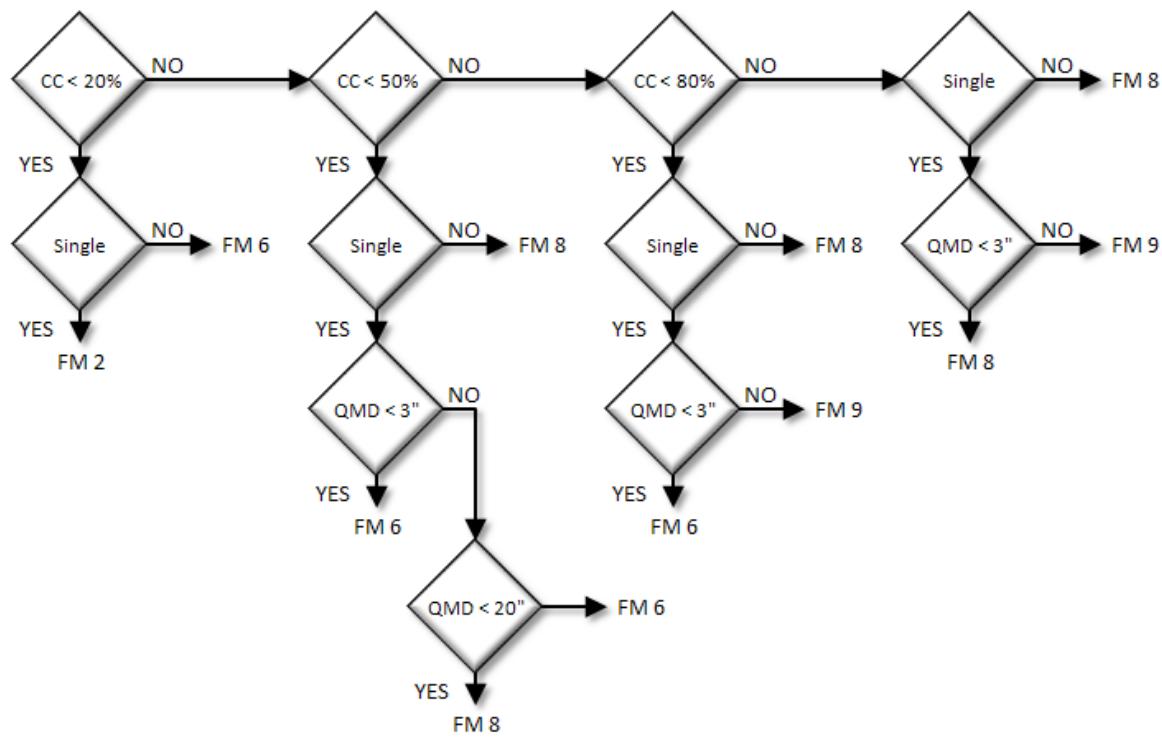
Western larch



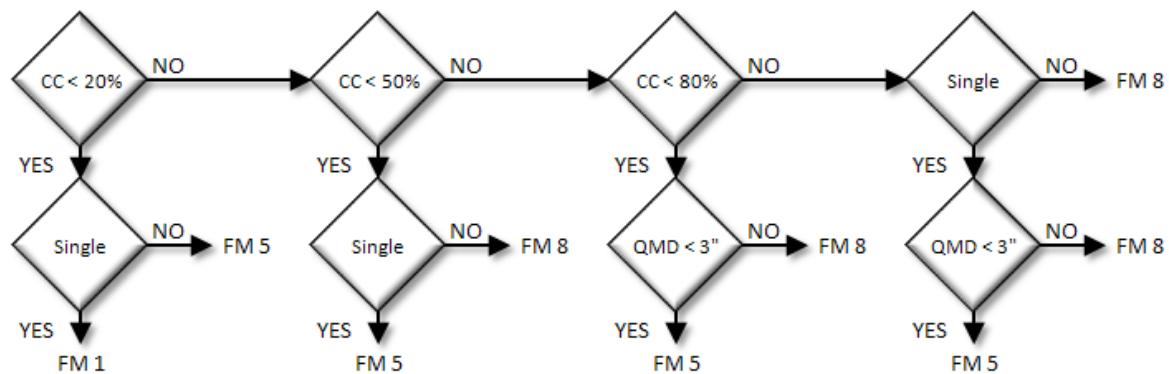
Ponderosa pine



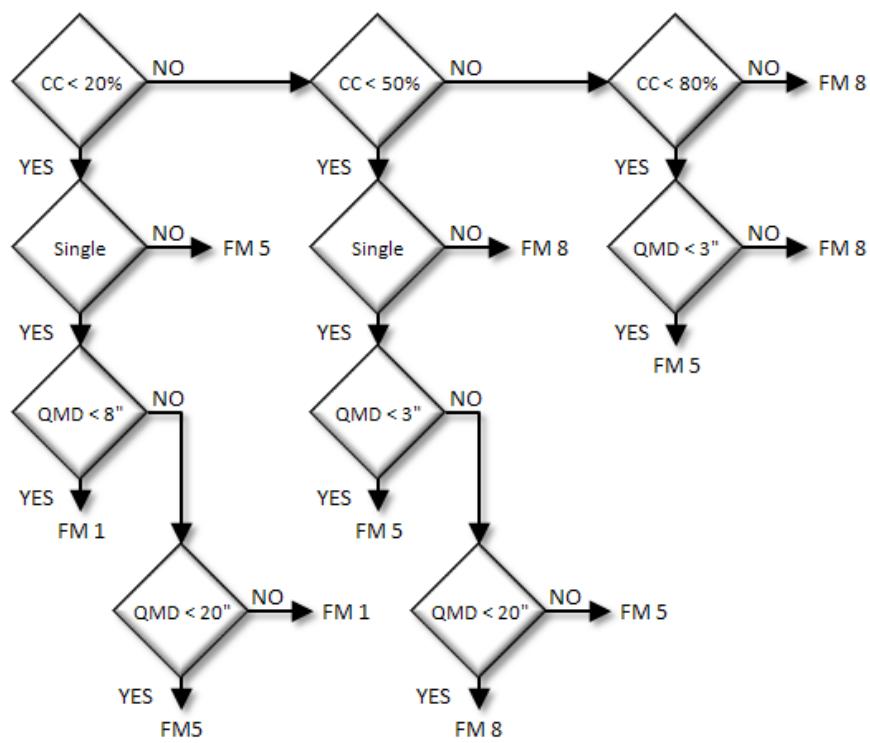
Ponderosa pine/Douglas fir

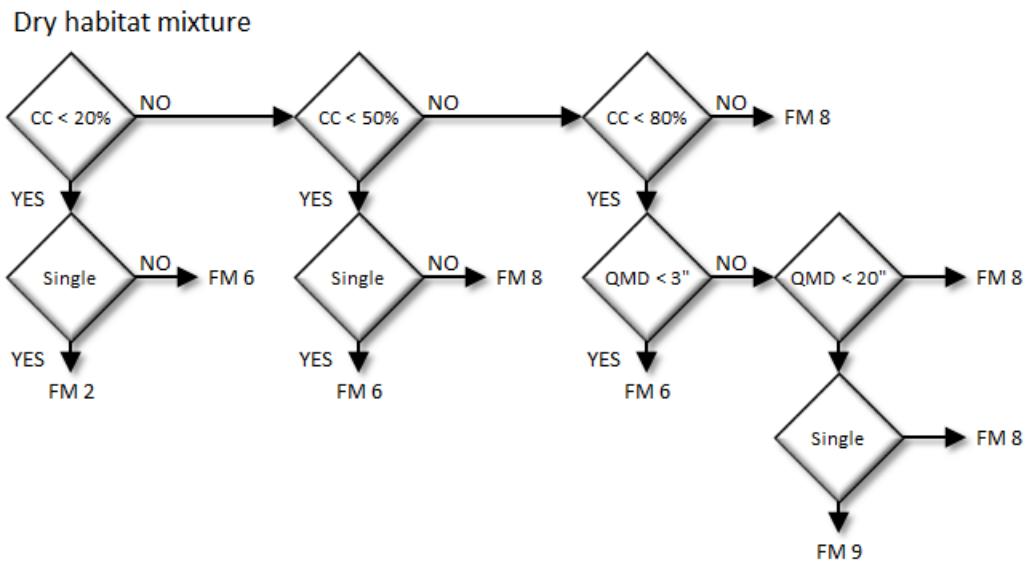


Lodgepole pine/Western larch



Moist habitat mixture





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 softwoods’ and ‘other hardwoods’, 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 | <i>Pinus albicaulis</i> | |
| western larch | <i>Larix occidentalis</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| limber pine | <i>Pinus flexilis</i> | = IE/TT limber pine |
| subalpine larch | <i>Larix lyallii</i> | = IE subalpine larch; = NI subalpine fir |
| Rocky Mountain juniper | <i>Juniperus scopulorum</i> | = IE/UT Rky Mtn juniper |
| lodgepole pine | <i>Pinus contorta</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| green ash | <i>Fraxinus pennsylvanica</i> | = IE/CR cottonwood |
| quaking aspen | <i>Populus tremuloides</i> | = IE/UT quaking aspen |
| black cottonwood | <i>Populus balsamifera var. trichocarpa</i> | = IE/CR cottonwood |
| balsam poplar | <i>Populus balsamifera</i> | = IE/CR cottonwood |
| plains cottonwood | <i>Populus deltoids var. monilifera</i> | = IE/CR cottonwood |
| narrowleaf cottonwood | <i>Populus angustifolia</i> | = IE/CR cottonwood |
| paper birch | <i>Betula papyrifera</i> | = IE paper birch; = UT quaking aspen |
| other softwoods | | |
| other hardwoods | | = 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 softwoods | 31 | 100 | 31 | 39 |
| other hardwoods | 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 softwoods | 1.0 | 1.0 | 1.0 |
| other hardwoods | 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 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/ft³) used in the EM-FFE variant.

| Species | Density (lb/ft ³) |
|------------------------|-------------------------------|
| 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 softwoods | 34.9 |
| other hardwoods | 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 softwoods | Grier and others (1992) |
| other hardwoods | 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.

| Species | Live | Dead | | |
|------------------------|----------------|----------------|------------------|----------------|
| | Foliage | Foliage | <0.25" | 0.25–1" |
| whitebark pine | 7 | 2 | 5 | 5 |
| western larch | 1 | 1 | 5 | 5 |
| Douglas-fir | 5 | 2 | 5 | 5 |
| limber pine | 3 | 2 | 5 | 5 |
| subalpine larch | 1 | 1 | 5 | 5 |
| Rocky Mountain juniper | 4 | 2 | 5 | 5 |
| lodgepole pine | 3 | 2 | 5 | 5 |
| Engelmann spruce | 6 | 2 | 5 | 5 |
| subalpine fir | 7 | 2 | 5 | 5 |
| ponderosa pine | 4 | 2 | 5 | 5 |
| green ash | 1 | 1 | 5 | 5 |
| quaking aspen | 1 | 1 | 5 | 5 |
| black cottonwood | 1 | 1 | 5 | 5 |
| balsam poplar | 1 | 1 | 5 | 5 |
| plains cottonwood | 1 | 1 | 5 | 5 |
| narrowleaf cottonwood | 1 | 1 | 5 | 5 |
| paper birch | 1 | 1 | 5 | 5 |
| other softwoods | 4 | 2 | 5 | 5 |
| other hardwoods | 1 | 1 | 5 | 5 |

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 | |
| | I | 0.25 | 0.10 | Use IE limber pine |
| subalpine larch | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | Use IE subalpine larch |
| Rocky Mountain juniper | E | 0.20 | 0.25 | |
| | I | 0.25 | 0.10 | Use IE RM juniper |
| 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 softwoods | E | 0.14 | 0.35 | Ottmar and others (1998) |
| | I | 0.10 | 2.06 | |
| other hardwoods | 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 assigned 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 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| western larch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| limber pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| subalpine larch | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| Rocky Mountain juniper | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Engelmann spruce | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| subalpine fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| ponderosa pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| green ash | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| quaking aspen | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| black cottonwood | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| balsam poplar | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| plains cottonwood | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| narrowleaf cottonwood | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| paper birch | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| other softwoods | E | 0.1 | 0.2 | 0.4 | 0.5 | 0.8 | 1.0 | 0.1 |
| | I | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 |
| other hardwoods | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |

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 softwoods | 0.025 |
| other hardwoods | 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 | |
| 0.25 – 1 | | |
| 1 – 3 | 0.09 | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.015 | |
| > 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 **FUELDECAY** 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 softwoods | 2 |
| other hardwoods | 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.

| Size Class | Moisture Group | | | |
|------------------------|----------------|-----|-------|-----|
| | 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 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.

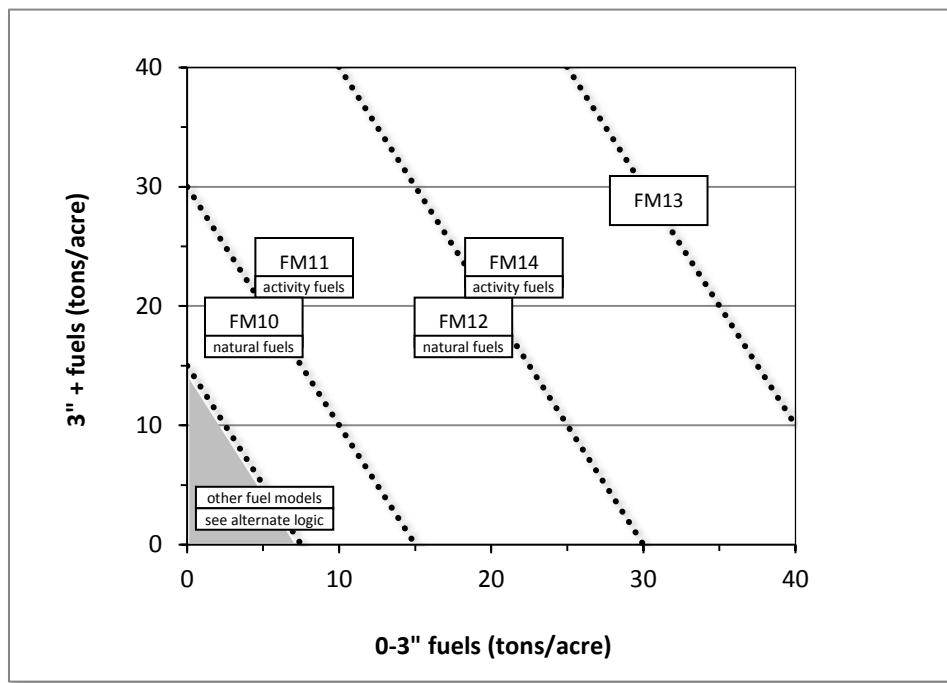


Figure 4.9.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.9.13. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further 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 | > 50 percent |
| 10 | Scree | Scree | 8 | 8 |
| 66 | Unknown | Dry Grass | 1 | 2 |
| 70 | PIFL/JUCO | Grassy Tall Shrub | 2 | 6 |
| 74 | Unknown | Dry Grass | 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 hardwoods’ and ‘other softwoods’ 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 | <i>Pinus monticola</i> | |
| Western larch | <i>Larix occidentalis</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| grand fir | <i>Abies grandis</i> | |
| Western hemlock | <i>Tsuga heterophylla</i> | |
| Western redcedar | <i>Thuja plicata</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| mountain hemlock | <i>Tsuga mertensiana</i> | |
| whitebark pine | <i>Pinus albicaulis</i> | |
| limber pine | <i>Pinus flexilis</i> | |
| subalpine larch | <i>Larix lyallii</i> | |
| pinyon pine | <i>Pinus monophylla</i> | |
| Western juniper | <i>Juniperus occidentalis</i> | |
| pacific yew | <i>Taxus brevifolia</i> | |
| Quaking aspen | <i>Populus tremuloides</i> | |
| cottonwood | <i>Populus spp.</i> | |
| Rocky mountain maple | <i>Acer glabrum</i> | |
| paper birch | <i>Betula papyrifera</i> | |
| other hardwoods | | = red alder |
| other softwoods | | = 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 |
| pinyon pine | 31 | 100 | 30 | 39 |
| western 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 hardwoods | 31 | 100 | 30 | 39 |
| other softwoods | 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 |
| pinyon pine | 1.0 | 1.0 | 1.0 |
| western 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 |

| Species | Snag Fall | Height loss | Hard-to-Soft |
|-----------------|-----------|-------------|--------------|
| paper birch | 1.0 | 1.0 | 1.0 |
| other hardwoods | 1.0 | 1.0 | 1.0 |
| other softwoods | 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 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/ft³) 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 (used w. white pine) | 22.5 |
| limber pine (used w. white pine) | 22.5 |
| subalpine larch (used subalpine fir) | 19.3 |
| pinyon pine | 31.8 |
| western juniper | 34.9 |
| pacific yew (used baldcypress) | 26.2 |
| quaking aspen | 21.8 |
| cottonwood (used black cottonwood) | 19.3 |
| Rocky mountain maple (used red maple) | 30.6 |
| paper birch | 29.9 |
| other hardwoods | 23.1 |
| other softwoods | 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) |
| pinyon pine | Grier and others (1992) |
| western 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 hardwoods | red alder: Snell and Little (1983) |
| other softwoods | 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.

| Species | Live | | Dead | | |
|--------------------|----------------|----------------|------------------|----------------|----------------|
| | 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 |
| pinyon pine | 3 | 2 | 5 | 5 | 15 |
| western juniper | 4 | 2 | 5 | 5 | 15 |

| Species | Live | | Dead | | |
|----------------------|---------|---------|--------|---------|------|
| | Foliage | Foliage | <0.25" | 0.25-1" | > 1" |
| pacific yew | 7 | 2 | 5 | 5 | 15 |
| quaking aspen | 1 | 1 | 5 | 5 | 15 |
| cottonwood | 1 | 1 | 5 | 5 | 15 |
| Rocky mountain maple | 1 | 1 | 5 | 5 | 15 |
| paper birch | 1 | 1 | 5 | 5 | 15 |
| other hardwoods | 1 | 1 | 5 | 5 | 15 |
| other softwoods | 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 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| western redcedar | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| 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 | |
| | I | 0.30 | 2.00 | Use spruce-subalpine fir |
| whitebark pine | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | Use spruce-subalpine fir |
| limber pine | E | 0.20 | 0.25 | |
| | I | 0.25 | 0.10 | Use ponderosa pine |
| subalpine larch | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | Use spruce-subalpine fir |
| pinyon pine | E | 0.20 | 0.25 | |
| | I | 0.25 | 0.10 | Use ponderosa pine |
| western juniper | E | 0.20 | 0.25 | |
| | I | 0.25 | 0.10 | Use ponderosa pine |
| pacific yew | E | 0.20 | 0.20 | Use Douglas-fir |

| Species | | Herbs | Shrubs | Notes |
|----------------------|---|--------------|---------------|---|
| quaking aspen | I | 0.40 | 2.00 | |
| | E | 0.25 | 0.25 | Ottmar and others 2000b |
| cottonwood | I | 0.18 | 1.32 | |
| | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and others 2000b |
| Rocky mountain maple | I | 0.40 | 2.00 | Use Douglas-fir |
| | E | 0.20 | 0.20 | |
| paper birch | I | 0.18 | 1.32 | Use quaking aspen - Ottmar and others 2000b |
| | E | 0.25 | 0.25 | |
| other hardwoods | I | 0.18 | 1.32 | Use quaking aspen - Ottmar and others 2000b |
| | E | 0.25 | 0.25 | |
| other softwoods | I | 0.30 | 2.00 | Use spruce-subalpine fir |
| | E | 0.15 | 0.20 | |

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 assigned 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 |
| | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 6.0 | 0.4 |
| western larch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| grand fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| western hemlock | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| western redcedar | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Engelmann spruce | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| subalpine fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| ponderosa pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| mountain hemlock | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| whitebark pine | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| limber pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| subalpine larch | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |

| Species | Size Class (in) | | | | | | | |
|----------------------|-----------------|----------|-------|-------|--------|------|--------|------|
| | < 0.25 | 0.25 – 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 | Litter | Duff |
| pinyon pine | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| western juniper | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| pacific yew | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| quaking aspen | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| cottonwood | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| Rocky mountain maple | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| paper birch | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| other hardwoods | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| other softwoods | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |

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 |
| pinyon pine (used <i>pinus</i> spp.) | 0.030 |
| western juniper | 0.025 |
| pacific yew | 0.025 |
| quaking aspen | 0.044 |
| cottonwood (used <i>populus</i> spp.) | 0.038 |
| Rocky mountain maple | 0.040 |
| paper birch | 0.027 |
| other hardwoods | 0.026 |
| other softwoods | 0.040 |

4.10.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.10.10). 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 | |
| 0.25 – 1 | | |
| 1 – 3 | 0.09 | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.015 | |
| > 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 **FUELDECAY** 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 (subalpine fir) | 4 |
| pinyon pine | 4 |
| western juniper | 2 |
| pacific yew | 1 |
| quaking aspen | 4 |
| cottonwood | 4 |
| Rocky mountain maple | 4 |
| paper birch | 4 |
| other hardwoods | 4 |
| other softwoods | 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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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.

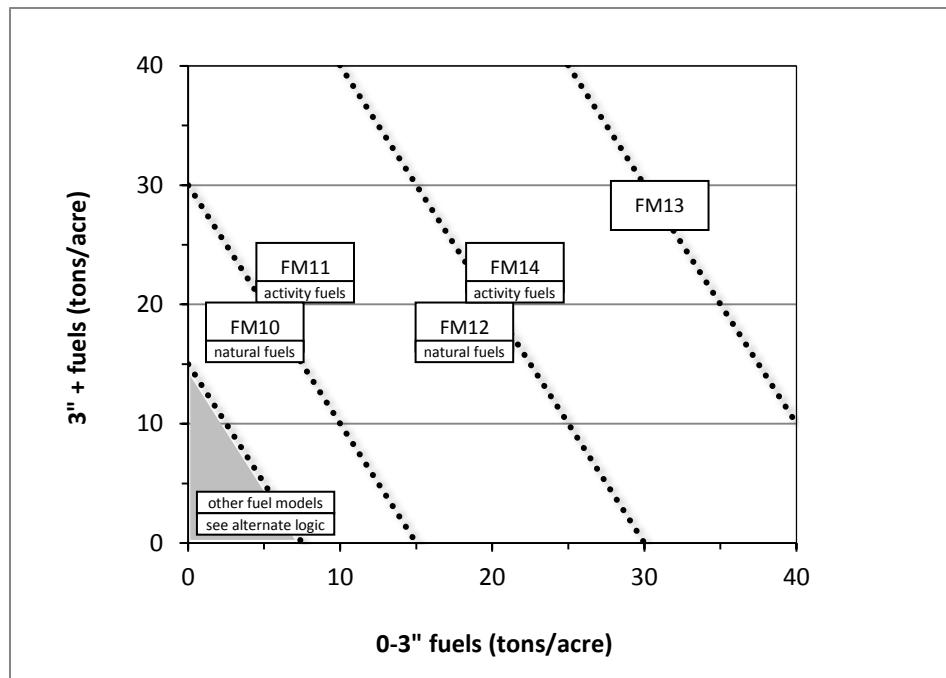


Figure 4.10.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.10.13. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further 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 | 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 68 tree species categories shown in Table 4.11.1.

Table 4.11.1 - Tree species simulated by the Lake States variant.

| Common name | Scientific name | Common name | Scientific name |
|----------------------|-------------------------------|-----------------------|------------------------------|
| jack pine | <i>Pinus banksiana</i> | black oak | <i>Quercus velutina</i> |
| scotch pine | <i>Pinus sylvestris</i> | northern pin oak | <i>Quercus ellipsoidalis</i> |
| red pine natural | <i>Pinus resinosa</i> | bitternut hickory | <i>Carya cordiformis</i> |
| red pine plantation | <i>Pinus resinosa</i> | pignut hickory | <i>Carya glabra</i> |
| eastern white pine | <i>Pinus strobus</i> | shagbark hickory | <i>Carya ovata</i> |
| white spruce | <i>Picea glauca</i> | bigtooth aspen | <i>Populus grandidentata</i> |
| Norway spruce | <i>Picea abies</i> | quaking aspen | <i>Populus tremuloides</i> |
| balsam fir | <i>Abies balsamea</i> | balsam poplar | <i>Populus balsamifera</i> |
| black spruce | <i>Picea mariana</i> | paper birch | <i>Betula papyrifera</i> |
| tamarack | <i>Larix laricina</i> | commercial hardwoods | |
| northern white-cedar | <i>Thuja occidentalis</i> | butternut | <i>Juglans cinerea</i> |
| eastern hemlock | <i>Tsuga canadensis</i> | black walnut | <i>Juglans nigra</i> |
| other softwoods | | eastern hophornbeam | <i>Ostrya virginiana</i> |
| eastern redcedar | <i>Juniperus virginiana</i> | black locust | <i>Robinia pseudoacacia</i> |
| black ash | <i>Fraxinus nigra</i> | non-commercial | |
| green ash | <i>Fraxinus pennsylvanica</i> | hardwoods | |
| eastern cottonwood | <i>Populus deltoides</i> | boxelder | <i>Acer negundo</i> |
| silver maple | <i>Acer saccharinum</i> | striped maple | <i>Acer pensylvanicum</i> |
| red maple | <i>Acer rubrum</i> | mountain maple | <i>Acer spicatum</i> |
| black cherry | <i>Prunus serotina</i> | American hornbeam | <i>Carpinus caroliniana</i> |
| American elm | <i>Ulmus americana</i> | American chestnut | <i>Castanea dentata</i> |
| slippery elm | <i>Ulmus rubra</i> | hackberry | <i>Celtis occidentalis</i> |
| rock elm | <i>Ulmus thomasii</i> | flowering dogwood | <i>Cornus florida</i> |
| yellow birch | <i>Betula alleghaniensis</i> | hawthorn species | <i>Crataegus sp.</i> |
| American basswood | <i>Tilia americana</i> | apple species | <i>Malus sp.</i> |
| sugar maple | <i>Acer saccharum</i> | black gum | <i>Nyssa sylvatica</i> |
| black maple | <i>Acer nigrum</i> | sycamore | <i>Platanus occidentalis</i> |
| American beech | <i>Fagus grandifolia</i> | pin cherry | <i>Prunus pensylvanica</i> |
| white ash | <i>Fraxinus americana</i> | chokecherry | <i>Prunus virginiana</i> |
| white oak | <i>Quercus alba</i> | plum, cherry species | <i>Prunus sp.</i> |
| swamp white oak | <i>Quercus bicolor</i> | willow species | <i>Salix sp.</i> |
| bur oak | <i>Quercus macrocarpa</i> | black willow | <i>Salix nigra</i> |
| chinkapin oak | <i>Quercus muehlenbergii</i> | diamond willow | <i>Salix eriocephala</i> |
| northern red oak | <i>Quercus rubra</i> | sassafras | <i>Sassafras albidum</i> |
| | | American mountain-ash | <i>Sorbus americana</i> |

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 tamarack, 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 | Species | Snag class |
|----------------------|------------|--------------------------|------------|
| jack pine | 2 | black oak | 6 |
| scotch pine | 4 | northern pin oak | 6 |
| red pine natural | 4 | bitternut hickory | 6 |
| red pine plantation | 4 | pignut hickory | 6 |
| eastern white pine | 3 | shagbark hickory | 6 |
| white spruce | 1 | bigtooth aspen | 1 |
| Norway spruce | 1 | quaking aspen | 1 |
| balsam fir | 1 | balsam poplar | 1 |
| black spruce | 1 | paper birch | 1 |
| tamarack | 6 | commercial hardwoods | 5 |
| northern white-cedar | 6 | butternut | 5 |
| eastern hemlock | 6 | black walnut | 5 |
| other softwoods | 6 | eastern hophornbeam | 5 |
| eastern redcedar | 6 | black locust | 5 |
| black ash | 5 | non-commercial hardwoods | 5 |
| green ash | 5 | boxelder | 5 |
| eastern cottonwood | 1 | striped maple | 5 |
| silver maple | 5 | mountain maple | 5 |
| red maple | 5 | American hornbeam | 5 |
| black cherry | 5 | American chestnut | 5 |
| American elm | 5 | hackberry | 5 |
| slippery elm | 5 | flowering dogwood | 5 |
| rock elm | 5 | hawthorn species | 5 |
| yellow birch | 1 | apple species | 5 |
| American basswood | 1 | black gum | 5 |
| sugar maple | 5 | sycamore | 5 |
| black maple | 5 | pin cherry | 5 |
| American beech | 5 | chokecherry | 5 |
| white ash | 5 | plum, cherry species | 5 |
| white oak | 6 | willow species | 5 |
| swamp white oak | 6 | black willow | 5 |
| bur oak | 6 | diamond willow | 5 |
| chinkapin oak | 6 | sassafras | 5 |
| northern red oak | 6 | 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
- $mR \geq 0.01$

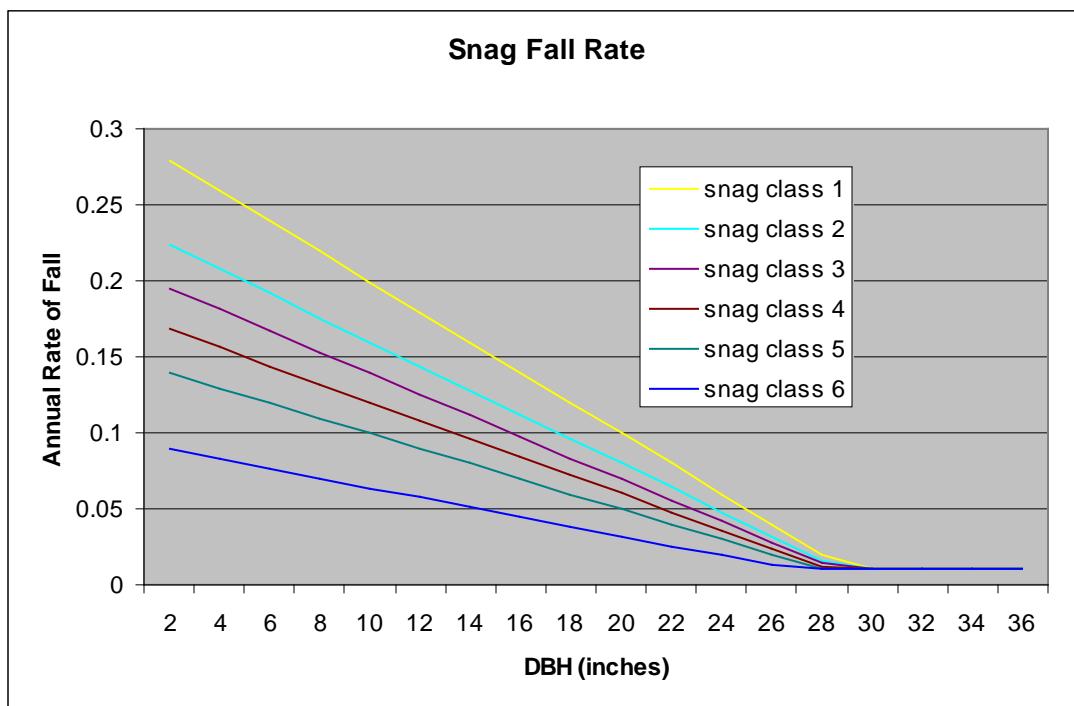


Figure 4.11.1 - The rate of fall of small snags and the first 95% of large snags.

For the last 5 percent of snags over 18 inches (12 inches for cedars and tamarack), the number of snags falling each year is:

$$F = 0.05/(A - T)* N_0$$

where:

- F = density of snags (stems/acre) that fall each year from that record
- A = maximum number of years that snags will remain standing (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.

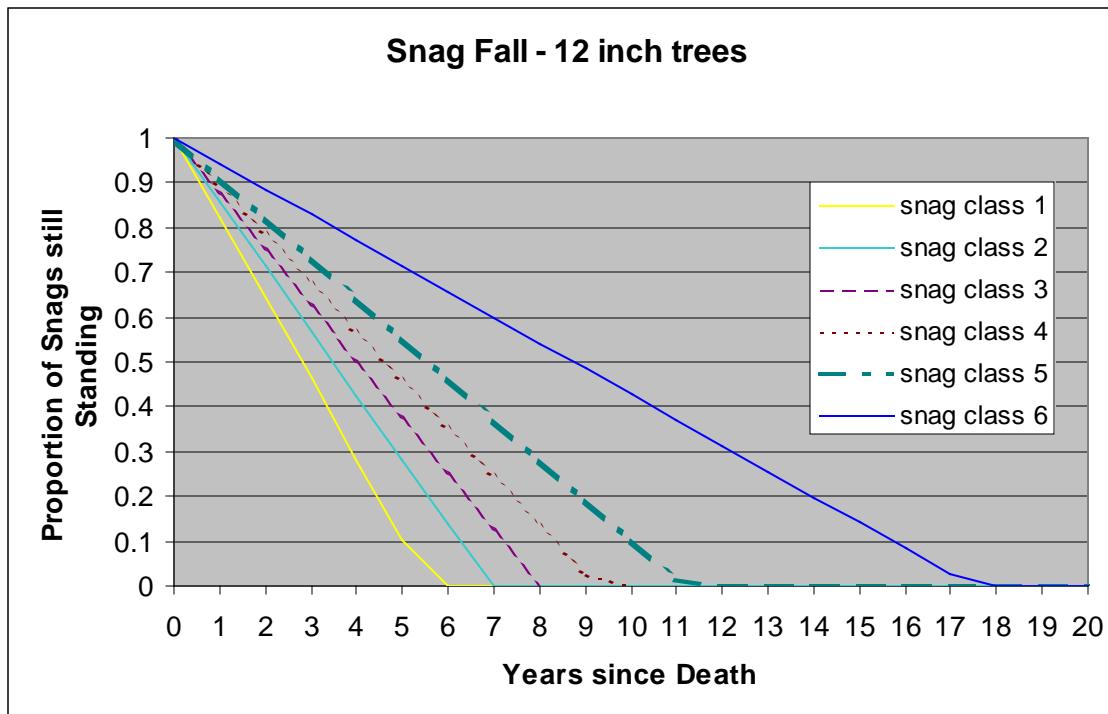


Figure 4.11.2 - Snag fall rates for 12 inch trees.

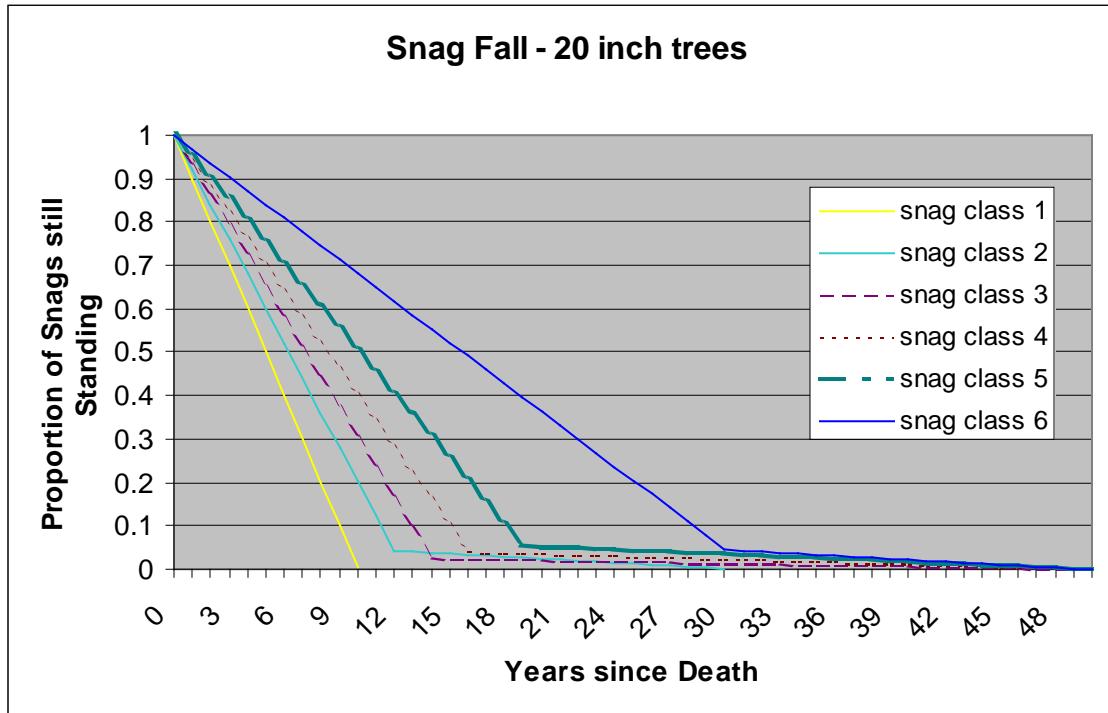


Figure 4.11.3 - Snag fall rates for 20 inch trees.

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:

$$\text{DecayTime} = m(0.65*d)$$

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.

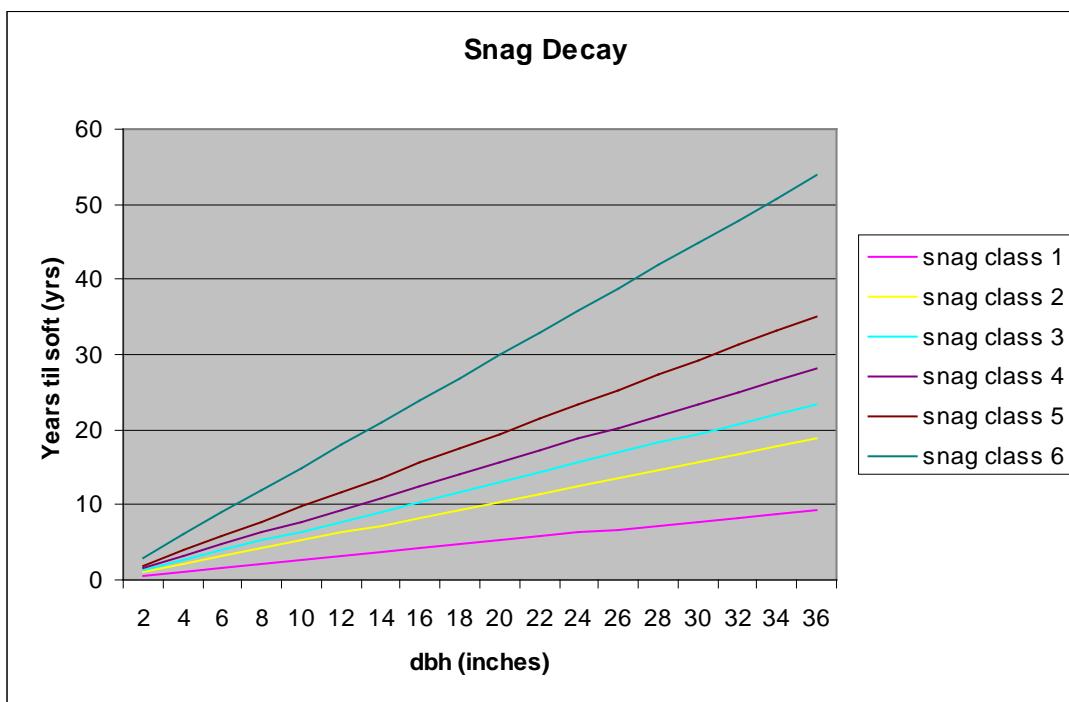


Figure 4.11.4 - The number of years until soft for various diameter snags.

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 ft³) used in the LS-FFE variant.

| Species | Ibs/cuft | Species used | Species | Ibs/cuft | Species used |
|----------------------|----------|--------------|-----------------------|----------|--------------|
| jack pine | 24.9 | | black oak | 34.9 | |
| scotch pine | 25.6 | red pine | northern pin oak | 36.2 | |
| red pine natural | 25.6 | | bitternut hickory | 37.4 | |
| red pine plantation | 25.6 | | pignut hickory | 41.2 | |
| eastern white pine | 21.2 | | shagbark hickory | 39.9 | |
| white spruce | 23.1 | | bigtooth aspen | 22.5 | |
| Norway spruce | 23.1 | white spruce | quaking aspen | 21.8 | |
| balsam fir | 20.6 | | balsam poplar | 19.3 | |
| black spruce | 23.7 | | paper birch | 29.9 | |
| tamarack | 30.6 | | commercial hardwoods | 31.8 | black walnut |
| northern white-cedar | 18.1 | | butternut | 22.5 | |
| eastern hemlock | 23.7 | | black walnut | 31.8 | |
| other softwoods | 27.4 | | eastern hop hornbeam | 31.8 | black walnut |
| eastern redcedar | 27.4 | | black locust | 41.2 | |
| black ash | 28.1 | | non-commercial | | default |
| green ash | 33.1 | | hardwoods | 28.7 | |
| eastern cottonwood | 23.1 | | boxelder | 30.6 | red maple |
| silver maple | 27.4 | | striped maple | 30.6 | red maple |
| red maple | 30.6 | | mountain maple | 30.6 | red maple |
| black cherry | 29.3 | | American hornbeam | 28.7 | default |
| American elm | 28.7 | | American chestnut | 28.7 | default |
| slippery elm | 29.9 | | hackberry | 30.6 | |
| rock elm | 35.6 | | flowering dogwood | 28.7 | default |
| yellow birch | 34.3 | | hawthorn species | 28.7 | default |
| American basswood | 20.0 | | apple species | 29.3 | black cherry |
| sugar maple | 34.9 | | black gum | 28.7 | |
| black maple | 32.4 | | sycamore | 28.7 | |
| American beech | 34.9 | | pin cherry | 29.3 | black cherry |
| white ash | 34.3 | | chokecherry | 29.3 | black cherry |
| white oak | 37.4 | | plum, cherry species | 29.3 | black cherry |
| swamp white oak | 39.9 | | willow species | 22.5 | black willow |
| bur oak | 36.2 | | black willow | 22.5 | |
| chinkapin oak | 37.4 | white oak | diamond willow | 22.5 | black willow |
| northern red oak | 34.9 | | 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 ($\text{Vol} = 0.0015 \times D^2 \times H$) 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 | Species | Leaf Life (years) | Crown Fall Class |
|----------------------|------------------------------|-----------------------------|----------------------|------------------------------|-----------------------------|
| jack pine | 2 | 4 | black oak | 1 | 2 |
| scotch pine | 3 | 4 | northern pin oak | 1 | 2 |
| red pine natural | 4 | 4 | bitternut hickory | 1 | 1 |
| red pine plantation | 4 | 4 | pignut hickory | 1 | 1 |
| eastern white pine | 2 | 4 | shagbark hickory | 1 | 1 |
| white spruce | 8 | 4 | bigtooth aspen | 1 | 4 |
| Norway spruce | 8 | 4 | quaking aspen | 1 | 4 |
| balsam fir | 8 | 4 | balsam poplar | 1 | 4 |
| black spruce | 8 | 4 | paper birch | 1 | 4 |
| tamarack | 1 | 1 | commercial hardwoods | 1 | 3 |
| northern white-cedar | 2 | 1 | butternut | 1 | 3 |
| eastern hemlock | 3 | 1 | black walnut | 1 | 3 |
| other softwoods | 5 | 1 | eastern hop hornbeam | 1 | 3 |
| eastern redcedar | 5 | 1 | black locust | 1 | 3 |
| | 1 | 3 | non-commercial | 1 | 3 |
| black ash | | | hardwoods | | |
| green ash | 1 | 3 | boxelder | 1 | 3 |
| eastern cottonwood | 1 | 4 | striped maple | 1 | 3 |
| silver maple | 1 | 3 | mountain maple | 1 | 3 |
| red maple | 1 | 3 | American hornbeam | 1 | 3 |
| black cherry | 1 | 3 | American chestnut | 1 | 3 |
| American elm | 1 | 3 | hackberry | 1 | 3 |
| slippery elm | 1 | 3 | flowering dogwood | 1 | 3 |
| rock elm | 1 | 3 | hawthorn species | 1 | 3 |
| yellow birch | 1 | 4 | apple species | 1 | 3 |
| American basswood | 1 | 4 | black gum | 1 | 3 |

| Species | Leaf Life (years) | Crown Fall Class | Species | Leaf Life (years) | Crown Fall Class |
|------------------|------------------------------|-----------------------------|-----------------------|------------------------------|-----------------------------|
| sugar maple | 1 | 3 | sycamore | 1 | 3 |
| black maple | 1 | 3 | pin cherry | 1 | 3 |
| American beech | 1 | 3 | chokecherry | 1 | 3 |
| white ash | 1 | 3 | plum, cherry species | 1 | 3 |
| white oak | 1 | 1 | willow species | 1 | 3 |
| swamp white oak | 1 | 1 | black willow | 1 | 3 |
| bur oak | 1 | 1 | diamond willow | 1 | 3 |
| chinkapin oak | 1 | 1 | sassafras | 1 | 3 |
| northern red oak | 1 | 2 | American mountain-ash | 1 | 3 |

Table 4.11.7 - 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 (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 |
| jack pine | 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 |
| white-red pine | 1 | 0.09 | 0.51 | 1.76 | 0.78 | 1.89 | 1.95 | 1.83 |
| | 2 | 0.07 | 0.51 | 0.93 | 0.06 | 0.26 | 0.00 | 0.54 |
| | 3 | 0.07 | 0.25 | 0.18 | 0.00 | 0.00 | 0.00 | 2.05 |
| jack pine | 1 | 0.31 | 2.22 | 4.99 | 0.64 | 2.11 | 1.46 | 1.44 |
| | 2 | 0.12 | 0.44 | 1.05 | 0.66 | 1.26 | 0.00 | 0.81 |
| | 3 | 0.11 | 0.89 | 4.58 | 4.98 | 4.76 | 0.00 | 0.20 |
| spruce-fir | 1 | 0.40 | 0.95 | 1.79 | 1.28 | 4.47 | 1.46 | 0.90 |
| | | | | | | | | 64.29 |

| FIA Forest Type | FIA Size Class | Size Class (in) | | | | | | |
|--------------------|----------------|-----------------|----------|-------|-------|--------|------|--------|
| | | < 0.25 | 0.25 – 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 | Litter |
| eastern redcedar | 2 | 0.19 | 0.60 | 1.22 | 0.52 | 1.88 | 0.57 | 2.36 |
| | 3 | 0.07 | 0.49 | 2.04 | 0.98 | 2.61 | 0.35 | 1.20 |
| oak-pine | any | 0.00 | 0.00 | 0.00 | 0.79 | 0.00 | 0.00 | 0.07 |
| | 1 | 0.12 | 0.57 | 1.14 | 0.62 | 3.71 | 0.37 | 0.81 |
| oak-hickory | 2 | 0.11 | 0.95 | 1.59 | 0.17 | 1.89 | 0.00 | 0.29 |
| | 3 | 0.12 | 0.49 | 0.60 | 0.67 | 0.77 | 0.00 | 0.20 |
| elm-ash- | 1 | 0.18 | 0.53 | 1.60 | 0.78 | 1.65 | 0.52 | 0.91 |
| | 2 | 0.24 | 0.59 | 1.41 | 0.74 | 1.61 | 1.30 | 0.44 |
| eastern cottonwood | 3 | 0.09 | 0.80 | 0.16 | 0.48 | 0.51 | 0.00 | 0.49 |
| | any | 0.13 | 0.26 | 0.74 | 0.49 | 1.88 | 0.12 | 1.17 |
| maple-beech-birch | 1 | 0.22 | 0.62 | 1.74 | 0.99 | 1.77 | 1.41 | 1.38 |
| | 2 | 0.29 | 0.74 | 2.11 | 0.96 | 1.92 | 3.33 | 0.90 |
| aspen-birch | 3 | 0.23 | 0.69 | 2.96 | 1.15 | 2.81 | 0.28 | 0.81 |
| | 1 | 0.13 | 0.86 | 2.10 | 0.82 | 2.76 | 1.10 | 0.71 |
| nonstocked | 2 | 0.12 | 0.70 | 2.51 | 1.04 | 2.41 | 2.70 | 0.53 |
| | 3 | 0.13 | 0.52 | 1.69 | 0.77 | 1.80 | 0.66 | 1.04 |
| nonstocked | any | 0.07 | 0.32 | 0.34 | 0.19 | 0.63 | 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 | Species | Multiplier (Vsp) | Species used |
|----------------------|------------------|------------------|--------------------------|------------------|--------------|
| jack pine | 0.04 | | black oak | 0.045 | |
| scotch pine | 0.03 | | northern pin oak | 0.038 | |
| red pine natural | 0.043 | | bitternut hickory | 0.037 | |
| red pine plantation | 0.043 | | pignut hickory | 0.037 | |
| eastern white pine | 0.045 | | shagbark hickory | 0.04 | |
| white spruce | 0.025 | | bigtooth aspen | 0.039 | |
| Norway spruce | 0.029 | | quaking aspen | 0.044 | |
| balsam fir | 0.031 | | balsam poplar | 0.04 | |
| black spruce | 0.032 | | paper birch | 0.027 | |
| tamarack | 0.031 | | commercial hardwoods | 0.041 | butternut |
| northern white-cedar | 0.025 | | butternut | 0.041 | |
| eastern hemlock | 0.039 | | black walnut | 0.041 | |
| | 0.038 | eastern redcedar | | 0.037 | |
| other softwoods | | | eastern hop hornbeam | | |
| eastern redcedar | 0.038 | | black locust | 0.049 | |
| black ash | 0.035 | | non-commercial hardwoods | 0.034 | boxelder |
| green ash | 0.039 | | boxelder | 0.034 | |
| eastern cottonwood | 0.04 | | striped maple | 0.045 | |
| silver maple | 0.031 | | mountain maple | 0.04 | |
| red maple | 0.028 | | American hornbeam | 0.03 | |
| black cherry | 0.03 | | American chestnut | 0.04 | |
| American elm | 0.031 | | hackberry | 0.036 | sugarberry |
| slippery elm | 0.032 | | flowering dogwood | 0.041 | |
| rock elm | 0.033 | | hawthorn species | 0.038 | |
| yellow birch | 0.031 | | apple species | 0.043 | |

| Species | Multiplier (Vsp) | Species used | Species | Multiplier (Vsp) | Species used |
|-------------------|-----------------------------|---------------------|-----------------------|-----------------------------|---------------------|
| American basswood | 0.038 | | black gum | 0.039 | |
| sugar maple | 0.033 | | sycamore | 0.033 | |
| black maple | 0.035 | | pin cherry | 0.045 | |
| American beech | 0.025 | | chokecherry | 0.04 | |
| white ash | 0.042 | | plum, cherry species | 0.04 | |
| white oak | 0.04 | | willow species | 0.041 | |
| swamp white oak | 0.045 | | black willow | 0.04 | |
| bur oak | 0.042 | | diamond willow | 0.04 | |
| chinkapin oak | 0.042 | | sassafras | 0.035 | |
| northern red oak | 0.042 | | American mountain-ash | 0.04 | |

4.11.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.11.11). 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 | | |
| 0.25 – 1 | 0.11 | |
| 1 – 3 | 0.09 | |
| 3 – 6 | 0.06 | 0.02 |
| 6 – 12 | 0.06 | |
| > 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 **FUELDECAY** 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 |
| scotch 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 | commercial hardwoods | 4 |

| Species | Decay Rate Class | Species | Decay Rate Class |
|----------------------|-------------------------|--------------------------|-------------------------|
| northern white-cedar | 2 | butternut | 4 |
| eastern hemlock | 4 | black walnut | 2 |
| other softwoods | 2 | eastern hophornbeam | 4 |
| eastern redcedar | 2 | black locust | 1 |
| black ash | 4 | non-commercial hardwoods | 4 |
| green ash | 4 | boxelder | 4 |
| eastern cottonwood | 4 | striped maple | 4 |
| silver maple | 4 | mountain maple | 4 |
| red maple | 4 | American hornbeam | 4 |
| black cherry | 2 | American chestnut | 2 |
| American elm | 4 | hackberry | 4 |
| slippery elm | 4 | flowering dogwood | 4 |
| rock elm | 4 | hawthorn species | 4 |
| yellow birch | 4 | apple species | 2 |
| American basswood | 4 | black gum | 4 |
| sugar maple | 4 | sycamore | 4 |
| black maple | 4 | pin cherry | 2 |
| American beech | 4 | chokecherry | 2 |
| white ash | 4 | plum, cherry species | 2 |
| white oak | 2 | willow species | 4 |
| swamp white oak | 2 | black willow | 4 |
| bur oak | 2 | diamond willow | 4 |
| chinkapin oak | 2 | sassafras | 2 |
| northern red oak | 2 | American mountain-ash | 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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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.

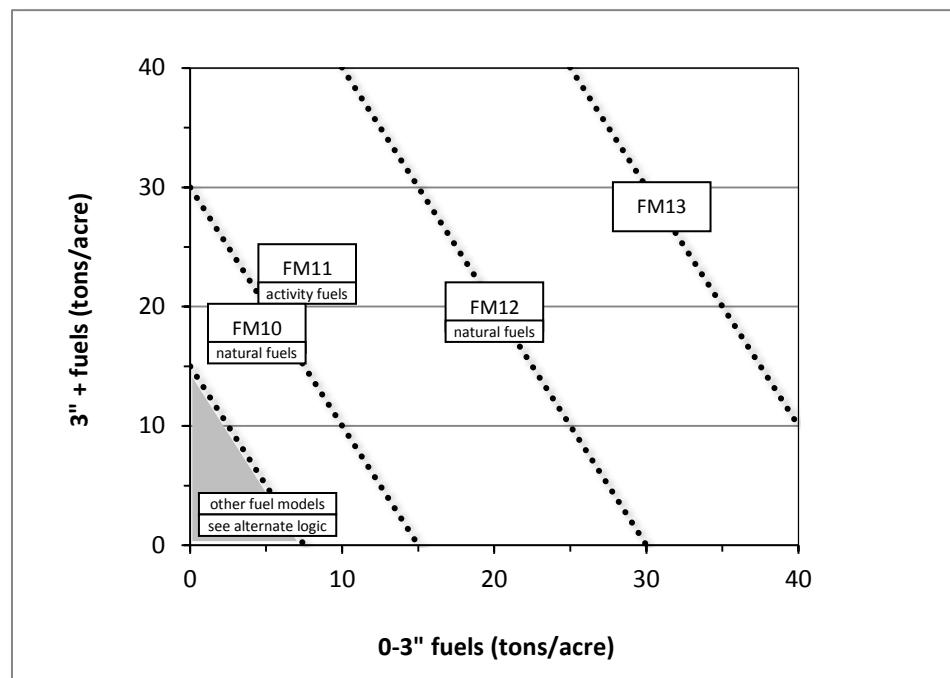


Figure 4.11.5 - Candidate fuel models are determined using the logic shown in Table 4.11.14 and Table 4.11.15. At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. Not all fuel models are candidates 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 \leq 70% and stand height \leq 25' | 4 |
| | canopy cover \leq 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 \leq 70% and stand height $>$ 25' and grass understory (native plant community is FDc12 or FDc23) | 2 |
| | canopy cover \leq 70% and stand height $>$ 25' and not a balsam fir or grass understory | 10 (before greenup) 161 (after greenup) |
| | canopy cover $>$ 70% and stand height \leq 15' | 4 |
| | canopy cover $>$ 70% and stand height $>$ 15' and midflame windspeed \leq 4mph | 8 |
| Northern Hardwoods | canopy cover $>$ 70% and stand height $>$ 15' and midflame windspeed $>$ 4mph | 10 |
| | 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 \geq 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 \geq 500 and midflame windspeed $>$ 4mph | 164 |
| | 0 – 3" surface fuel is $<$ 5 tons/acre and 1 – 3" conifer trees/acre \geq 500 and midflame windspeed \leq 4mph and birch dominant | 9 |
| | 0 – 3" surface fuel is $<$ 5 tons/acre and 1 – 3" conifer trees/acre \geq 500 and midflame windspeed \leq 4mph and aspen dominant | 8 |
| Oak | surface fuel load is high (see Figure 4.17.5) | 10, 11 |
| | overstory canopy cover (trees 5"+) \geq 45% and it is an early spring burn and the fine fuel moisture is $<$ 8% | 186 |
| | overstory canopy cover (trees 5"+) \geq 45% and it is an early spring burn and the fine fuel moisture is \geq 8% | 8 |
| | overstory canopy cover (trees 5"+) \geq 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 |

| Forest Type | | Fuel Model |
|---|---|-------------------|
| | 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 |
| | 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 |

| NPV Code | NPV description | NPV Code | NPV description |
|----------|--|----------|--|
| 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 9 tree species shown in Table 4.12.1. Two additional categories, ‘other hardwoods’ and ‘other softwoods’ 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 | <i>Pinus lambertiana</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| white fir | <i>Abies concolor</i> | |
| madrone | <i>Arbutus menziesii</i> | |
| incense-cedar | <i>Calocedrus decurrens</i> | = <i>Libocedrus decurrens</i> |
| California black oak | <i>Quercus kelloggii</i> | |
| tanoak | <i>Lithocarpus densiflorus</i> | |
| red fir | <i>Abies magnifica</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| 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 | — |
| madrone | 20 | 50 | 20 | — |
| incense-cedar | 45 | 100 | 20 | — |
| California black oak | 20 | 50 | 20 | — |
| tanoak | 20 | 50 | 20 | — |
| red fir | 35 | 100 | 20 | — |
| ponderosa pine | 25 | 100 | 20 | — |
| 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 | — |
| madrone | 1.54 | 1.49 | — |
| incense-cedar | 0.69 | 1.49 | — |
| California black oak | 1.54 | 1.49 | — |
| tanoak | 1.54 | 1.49 | — |
| red fir | 0.88 | 1.49 | — |
| ponderosa pine | 1.24 | 1.49 | — |
| 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/ft³) used in the NC-FFE variant.

| Species | Density (lb/ft₃) |
|----------------------|------------------------------------|
| sugar pine | 21.2 |
| Douglas-fir | 28.7 |
| white fir | 23.1 |
| madrone | 36.2 |
| incense-cedar | 21.8 |
| California black oak | 34.9 |
| tanoak | 36.2 |
| red fir | 22.5 |
| ponderosa pine | 23.7 |
| 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) |
| 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 |
| red fir | grand fir (Brown and Johnston 1976) |
| ponderosa pine | Brown and Johnston 1976 |
| other softwoods | lodgepole pine (Brown and Johnston 1976) |
| other hardwoods | 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.

| 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 |
| 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 |
| red fir | 7 | 3 | 10 | 15 | 15 |
| ponderosa pine | 3 | 3 | 10 | 10 | 10 |
| other softwoods | 5 | 3 | 10 | 15 | 15 |
| other hardwoods | 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 | |
| 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 | |
| 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 | |
| other softwoods | E | 0.20 | 0.20 | Douglas-fir, NI-FFE |
| | I | 0.40 | 2.00 | |
| other hardwoods | 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.

| 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 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| white fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| madrone | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| incense-cedar | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| California black oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| tanoak | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| red fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| ponderosa pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| other softwoods | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| other hardwoods | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |

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 |
| madrone | 0.060 |
| incense-cedar | 0.060 |
| California black oak | 0.030 |
| tanoak | 0.052 |
| red fir | 0.039 |
| ponderosa pine | 0.063 |
| other softwoods | 0.063 |
| other hardwoods | 0.052 |

4.12.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.12.10). 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 | | |
| 0.25 – 1 | 0.025 | |
| 1 – 3 | | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.0125 | |
| > 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 **FUELDECAY** 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 |
| madrone | 3 |
| incense-cedar | 2 |
| California black oak | 2 |
| tanoak | 4 |
| red fir | 4 |
| ponderosa pine | 4 |
| other softwoods | 3 |
| other hardwoods | 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

| Size Class | Moisture Group | | | |
|-------------------------|----------------|-----|-------|-----|
| | 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 class² (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 |
| 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

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.

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.

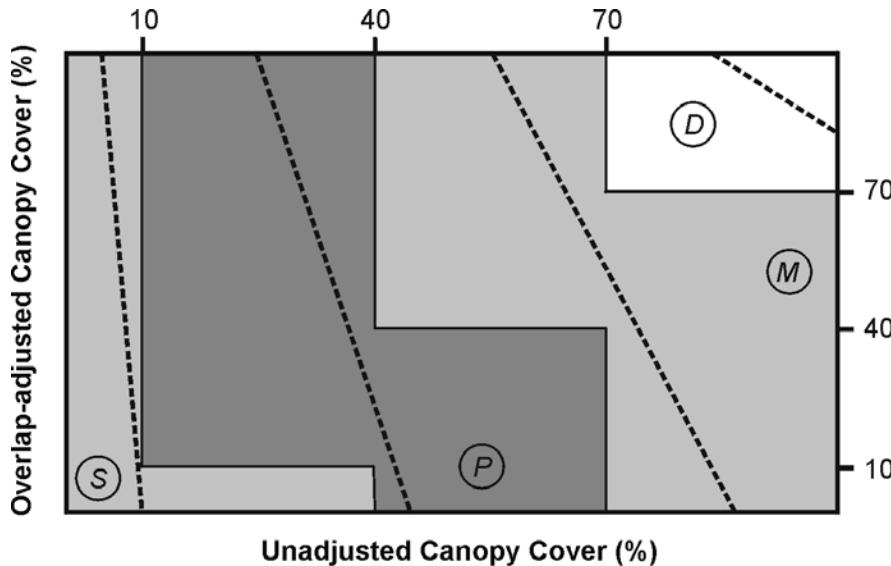


Figure 4.12.1 - Two measures of canopy cover, unadjusted and overlap-adjusted percent canopy cover, are used to derive weighted estimates of the four CWHR density classes. (S = sparse, P = open, M = moderate and D = dense)

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 | |
| Forest Type | | | | | | | | | | | | | | |
| Pine | 5 | 6 | 6 | 6 | 6 | 2 | 2 | 9 | 9 | 2 | 2 | 2 | 9 | 10 |
| Red fir | 5 | 5 | 5 | 8 | 8 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 8 | 10 |
| White fir – east side | 5 | 5 | 5 | 8 | 8 | 11 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 10 |
| White fir – west side | 5 | 5 | 5 | 8 | 8 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 8 | 10 |
| Douglas-fir | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 8 | 8 | 11 | 11 | 9 | 8 | 10 |
| Hardwoods | 5 | 5 | 5 | 6 | 6 | 11 | 11 | 11 | 9 | 9 | 9 | 9 | 9 | 10 |
| Pine mixed – conifer | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 9 | 9 | 9 | 8 | 8 | 10 |
| Fir mixed – conifer | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 8 | 6 | 6 | 8 | 8 | 10 |
| Other softwood | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 8 | 6 | 6 | 8 | 8 | 10 |

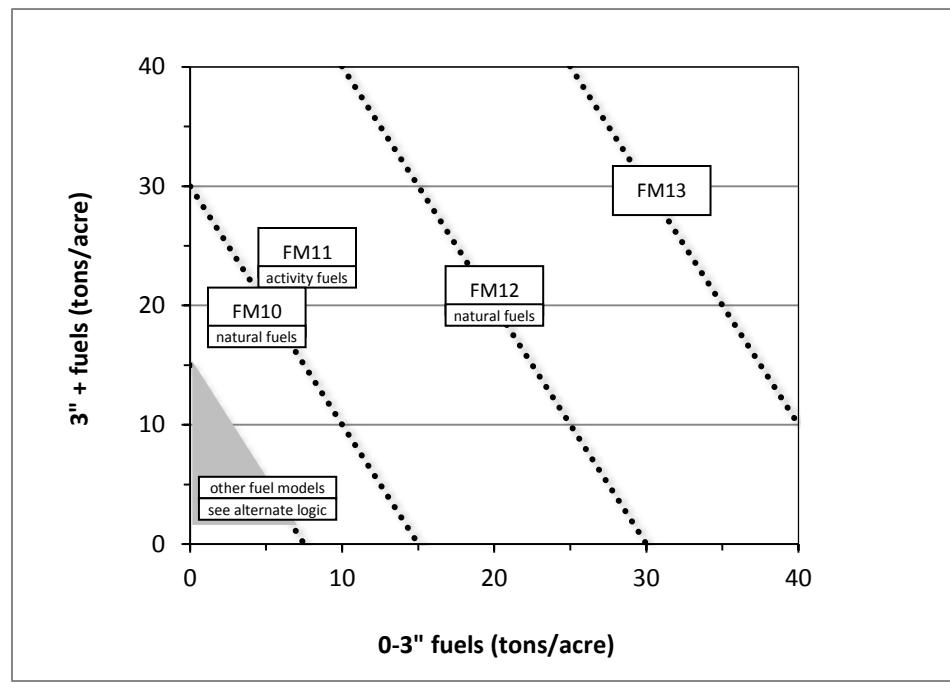


Figure 4.12.2 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.12.15. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

4.13 Northeastern (NE)

4.13.1 Tree Species

The Northeastern variant models the 108 tree species categories shown in Table 4.13.1.

Table 4.13.1 - Tree species simulated by the Northeast variant.

| Common name | Scientific name | Common name | Scientific name |
|-----------------------|--------------------------------|--------------------|--|
| balsam fir | <i>Abies balsamea</i> | white oak | <i>Quercus alba</i> |
| tamarack | <i>Larix laricina</i> | bur oak | <i>Quercus macrocarpa</i> |
| white spruce | <i>Picea glauca</i> | chinkapin oak | <i>Quercus muehlenbergii</i> |
| red spruce | <i>Picea rubens</i> | post oak | <i>Quercus stellata</i> |
| Norway spruce | <i>Picea abies</i> | other oak species | <i>Quercus</i> sp. |
| black spruce | <i>Picea mariana</i> | scarlet oak | <i>Quercus coccinea</i> |
| other spruce species | <i>Picea</i> sp. | shingle oak | <i>Quercus imbricaria</i> |
| red pine | <i>Pinus resinosa</i> | water oak | <i>Quercus nigra</i> |
| eastern white pine | <i>Pinus strobus</i> | pin oak | <i>Quercus palustris</i> |
| loblolly pine | <i>Pinus taeda</i> | chestnut oak | <i>Quercus prinus</i> |
| Virginia pine | <i>Pinus virginiana</i> | swamp white oak | <i>Quercus bicolor</i> |
| northern white-cedar | <i>Thuja occidentalis</i> | swamp chestnut oak | <i>Quercus michauxii</i> |
| Atlantic white-cedar | <i>Chamaecyparis thyoides</i> | northern red oak | <i>Quercus rubra</i> |
| eastern redcedar | <i>Juniperus virginiana</i> | southern red oak | <i>Quercus falcata</i> var. <i>falcata</i> |
| other cedar species | <i>juniperus</i> species | black oak | <i>Quercus velutina</i> |
| eastern hemlock | <i>Tsuga canadensis</i> | cherrybark oak | <i>Quercus falcata</i> var. <i>pagodaefolia</i> |
| other hemlock species | <i>Tsuga</i> sp. | other hardwoods | |
| other pine species | <i>Pinus</i> sp. | buckeye species | <i>Aesculus</i> sp. |
| jack pine | <i>Pinus banksiana</i> | yellow buckeye | <i>Aesculus octandra</i> |
| shortleaf pine | <i>Pinus echinata</i> | water birch | <i>Betula occidentalis</i> |
| Table Mountain pine | <i>Pinus pungens</i> | hackberry | <i>Celtis occidentalis</i> |
| pitch pine | <i>Pinus rigida</i> | common persimmon | <i>Diospyros virginiana</i> |
| pond pine | <i>Pinus serotina</i> | American holly | <i>Ilex opaca</i> |
| Scotch pine | <i>Pinus sylvestris</i> | butternut | <i>Juglans cinerea</i> |
| other softwoods | | black walnut | <i>Juglans nigra</i> |
| red maple | <i>Acer rubrum</i> | Osage-orange | <i>Maclura pomifera</i> |
| sugar maple | <i>Acer saccharum</i> | magnolia species | <i>Magnolia</i> sp. |
| black maple | <i>Acer nigrum</i> | sweetbay | <i>Magnolia virginiana</i> |
| silver maple | <i>Acer saccharinum</i> | apple species | <i>Malus</i> sp. |
| yellow birch | <i>Betula alleghaniensis</i> | water tupelo | <i>Nyssa aquatica</i> |
| sweet birch | <i>Betula lenta</i> | blackgum | <i>Nyssa sylvatica</i> |
| river birch | <i>Betula nigra</i> | sourwood | <i>Oxydendrum arboreum</i> |
| paper birch | <i>Betula papyrifera</i> | Paulownia | <i>Paulownia tomentosa</i> |
| gray birch | <i>Betula populifolia</i> | sycamore | <i>Platanus occidentalis</i> |
| hickory species | <i>Carya</i> sp. | willow oak | <i>Quercus phellos</i> |
| pignut hickory | <i>Carya glabra</i> | black locust | <i>Robinia pseudoacacia</i> |
| shellbark hickory | <i>Carya laciniosa</i> | black willow | <i>Salix nigra</i> |
| shagbark hickory | <i>Carya ovata</i> | sassafras | <i>Sassafras albidum</i> |
| mockernut hickory | <i>Carya tomentosa</i> | American basswood | <i>Sorbus americana</i> |
| American beech | <i>Fagus grandifolia</i> | white basswood | <i>Tilia heterophylla</i> |
| ash species | <i>Fraxinus</i> sp. | other elm species | <i>Ulmus</i> sp. |
| white ash | <i>Fraxinus americana</i> | American elm | <i>Ulmus americana</i> |
| black ash | <i>Fraxinus nigra</i> | slippery elm | <i>Ulmus rubra</i> |
| green ash | <i>Fraxinus pennsylvanica</i> | non-commercial | |
| pumpkin ash | <i>Fraxinus profunda</i> | hardwoods | |
| yellow-poplar | <i>Liriodendron tulipifera</i> | boxelder | <i>Acer negundo</i> |
| sweetgum | <i>Liquidambar styraciflua</i> | striped maple | <i>Acer pensylvanicum</i> |
| cucumbertree | <i>Magnolia acuminata</i> | ailanthus | <i>Ailanthus altissima</i> |
| | | serviceberry | <i>Amelanchier</i> sp. |

| Common name | Scientific name | Common name | Scientific name |
|--------------------|------------------------------|----------------------|-----------------------------|
| quaking aspen | <i>Populus tremuloides</i> | American hornbeam | <i>Carpinus caroliniana</i> |
| balsam poplar | <i>Populus balsamifera</i> | flowering dogwood | <i>Cornus florida</i> |
| eastern cottonwood | <i>Populus deltoides</i> | hawthorn species | <i>Crataegus sp.</i> |
| bigtooth aspen | <i>Populus grandidentata</i> | eastern hophornbeam | <i>Ostrya virginiana</i> |
| swamp cottonwood | <i>Populus heterophylla</i> | plum, cherry species | <i>Prunus sp.</i> |
| black cherry | <i>Prunus serotina</i> | pin cherry | <i>Prunus pensylvanica</i> |

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 | other oak species | 3 |
| black spruce | 1 | scarlet oak | 2 |
| other spruce species | 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 |
| northern white-cedar | 3 | swamp chestnut oak | 3 |
| Atlantic white-cedar | 3 | northern red oak | 2 |
| eastern redcedar | 3 | southern red oak | 2 |
| other cedar species | 3 | black oak | 2 |
| eastern hemlock | 3 | cherrybark oak | 2 |
| other hemlock species | 3 | other hardwoods | 2 |
| other pine species | 1 | buckeye species | 2 |
| jack pine | 1 | yellow buckeye | 2 |
| shortleaf pine | 1 | water birch | 1 |
| Table Mountain pine | 1 | hackberry | 2 |
| pitch pine | 1 | common persimmon | 3 |
| pond pine | 1 | American holly | 2 |
| Scotch pine | 1 | butternut | 2 |
| other softwoods | 1 | black walnut | 2 |
| red maple | 2 | Osage-orange | 2 |
| sugar maple | 2 | magnolia species | 2 |
| black maple | 2 | sweetbay | 2 |
| silver maple | 2 | apple species | 2 |
| yellow birch | 1 | water tupelo | 3 |
| sweet birch | 1 | blackgum | 3 |
| river birch | 1 | sourwood | 2 |
| paper birch | 1 | Paulownia | 2 |
| gray birch | 1 | sycamore | 2 |
| hickory species | 3 | willow oak | 2 |

| Species | Snag class | Species | Snag class |
|--------------------|-------------------|--------------------------|-------------------|
| pignut hickory | 3 | black locust | 3 |
| shellbark hickory | 3 | black willow | 1 |
| shagbark hickory | 3 | sassafras | 2 |
| mockernut hickory | 3 | American basswood | 1 |
| American beech | 2 | white basswood | 1 |
| ash species | 2 | other elm species | 1 |
| white ash | 2 | American elm | 1 |
| black ash | 2 | slippery elm | 1 |
| green ash | 2 | non-commercial hardwoods | 2 |
| pumpkin ash | 2 | boxelder | 2 |
| yellow-poplar | 2 | striped maple | 2 |
| sweetgum | 2 | ailanthus | 2 |
| cucumbertree | 2 | serviceberry | 2 |
| quaking aspen | 1 | American hornbeam | 2 |
| balsam poplar | 1 | flowering dogwood | 2 |
| eastern cottonwood | 1 | hawthorn species | 2 |
| bigtooth aspen | 1 | eastern hop hornbeam | 2 |
| swamp cottonwood | 1 | plum, cherry species | 2 |
| black cherry | 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.

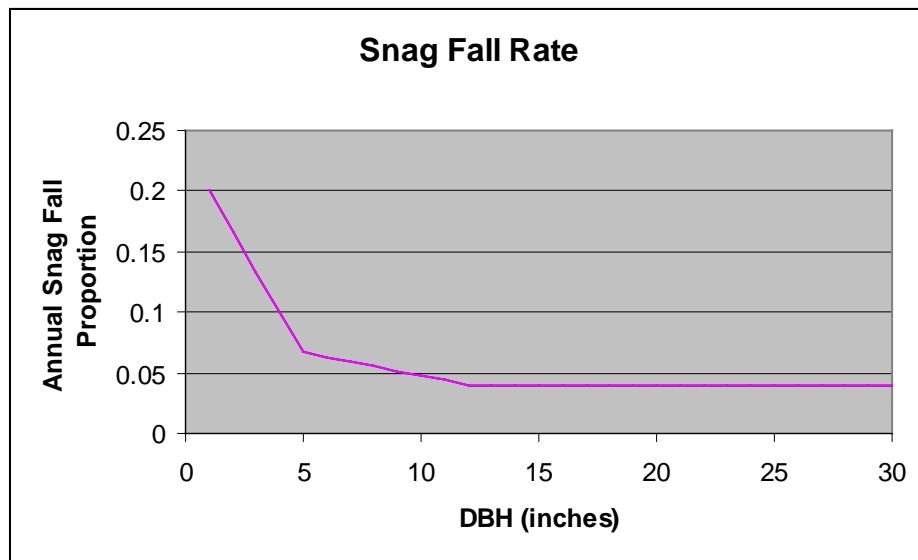


Figure 4.13.1 - The rate of fall of small snags and the first 95% of large snags.

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.

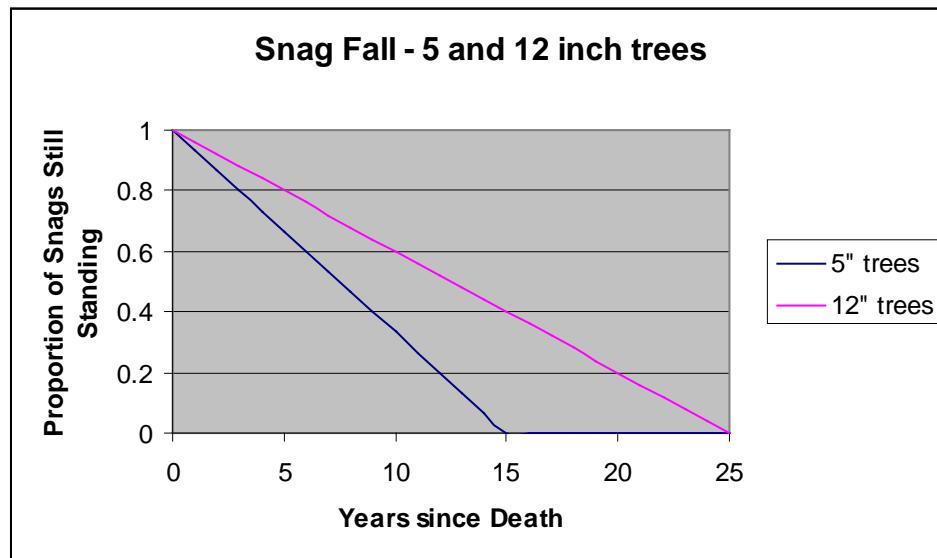


Figure 4.13.2 - Snag fall rates for 5 and 12 inch trees.

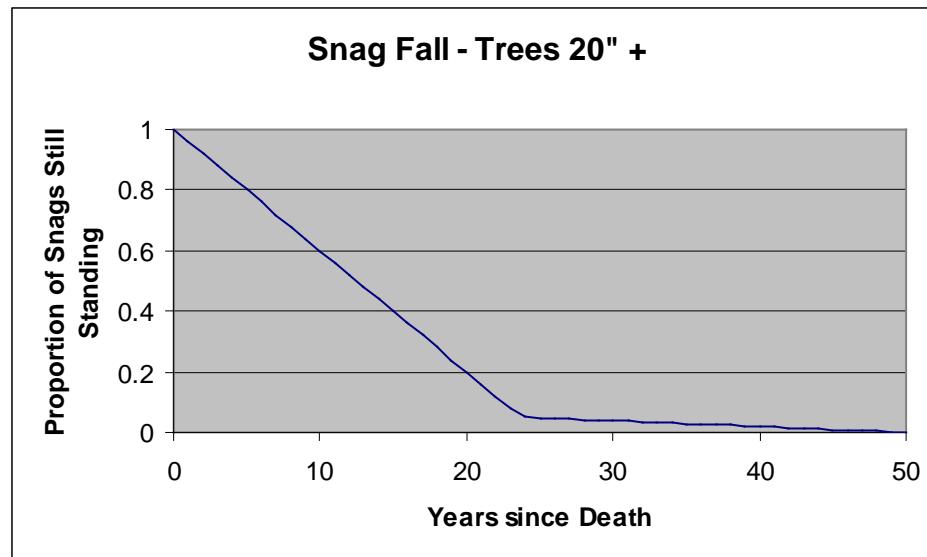


Figure 4.13.3 - Snag fall rates for trees larger than 20 inches dbh.

Figure 4.18.4 shows the number of years it takes a hard snag to become soft for different diameter snags.

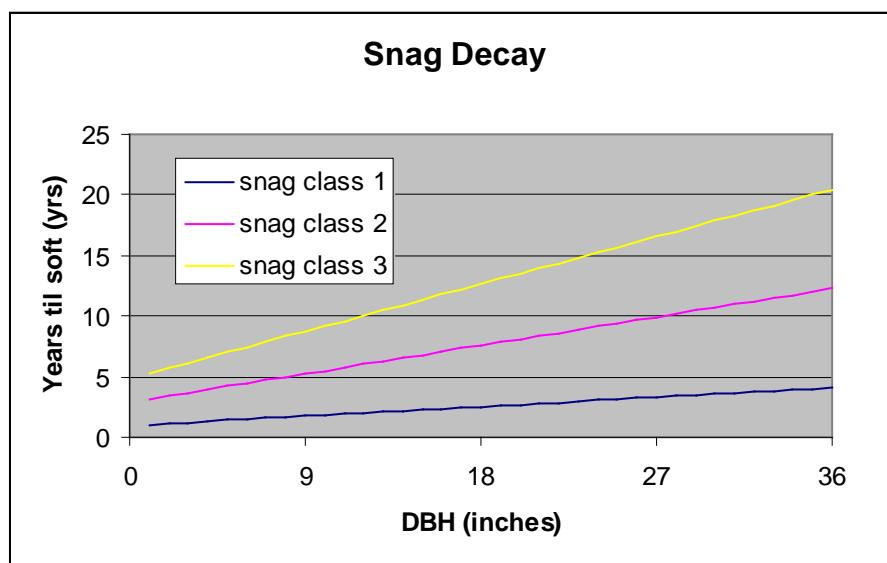


Figure 4.13.4 - The number of years until soft for various diameter snags.

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 Northeastern 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 Northeastern 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 Northeastern 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 Northeastern 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 | Ibs/cuft | Species used | Species | Ibs/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 | other oak species | 37.4 | |
| black spruce | 23.7 | | scarlet oak | 37.4 | |
| other spruce species | 23.1 | Red / white spruce | shingle oak | 34.9 | |
| 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 | |

| Species | lbs/cuft | Species used | Species | lbs/cuft | Species used |
|-----------------------|-----------------|------------------------------|--------------------------|-----------------|---------------------|
| northern white-cedar | 18.1 | | swamp chestnut oak | 37.4 | |
| Atlantic white-cedar | 19.3 | | northern red oak | 34.9 | |
| eastern redcedar | 27.4 | | southern red oak | 32.4 | |
| other cedar species | 27.4 | Eastern redcedar | black oak | 34.9 | |
| eastern hemlock | 23.7 | | cherrybark oak | 38.0 | |
| | | Mountain / western hemlock | | | Default |
| other hemlock species | 26.2 | | other hardwoods | 28.7 | |
| other pine species | 25.6 | Red pine | buckeye species | 28.7 | Default |
| jack pine | 24.9 | | yellow buckeye | 28.7 | Default |
| shortleaf pine | 29.3 | | water birch | 29.9 | Paper birch |
| Table Mountain pine | 28.1 | Virginia pine | hackberry | 30.6 | |
| pitch pine | 29.3 | | common persimmon | 28.7 | Default |
| pond pine | 31.8 | | American holly | 28.7 | Default |
| Scotch pine | 25.6 | Red pine | butternut | 22.5 | |
| other softwoods | 25.6 | Red pine | black walnut | 31.8 | |
| red maple | 30.6 | | Osage-orange | 28.7 | Default |
| sugar maple | 34.9 | | magnolia species | 28.7 | Southern magnolia |
| black maple | 32.4 | | sweetbay | 28.7 | Southern magnolia |
| silver maple | 27.4 | | apple species | 29.3 | Black cherry |
| yellow birch | 34.3 | | water tupelo | 28.7 | |
| sweet birch | 37.4 | | blackgum | 28.7 | |
| river birch | 29.9 | Paper birch | sourwood | 28.7 | Default |
| paper birch | 29.9 | | Paulownia | 28.7 | Default |
| gray birch | 29.9 | Paper birch | sycamore | 28.7 | |
| hickory species | 39.9 | Mockernut / shagbark hickory | willow oak | 34.9 | |
| pignut hickory | 41.2 | | black locust | 41.2 | |
| shellbark hickory | 38.7 | | black willow | 22.5 | |
| shagbark hickory | 39.9 | | sassafras | 26.2 | |
| mockernut hickory | 39.9 | | American basswood | 20.0 | |
| American beech | 34.9 | | white basswood | 20.0 | American basswood |
| ash species | 33.1 | Green ash | other elm species | 28.7 | American elm |
| white ash | 34.3 | | American elm | 28.7 | |
| black ash | 28.1 | | slippery elm | 29.9 | |
| green ash | 33.1 | | non-commercial hardwoods | 28.7 | Default |
| pumpkin ash | 33.1 | Green ash | boxelder | 30.6 | Red maple |
| yellow-poplar | 24.9 | | striped maple | 30.6 | Red maple |
| sweetgum | 28.7 | | ailanthus | 28.7 | Default |
| cucumbertree | 27.4 | | serviceberry | 28.7 | Default |
| quaking aspen | 21.8 | | American hornbeam | 28.7 | Default |
| balsam poplar | 19.3 | | flowering dogwood | 28.7 | Default |
| eastern cottonwood | 23.1 | | hawthorn species | 28.7 | Default |
| bigtooth aspen | 22.5 | Eastern cottonwood | eastern hop hornbeam | 28.7 | Default |
| swamp cottonwood | 23.1 | | plum, cherry species | 29.3 | Black cherry |
| black cherry | 29.3 | | 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 Northeastern 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 ($\text{Vol} = 0.0015 \times D^2 \times H$) 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 | other oak species | 1 | 3 |
| black spruce | 8 | 6 | scarlet oak | 1 | 4 |
| other spruce species | 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 |
| northern white-cedar | 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 |
| other cedar species | 5 | 1 | black oak | 1 | 4 |
| eastern hemlock | 3 | 3 | cherrybark oak | 1 | 4 |
| other hemlock species | 3 | 3 | other hardwoods | 1 | 5 |
| other pine species | 2 | 6 | buckeye species | 1 | 5 |
| jack pine | 2 | 6 | yellow buckeye | 1 | 5 |
| shortleaf pine | 4 | 6 | water birch | 1 | 6 |
| Table Mountain pine | 3 | 6 | hackberry | 1 | 4 |
| pitch pine | 2 | 6 | common persimmon | 1 | 4 |

| Species | Leaf Life (years) | Crown Fall Class | Species | Leaf Life (years) | Crown Fall Class |
|--------------------|------------------------------|-----------------------------|----------------------|------------------------------|-----------------------------|
| pond pine | 2 | 6 | American holly | 3 | 4 |
| Scotch pine | 3 | 6 | butternut | 1 | 4 |
| other softwoods | 2 | 6 | black walnut | 1 | 4 |
| red maple | 1 | 5 | Osage-orange | 1 | 5 |
| sugar maple | 1 | 5 | magnolia species | 1 | 4 |
| black maple | 1 | 5 | sweetbay | 1 | 4 |
| silver maple | 1 | 5 | apple species | 1 | 4 |
| yellow birch | 1 | 6 | water tupelo | 1 | 3 |
| sweet birch | 1 | 6 | blackgum | 1 | 3 |
| river birch | 1 | 6 | sourwood | 1 | 5 |
| paper birch | 1 | 6 | Paulownia | 1 | 5 |
| gray birch | 1 | 6 | sycamore | 1 | 5 |
| hickory species | 1 | 2 | willow oak | 1 | 4 |
| pignut hickory | 1 | 2 | black locust | 1 | 2 |
| shellbark hickory | 1 | 2 | black willow | 1 | 6 |
| shagbark hickory | 1 | 2 | sassafras | 1 | 4 |
| mockernut hickory | 1 | 2 | American basswood | 1 | 6 |
| American beech | 1 | 4 | white basswood | 1 | 6 |
| ash species | 1 | 5 | other elm species | 1 | 5 |
| white ash | 1 | 5 | American elm | 1 | 5 |
| black ash | 1 | 5 | slippery elm | 1 | 5 |
| green ash | 1 | 5 | non-commercial | | |
| pumpkin ash | 1 | 5 | hardwoods | 1 | 5 |
| yellow-poplar | 1 | 4 | boxelder | 1 | 5 |
| sweetgum | 1 | 5 | striped maple | 1 | 5 |
| cucumbertree | 1 | 4 | ailanthus | 1 | 5 |
| quaking aspen | 1 | 6 | serviceberry | 1 | 5 |
| balsam poplar | 1 | 6 | American hornbeam | 1 | 4 |
| eastern cottonwood | 1 | 6 | flowering dogwood | 1 | 5 |
| bigtooth aspen | 1 | 6 | hawthorn species | 1 | 5 |
| swamp cottonwood | 1 | 6 | eastern hop hornbeam | 1 | 4 |
| black cherry | 1 | 4 | plum, cherry species | 1 | 4 |
| | | | pin 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 |
| white / red / jack pine | all | 0.81 | 1.19 | 1.66 | 0.73 | 2.24 | 2.01 | 3.06 |
| spruce –fir | 1 | 0.37 | 0.59 | 1.85 | 0.82 | 2.47 | 5.40 | 3.36 |
| spruce –fir | 2 | 0.50 | 0.68 | 1.77 | 1.52 | 3.17 | 1.64 | 1.91 |
| spruce –fir | 3 | 0.31 | 0.65 | 1.55 | 1.45 | 2.82 | 1.08 | 1.57 |
| loblolly-shortleaf pine | all | 0.21 | 1.08 | 7.32 | 0.53 | 0.57 | 0.00 | 4.21 |
| exotic softwoods | all | 0.34 | 0.50 | 0.56 | 0.08 | 0.00 | 0.00 | 0.60 |
| oak-pine | 1 | 0.23 | 0.82 | 2.55 | 0.83 | 2.11 | 1.20 | 4.06 |
| oak-pine | 2 or 3 | 0.26 | 0.84 | 1.15 | 0.49 | 0.50 | 4.64 | 3.12 |
| oak-hickory | 1 | 0.31 | 0.72 | 2.09 | 0.86 | 1.49 | 2.34 | 2.01 |
| oak-hickory | 2 | 0.32 | 1.13 | 2.51 | 0.53 | 0.98 | 0.52 | 1.75 |
| oak-hickory | 3 | 0.17 | 0.77 | 1.43 | 0.45 | 0.54 | 0.06 | 1.35 |
| oak-gum-cypress | all | 0.32 | 0.75 | 1.31 | 0.64 | 2.10 | 0.98 | 1.07 |
| elm-ash-cottonwood | 1 or 2 | 0.17 | 0.68 | 1.65 | 0.57 | 1.20 | 1.66 | 0.70 |
| elm-ash-cottonwood | 3 | 0.22 | 2.15 | 0.85 | 0.03 | 0.05 | 0.21 | 0.36 |
| maple-beech-birch | 1 | 0.39 | 0.90 | 2.88 | 0.95 | 2.25 | 1.96 | 2.39 |
| maple-beech-birch | 2 | 0.37 | 1.03 | 2.61 | 0.91 | 1.46 | 1.57 | 2.28 |
| maple-beech-birch | 3 | 0.33 | 0.73 | 1.25 | 0.54 | 0.92 | 1.99 | 1.71 |
| aspen-birch | 1 or 2 | 0.48 | 1.66 | 2.80 | 0.87 | 1.70 | 2.97 | 2.72 |
| aspen-birch | 3 | 0.52 | 0.76 | 2.57 | 1.15 | 0.94 | 0.34 | 1.34 |
| 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 | | other oak species | 0.045 | Quercus sp. |
| black spruce | 0.032 | | scarlet oak | 0.04 | |
| other spruce species | 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 | |
| northern white-cedar | 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 | |
| other cedar species | 0.033 | Juniperus sp. | black oak | 0.045 | |
| eastern hemlock | 0.039 | | cherrybark oak | 0.044 | Middle of this group |
| | | Western / mountain | | | |
| other hemlock species | 0.04 | hemlock | other hardwoods | 0.04 | |
| other pine species | 0.03 | Pinus sp. | buckeye species | 0.036 | Ohio buckeye |
| jack pine | 0.04 | | yellow buckeye | 0.05 | |
| shortleaf pine | 0.037 | | water birch | 0.05 | |
| Table Mountain pine | 0.04 | | hackberry | 0.036 | sugarberry |

| Species | Multiplier (Vsp) | Species used | Species | Multiplier (Vsp) | Species used |
|--------------------|-----------------------------|---------------------|--------------------------|-----------------------------|----------------------|
| pitch pine | 0.045 | | common persimmon | 0.041 | |
| pond pine | 0.62 | | American holly | 0.042 | |
| Scotch pine | 0.03 | | butternut | 0.041 | |
| other softwoods | 0.03 | Pinus sp. | black walnut | 0.041 | |
| red maple | 0.028 | | Osage-orange | 0.037 | |
| sugar maple | 0.033 | | magnolia species | 0.039 | Magnolia sp. |
| black maple | 0.035 | | sweetbay | 0.04 | |
| silver maple | 0.031 | | apple species | 0.043 | |
| yellow birch | 0.031 | | water tupelo | 0.03 | |
| sweet birch | 0.03 | | blackgum | 0.039 | |
| river birch | 0.029 | | sourwood | 0.036 | |
| paper birch | 0.027 | | Paulownia | 0.05 | |
| gray birch | 0.033 | Betula sp. | sycamore | 0.033 | |
| hickory species | 0.044 | Carya sp. | willow oak | 0.041 | |
| pignut hickory | 0.037 | | black locust | 0.049 | |
| shellbark hickory | 0.043 | | black willow | 0.04 | |
| shagbark hickory | 0.04 | | sassafras | 0.035 | |
| mockernut hickory | 0.043 | | American basswood | 0.04 | |
| American beech | 0.025 | | white basswood | 0.05 | |
| ash species | 0.042 | Fraxinus sp. | other elm species | 0.039 | Ulmus sp. |
| white ash | 0.042 | | American elm | 0.031 | |
| black ash | 0.035 | | slippery elm | 0.032 | |
| green ash | 0.039 | | non-commercial hardwoods | 0.045 | Middle of this group |
| pumpkin ash | 0.037 | | boxelder | 0.034 | |
| yellow-poplar | 0.041 | | striped maple | 0.045 | |
| sweetgum | 0.036 | | ailanthus | 0.05 | |
| cucumbertree | 0.036 | | serviceberry | 0.05 | |
| quaking aspen | 0.044 | | American hornbeam | 0.03 | |
| balsam poplar | 0.04 | | flowering dogwood | 0.041 | |
| eastern cottonwood | 0.04 | | hawthorn species | 0.038 | |
| bigtooth aspen | 0.039 | | eastern hophornbeam | 0.037 | |
| swamp cottonwood | 0.05 | | plum, cherry species | 0.05 | Prunus sp. |
| black cherry | 0.03 | | pin cherry | 0.045 | |

4.13.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.13.11). 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 | |
| 0.25 – 1 | | |
| 1 – 3 | 0.11 | |
| 3 – 6 | 0.07 | 0.02 |
| 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 **FUELDECAY** 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 | Species | Decay Rate Class |
|-----------------------|-------------------------|--------------------------|-------------------------|
| balsam fir | 4 | white oak | 2 |
| tamarack | 3 | bur oak | 2 |
| white spruce | 4 | chinkapin oak | 2 |
| red spruce | 4 | post oak | 2 |
| Norway spruce | 4 | other oak species | 2 |
| black spruce | 4 | scarlet oak | 2 |
| other spruce species | 4 | shingle oak | 2 |
| red pine | 4 | water oak | 2 |
| eastern white pine | 4 | pin oak | 2 |
| loblolly pine | 4 | chestnut oak | 2 |
| Virginia pine | 4 | swamp white oak | 2 |
| northern white-cedar | 2 | swamp chestnut oak | 2 |
| Atlantic white-cedar | 2 | northern red oak | 2 |
| eastern redcedar | 2 | southern red oak | 2 |
| other cedar species | 2 | black oak | 2 |
| eastern hemlock | 4 | cherrybark oak | 2 |
| other hemlock species | 4 | other hardwoods | 4 |
| other pine species | 4 | buckeye species | 4 |
| jack pine | 4 | yellow buckeye | 4 |
| shortleaf pine | 4 | water birch | 4 |
| Table Mountain pine | 4 | hackberry | 4 |
| pitch pine | 4 | common persimmon | 4 |
| pond pine | 4 | American holly | 4 |
| Scotch pine | 4 | butternut | 4 |
| other softwoods | 4 | black walnut | 2 |
| red maple | 4 | Osage-orange | 1 |
| sugar maple | 4 | magnolia species | 4 |
| black maple | 4 | sweetbay | 4 |
| silver maple | 4 | apple species | 2 |
| yellow birch | 4 | water tupelo | 4 |
| sweet birch | 4 | blackgum | 4 |
| river birch | 4 | sourwood | 4 |
| paper birch | 4 | Paulownia | 4 |
| gray birch | 4 | sycamore | 4 |
| hickory species | 4 | willow oak | 2 |
| pignut hickory | 4 | black locust | 1 |
| shellbark hickory | 4 | black willow | 4 |
| shagbark hickory | 4 | sassafras | 2 |
| mockernut hickory | 4 | American basswood | 4 |
| American beech | 4 | white basswood | 4 |
| ash species | 4 | other elm species | 4 |
| white ash | 4 | American elm | 4 |
| black ash | 4 | slippery elm | 4 |
| green ash | 4 | non-commercial hardwoods | 4 |
| pumpkin ash | 4 | boxelder | 4 |
| yellow-poplar | 4 | striped maple | 4 |
| sweetgum | 4 | ailanthus | 4 |
| cucumbertree | 4 | serviceberry | 4 |
| quaking aspen | 4 | American hornbeam | 4 |
| balsam poplar | 4 | flowering dogwood | 4 |
| eastern cottonwood | 4 | hawthorn species | 4 |
| bigtooth aspen | 4 | eastern hophornbeam | 4 |
| swamp cottonwood | 4 | plum, cherry species | 2 |
| black cherry | 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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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.

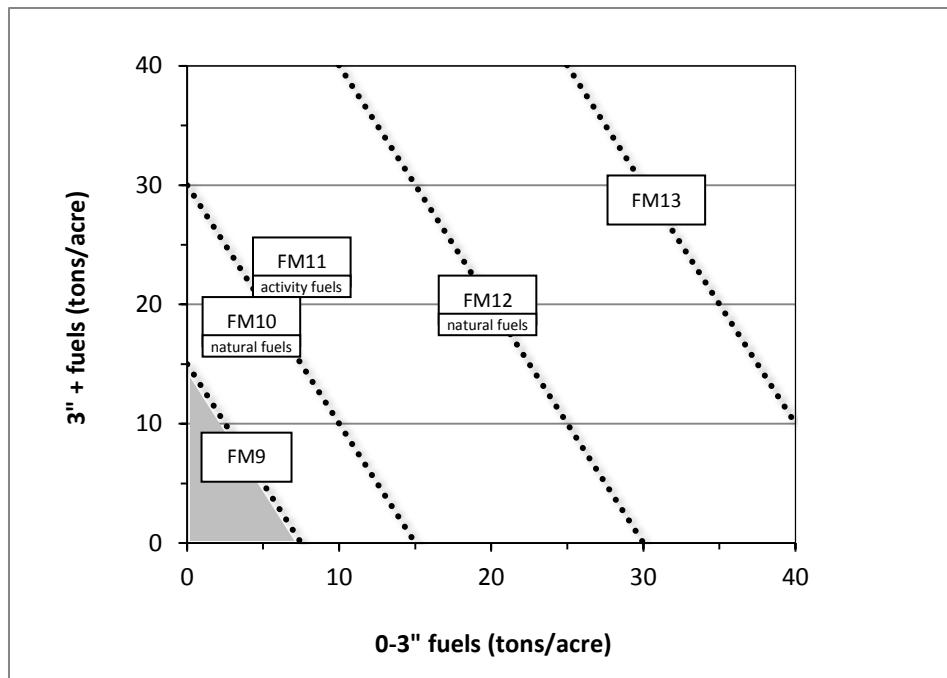


Figure 4.13.5 - At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. At low fuel loads, fuel model 9 is selected.

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 species’, 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 | <i>Abies amabilis</i> | |
| white fir | <i>Abies concolor</i> | |
| grand fir | <i>Abies grandis</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| California red fir / Shasta red fir | <i>Abies magnifica</i> | |
| Sitka spruce | <i>Picea sitchensis</i> | |
| noble fir | <i>Abies procera</i> | |
| Alaska cedar / western larch | <i>Callitropsis nootkatensis / Larix occidentalis</i> | |
| incense-cedar | <i>Calocedrus decurrens</i> | = <i>Libocedrus decurrens</i> |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Jeffrey pine | <i>Pinus jeffreyi</i> | |
| sugar pine | <i>Pinus lambertiana</i> | |
| western white pine | <i>Pinus monticola</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| coast redwood | <i>Sequoia sempervirens</i> | |
| western redcedar | <i>Thuja plicata</i> | |
| western hemlock | <i>Tsuga heterophylla</i> | |
| mountain hemlock | <i>Tsuga mertensiana</i> | |
| bigleaf maple | <i>Acer macrophyllum</i> | |
| red alder | <i>Alnus rubra</i> | |
| white alder / Pacific madrone | <i>Alnus rhombifolia / Arbutus menziesii</i> | |
| paper birch | <i>Betula papyrifera</i> | |
| giant chinquapin / tanoak | <i>Chrysolepis chrysophylla / Lithocarpus densiflorus</i> | |
| quaking aspen | <i>Populus tremuloides</i> | |
| black cottonwood | <i>Populus trichocarpa</i> | |
| Oregon white oak / California black oak | <i>Quercus garryana / Quercus kelloggii</i> | |
| western juniper | <i>Juniperus occidentalis</i> | |
| subalpine larch | <i>Larix lyallii</i> | |
| whitebark pine | <i>Pinus albicaulis</i> | |
| knobcone pine | <i>Pinus attenuata</i> | |
| Pacific yew | <i>Taxus brevifolia</i> | |
| Pacific dogwood | <i>Cornus nuttallii</i> | |
| hawthorn species | <i>Crataegus spp.</i> | |
| bitter cherry | <i>Prunus emarginata</i> | |
| willow species | <i>Salix spp.</i> | |
| 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/fmfc/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 ft³) 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 / Pacific madrone | 36.2 |
| California red fir / Shasta red fir | 22.5 | paper birch | 29.9 |
| Sitka spruce | 20.6 | giant chinquapin / tanoak | 36.2 |
| noble fir | 23.1 | quaking aspen | 21.8 |
| Alaska cedar / western larch | 26.2 | black cottonwood | 19.3 |
| incense-cedar | 21.8 | Oregon white oak / California black 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 species | 27.4 |
| coast redwood | 21.2 | bitter cherry | 29.3 |

| Species | Density (lbs/ft ³) | Species | Density (lbs/ft ³) |
|------------------|-----------------------------------|---------------|-----------------------------------|
| western redcedar | 19.3 | willow | 22.5 |
| western hemlock | 26.2 | other species | 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) |
| grand fir | Brown and Johnston (1976) |
| Subalpine fir | Brown and Johnston (1976) |
| California red fir / Shasta 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 | 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) |
| coast 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 / Pacific madrone | madrone; Snell and Little (1983) |
| paper birch | Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| giant chinquapin / tanoak | 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 / California black 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 species | 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 species | 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.

| Species | Live | | Dead | | |
|---|----------------|----------------|------------------|----------------|----------------|
| | 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 / Shasta red fir | 7 | 2 | 5 | 5 | 15 |
| Sitka spruce | 5 | 2 | 5 | 5 | 15 |
| noble fir | 7 | 2 | 5 | 5 | 15 |
| Alaska cedar / western larch | 5 | 2 | 5 | 5 | 20 |
| 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 |
| coast 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 / Pacific madrone | 1 | 1 | 10 | 15 | 15 |
| paper birch | 1 | 1 | 10 | 15 | 15 |
| giant chinquapin / tanoak | 1 | 1 | 10 | 15 | 15 |
| quaking aspen | 1 | 1 | 10 | 15 | 15 |
| black cottonwood | 1 | 1 | 10 | 15 | 15 |
| Oregon white oak / California black 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 species | 1 | 1 | 10 | 15 | 15 |
| bitter cherry | 1 | 1 | 10 | 15 | 15 |
| willow | 1 | 1 | 10 | 15 | 15 |
| other species | 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 / Shasta 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 |
| | I | 0.30 | 2.00 | |
| noble fir | E | 0.15 | 0.10 | Use grand fir |
| | I | 0.30 | 2.00 | |
| Alaska cedar / western larch | 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 | |
| coast 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 / Pacific madrone | 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 / tanoak | 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 | |

| Species | | Herbs | Shrubs | Notes |
|---|---|--------------|---------------|---|
| Oregon white oak / California black oak | E | 0.23 | 0.22 | Gambel oak – Ottmar and others |
| | I | 0.55 | 0.35 | 2000b |
| 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 species | 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 species | 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.

| Species | Size Class (in) | | | | | | | |
|-------------------------------------|------------------------|-----------------|--------------|--------------|---------------|----------------|---------------|-------------|
| | < 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 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| white fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| grand fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| subalpine fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| California red fir / Shasta red fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| Sitka spruce | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 10.0 | 1.0 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 6.0 | 0.5 |
| noble fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| Alaska cedar / western larch | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |

| Species | Size Class (in) | | | | | | | | |
|--|-----------------|----------|-------|-------|--------|------|--------|------|------|
| | < 0.25 | 0.25 – 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 | Litter | Duff | |
| 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 |
| coast 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 / 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 |
| 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 / 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 |
| 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 / California black 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 species | 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 |

| Species | Size Class (in) | | | | | | | |
|---------------|-----------------|----------|-------|-------|--------|------|--------|------|
| | < 0.25 | 0.25 – 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 | Litter | Duff |
| other species | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 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 / Pacific madrone | 0.060 |
| California red fir / Shasta red fir | 0.039 | paper birch | 0.027 |
| Sitka spruce | 0.027 | giant chinquapin / tanoak | 0.045 |
| noble fir | 0.045 | quaking aspen | 0.044 |
| Alaska cedar / western larch | 0.022 | black cottonwood | 0.044 |
| incense-cedar | 0.081 | Oregon white oak / | 0.029 |
| Engelmann spruce | 0.036 | California black oak | |
| lodgepole pine | 0.028 | western juniper | 0.025 |
| Jeffrey pine | 0.068 | subalpine larch | 0.050 |
| sugar pine | 0.072 | whitebark pine | 0.030 |
| western white pine | 0.035 | knobcone pine | 0.030 |
| ponderosa pine | 0.063 | Pacific yew | 0.025 |
| Douglas-fir | 0.063 | Pacific dogwood | 0.062 |
| coast redwood | 0.081 | hawthorn species | 0.038 |
| western redcedar | 0.035 | bitter cherry | 0.062 |
| western hemlock | 0.040 | willow | 0.041 |
| | | other species | 0.044 |

4.14.5 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 (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 | | | | |
| | 0.25 – 1 | 0.057 | 0.067 | 0.080 | 0.108 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | |
| | 6 – 12 | 0.016 | 0.033 | 0.053 | 0.100 |
| | > 12 | 0.010 | 0.021 | 0.034 | 0.064 |
| moderate, mesic | < 0.25 | | | | |
| | 0.25 – 1 | 0.069 | 0.081 | 0.097 | 0.154 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | |
| | 6 – 12 | 0.024 | 0.050 | 0.082 | 0.154 |
| | > 12 | 0.012 | 0.025 | 0.041 | 0.077 |
| moderate, dry | < 0.25 | | | | |
| | 0.25 – 1 | 0.093 | 0.109 | 0.131 | 0.177 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | |
| | 6 – 12 | 0.024 | 0.050 | 0.082 | 0.154 |
| | > 12 | 0.016 | 0.034 | 0.055 | 0.104 |
| cold, wet | < 0.25 | | | | |
| | 0.25 – 1 | 0.052 | 0.061 | 0.073 | 0.098 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | |
| | 6 – 12 | 0.012 | 0.025 | 0.041 | 0.077 |
| | > 12 | 0.009 | 0.019 | 0.031 | 0.058 |
| cold, mesic | < 0.25 | | | | |
| | 0.25 – 1 | 0.052 | 0.061 | 0.073 | 0.098 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | |
| | 6 – 12 | 0.012 | 0.025 | 0.041 | 0.077 |
| | > 12 | 0.009 | 0.019 | 0.031 | 0.058 |
| cold, dry | < 0.25 | | | | |
| | 0.25 – 1 | 0.064 | 0.075 | 0.090 | 0.131 |
| | 1 – 3 | | | | |
| | 3 – 6 | | | | |
| | 6 – 12 | 0.020 | 0.043 | 0.070 | 0.131 |
| | > 12 | 0.011 | 0.023 | 0.038 | 0.071 |
| All | Litter | 0.5 | 0.5 | 0.5 | 0.02 |
| | Duff | 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 / Pacific madrone | 4 |
| California red fir / Shasta red fir | 3 | paper birch | 4 |
| Sitka spruce | 2 | giant chinquapin / tanoak | 3 |
| noble fir | 3 | quaking aspen | 4 |
| Alaska cedar / western larch | 1 | black cottonwood | 4 |
| incense-cedar | 1 | Oregon white oak / California black 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 |

| Species | Decay Rate Class | Species | Decay Rate Class |
|------------------|-------------------------|------------------|-------------------------|
| Douglas-fir | 1 | hawthorn species | 4 |
| coast redwood | 1 | bitter cherry | 4 |
| western redcedar | 1 | willow | 4 |
| western hemlock | 2 | other species | 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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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 |
|-------------------|--------------|-------------------|--------------|-------------------|--------------|-------------------|--------------|
| 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.

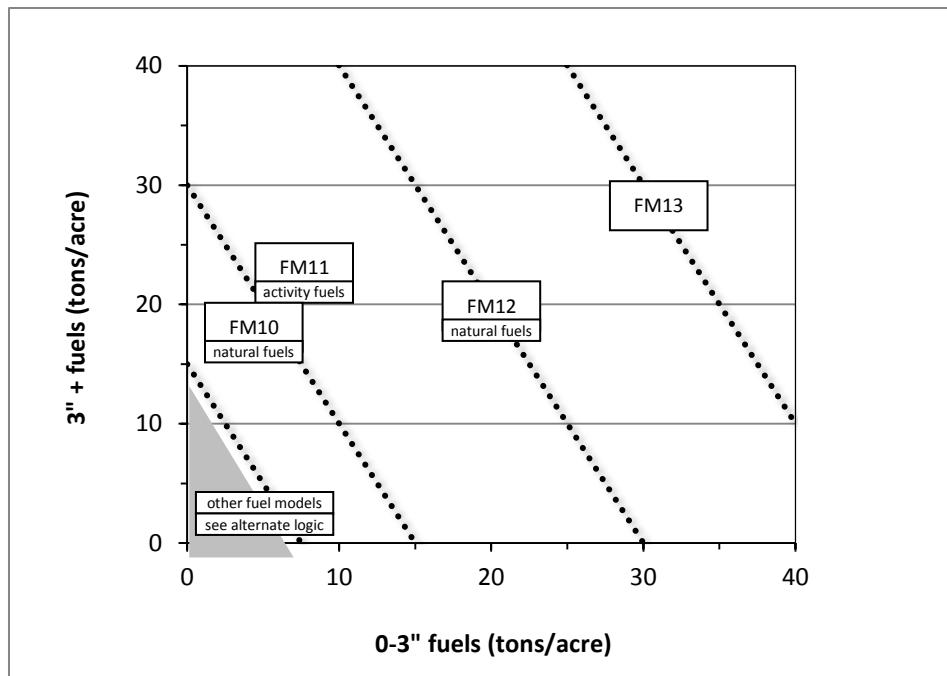


Figure 4.14.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.14.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

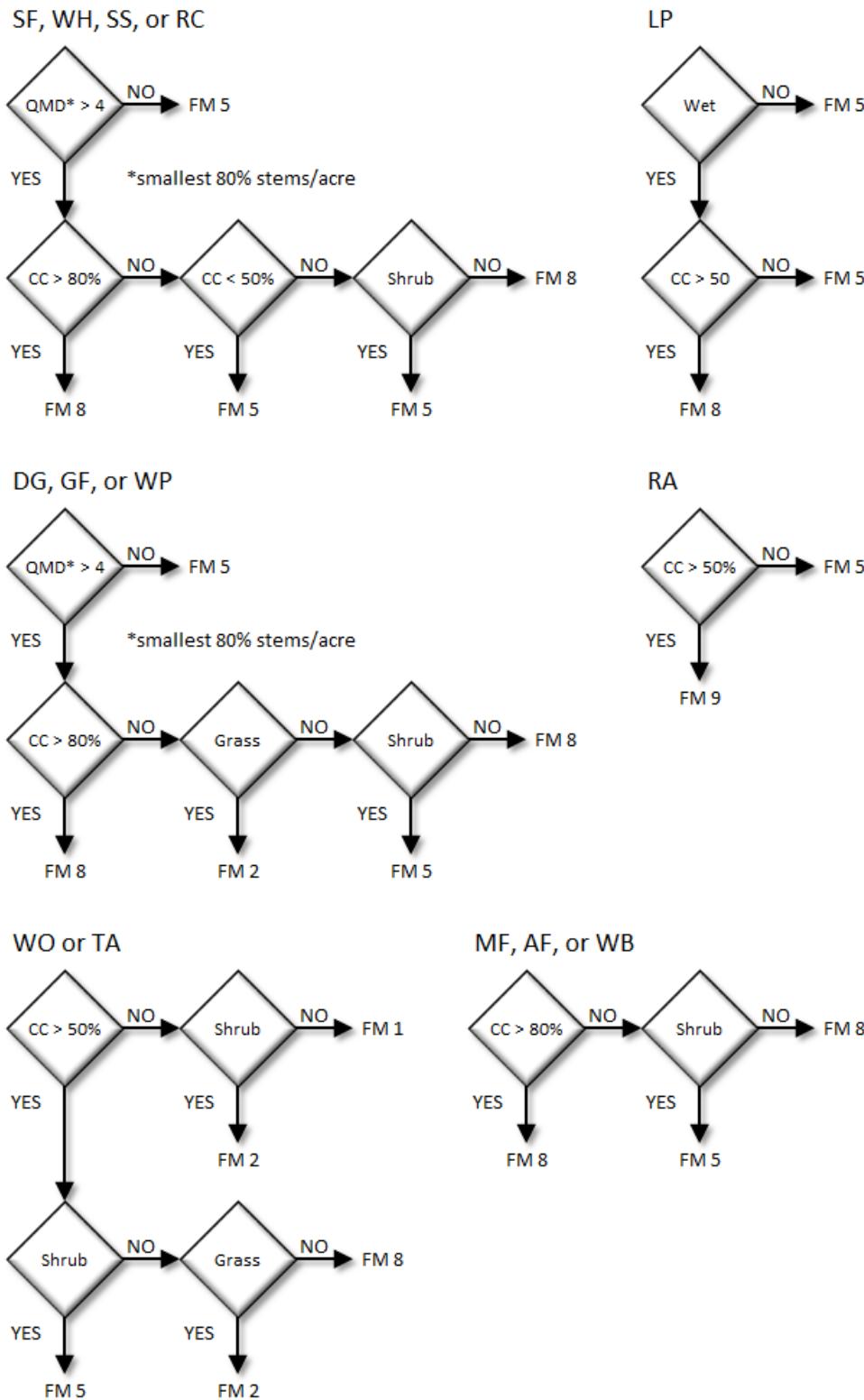


Figure 4.14.2 - Fuel models for the PN-FFE variant.

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 softwoods’ and ‘other hardwoods’, 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 | <i>Pinus monticola</i> | |
| sugar pine | <i>Pinus lambertiana</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| white fir | <i>Abies concolor</i> | |
| mountain hemlock | <i>Tsuga mertensiana</i> | |
| incense-cedar | <i>Calocedrus decurrens</i> | = <i>Libocedrus decurrens</i> |
| lodgepole pine | <i>Pinus contorta</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| Shasta red fir | <i>Abies magnifica</i> | |
| ponderosa pine / Jeffrey pine | <i>Pinus ponderosa / Pinus jeffreyi</i> | |
| western juniper | <i>Juniperus occidentalis</i> | |
| grand fir | <i>Abies grandis</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| pacific silver fir | <i>Abies amabilis</i> | |
| noble fir | <i>Abies procera</i> | |
| whitebark pine | <i>Pinus albicaulis</i> | |
| western larch | <i>Larix occidentalis</i> | |
| western redcedar | <i>Thuja plicata</i> | |
| western hemlock | <i>Tsuga heterophylla</i> | |
| pacific yew | <i>Taxus brevifolia</i> | |
| white alder | <i>Alnus rhombifolia</i> | |
| red alder | <i>Alnus rubra</i> | |
| bigleaf maple | <i>Acer macrophyllum</i> | |
| quaking aspen | <i>Populus tremuloides</i> | |
| black cottonwood | <i>Populus trichocarpa</i> | |
| bitter cherry | <i>Prunus emarginata</i> | |
| Oregon white oak | <i>Quercus garryana</i> | |
| willow species | <i>Salix spp.</i> | |
| giant chinquapin | <i>Chrysolepis chrysophylla</i> | |
| curl-leaf mt. mahogany | <i>Cercocarpus ledifolius</i> | |
| birch-leaf mt. mahogany | <i>Cercocarpus betuloides</i> | = <i>C. montanus</i> var. <i>glaber</i> ? |
| other softwoods | | = Douglas-fir |
| other hardwoods | | = 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 / Jeffrey 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 | — |

| Species | 95% Fallen | All Down | 50% Height | Hard-to-Soft |
|-------------------------|------------|----------|------------|--------------|
| | Years | | | |
| 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 | — |
| black cottonwood | 25 | 100 | 20 | — |
| bitter cherry | 25 | 100 | 20 | — |
| Oregon white oak | 25 | 100 | 20 | — |
| willow species | 25 | 100 | 20 | — |
| giant chinquapin | 25 | 100 | 20 | — |
| curl-leaf mt. mahogany | 25 | 100 | 20 | — |
| birch-leaf mt. mahogany | 25 | 100 | 20 | — |
| other softwoods | 35 | 100 | 20 | — |
| other hardwoods | 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 / Jeffrey 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 species | 1.24 | 1.49 | — |
| giant chinquapin | 1.24 | 1.49 | — |
| curl-leaf mt. mahogany | 1.24 | 1.49 | — |
| birch-leaf mt. mahogany | 1.24 | 1.49 | — |
| other softwoods | 0.88 | 1.49 | — |
| other hardwoods | 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 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 ft³) 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, subalpine fir | 22.5 |
| ponderosa pine / Jeffrey 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 species | 22.5 |
| giant chinquapin | 36.2 |
| curl-leaf mt. mahogany | 21.8 |
| birch-leaf mt. mahogany | 21.8 |
| other softwoods | 28.7 |
| other hardwoods | 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 / Jeffrey 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 species | Jenkins et. al. (2003), Loomis and Roussopoulos (1978) |
| giant chinquapin | tanoak; Snell and Little (1983), Snell (1979) |
| curl-leaf mt. mahogany | aspen; Jenkins et. al. (2003), Loomis and Roussopoulos (1978) |
| birch-leaf mt. mahogany | aspen; Jenkins et. al. (2003), Loomis and Roussopoulos (1978) |
| other softwoods | Douglas-fir; Brown and Johnston (1976) |
| other hardwoods | 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.

| Species | Live Foliage | Dead | | |
|---------|-----------------|---------|--------|---------|
| | | Foliage | <0.25" | 0.25-1" |

| Species | Live Foliage | | Dead | | |
|-------------------------------|--------------|---------|--------|---------|------|
| | | 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 |
| 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 / Jeffrey 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 species | 1 | 1 | 5 | 5 | 15 |
| giant chinquapin | 1 | 1 | 5 | 5 | 15 |
| curl-leaf mt. mahogany | 1 | 1 | 5 | 5 | 15 |
| birch-leaf mt. mahogany | 1 | 1 | 5 | 5 | 15 |
| other softwoods | 5 | 2 | 5 | 5 | 15 |
| other hardwoods | 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 / Jeffrey 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 |

| Species | Live | | Dead | | |
|-------------------------|---------|---------|--------|---------|------|
| | Foliage | Foliage | <0.25" | 0.25-1" | > 1" |
| bitter cherry | 1 | 1 | 10 | 15 | 15 |
| Oregon white oak | 1 | 1 | 10 | 15 | 15 |
| willow species | 1 | 1 | 10 | 15 | 15 |
| giant chinquapin | 1 | 1 | 10 | 15 | 15 |
| curl-leaf mt. mahogany | 1 | 1 | 10 | 15 | 15 |
| birch-leaf mt. mahogany | 1 | 1 | 10 | 15 | 15 |
| other softwoods | 5 | 3 | 10 | 15 | 15 |
| other hardwoods | 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.

| Species | Structural Stage § | | | | | |
|-------------------------------|--------------------|-----|-----|------|-----|-----|
| | 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 / Jeffrey 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 |

| Species | Structural Stage § | | | | | |
|-------------------------|---------------------------|----------|----------|-------------|----------|----------|
| | 1 | 2 | 3 | 4, 5 | 6 | 7 |
| 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 |
| 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 species | 52 | 53 | 56 | 58 | 62 | 62 |
| giant chinquapin | 52 | 53 | 56 | 58 | 62 | 62 |
| curl-leaf mt. mahogany | 52 | 53 | 56 | 58 | 62 | 62 |
| birch-leaf mt. mahogany | 52 | 53 | 56 | 58 | 62 | 62 |
| other softwoods | 52 | 53 | 56 | 58 | 62 | 62 |
| other hardwoods | 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.

| FCC | Size Class (in) | | | | | | | |
|-----|-----------------|----------|-------|-------|--------|------|--------|------|
| | < 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 |
| 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 / Jeffrey 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 |

| Species | Multiplier (V_{sp}) |
|-------------------------|---|
| quaking aspen | 0.044 |
| black cottonwood | 0.044 |
| bitter cherry | 0.062 |
| Oregon white oak | 0.029 |
| willow species | 0.041 |
| giant chinquapin | 0.045 |
| curl-leaf mt. mahogany | 0.044 |
| birch-leaf mt. mahogany | 0.044 |
| other softwoods | 0.063 |
| other hardwoods | 0.044 |

4.15.5 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 4.15.12) 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. | | |
| 0.25 – 1.0 in. | 0.025 | |
| 1.0 – 3.0 in. | | |
| 3.0 – 6.0 in. | | 0.02 |
| 6.0 – 12.0 in. | 0.0125 | |
| > 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 | | | | |
| | 0.25 – 1 | 0.113 | 0.121 | 0.134 | 0.168 |
| | 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 | | | | |
| | 0.25 – 1 | 0.057 | 0.061 | 0.068 | 0.085 |
| | 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 | | | | |
| | 0.25 – 1 | 0.103 | 0.109 | 0.122 | 0.153 |
| | 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 | | | | |
| | 0.25 – 1 | 0.076 | 0.081 | 0.090 | 0.113 |
| | 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 | | | | |
| | 0.25 – 1 | 0.067 | 0.071 | 0.079 | 0.099 |
| | 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 | | | | |
| | 0.25 – 1 | 0.092 | 0.098 | 0.109 | 0.137 |
| | 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 | | | | |
| | 0.25 – 1 | 0.087 | 0.092 | 0.103 | 0.129 |
| | 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 | | | | |
| | 0.25 – 1 | 0.057 | 0.061 | 0.068 | 0.085 |
| | 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 | 0.02 |
| | Duff | 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 / Jeffrey 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 species | 4 |
| giant chinquapin | 3 |
| curl-leaf mt. mahogany | 4 |
| birch-leaf mt. mahogany | 4 |
| other softwoods | 1 |
| other hardwoods | 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.

| Size Class | Moisture Group | | | |
|-------------------------|-----------------------|------------|--------------|------------|
| | 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.

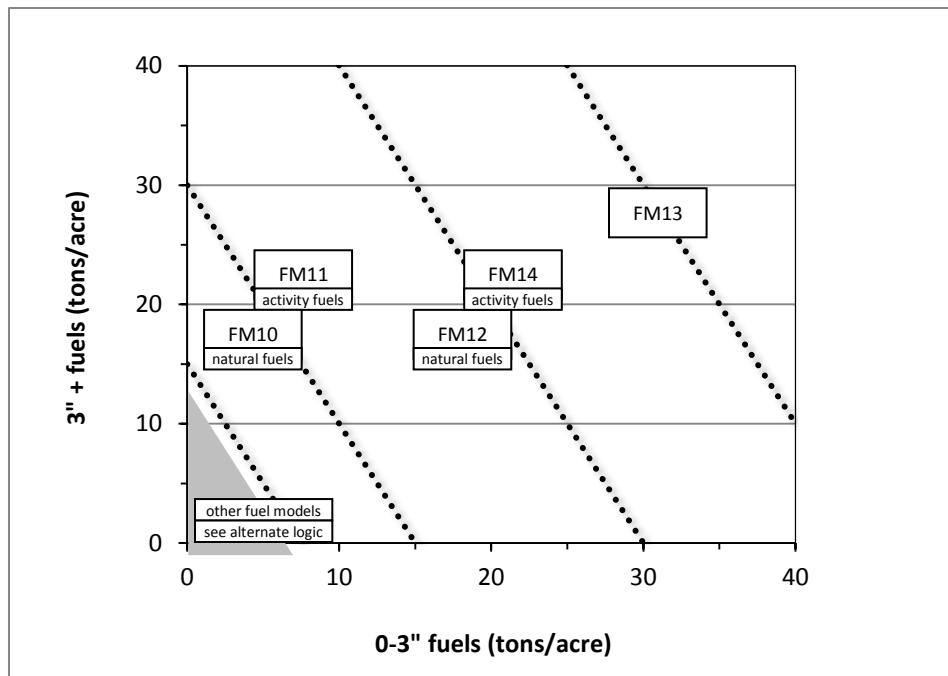
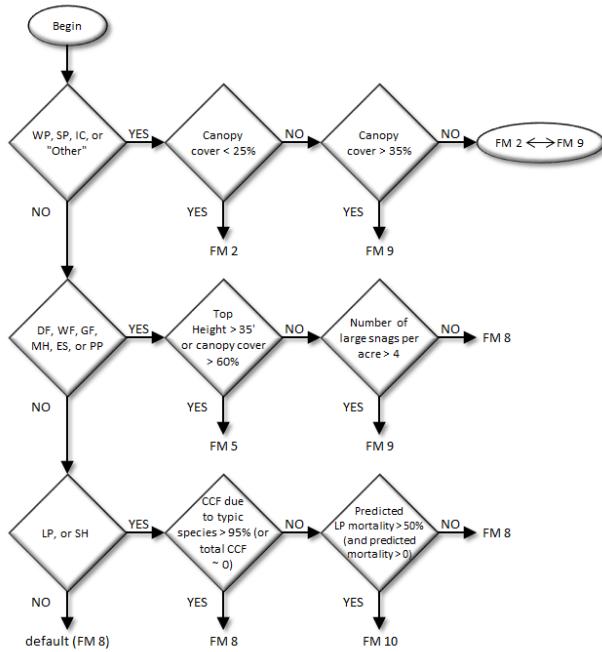


Figure 4.15.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.15.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description section 2.4.8 for further details).

SORNEC Fuel Model Logic

(for low natural fuel conditions)

Part 1: Rules for all private lands and Region 5 forests



SORNEC Fuel model Logic

(for low natural fuel conditions)

Part 2: Rules for all Region 6 forests

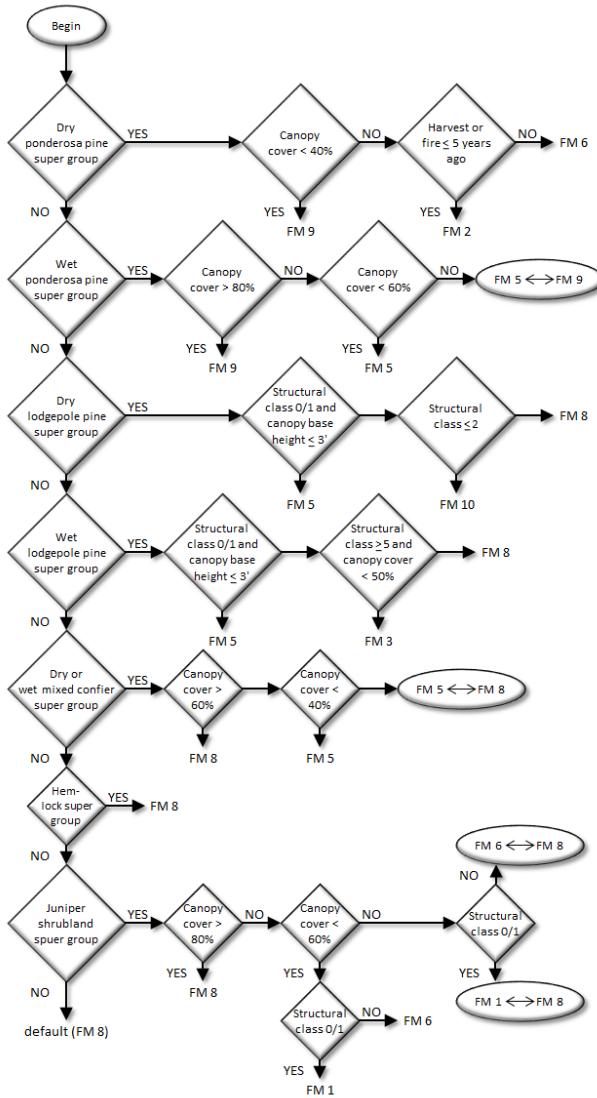


Figure 4.15.2 - Fuel model logic for Region 5 (a) and Region 6 (b) forests modeled in the SO-FFE.

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

$$C = 0.9 - 0.0535 \left[M_{10} - 0.03 \left(\frac{\ln(0.5F) \left(1 + \frac{Slope - 20}{60} + \frac{Wind}{4} \right)}{\ln(2)} \right) - 12 \right]$$

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: $DRED = -0.005 \times M + 0.731$ |
| $M > 44\% \text{ and } M \leq 60\%$ | 2: $DRED = -0.0178 \times M + 1.489$ |
| $M \geq 44\% \text{ and Consumption of 100hr} \leq 75\%$ | 3: $DRED = -0.096 \times M + 4.6495$ |
| $M < 44\% \text{ and Consumption of 100hr} \geq 85\%$ | 4: $DRED = -0.125 \times M + 6.27$ |
| $M < 44\% \text{ and Consumption of 100hr} 75\% - 85\%$ | 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 |
|-----------------------|---------------------------------|
| $M \leq 40\%$ | $DRED = DRED \times (1 - 0.22)$ |
| $M 40\%-50\%$ | $DRED = DRED \times (1 - 0.11)$ |

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 |
|-----------------|-----------------------------------|
| $\geq 200\%$ | $R = 0.537 + (C1000 + C10000)$ |
| $125\% - 200\%$ | $R = 0.323 + 1.034 + \sqrt{DRED}$ |
| $50\% - 125\%$ | $R = 1.323 + 1.034 + \sqrt{DRED}$ |
| $< 50\%$ | $R = 2.323 + 1.034 + \sqrt{DRED}$ |

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 90 tree species categories shown in Table 4.16.1.

Table 4.16.1 - Tree species simulated by the Southern variant.

| Common name | Scientific name | Common name | Scientific name |
|-----------------------|--------------------------------|---------------------|------------------------------|
| fir sp. | <i>abies</i> sp. | magnolia sp. | <i>magnolia</i> sp. |
| redcedar | <i>juniperus</i> sp. | cucumbertree | <i>magnolia acuminata</i> |
| spruce | <i>picea</i> sp. | southern magnolia | <i>magnolia grandiflora</i> |
| sand pine | <i>pinus clausa</i> | sweetbay | <i>magnolia virginiana</i> |
| shortleaf pine | <i>pinus echinata</i> | bigleaf magnolia | <i>magnolia macrophylla</i> |
| slash pine | <i>pinus elliottii</i> | apple sp. | <i>malus</i> sp. |
| spruce pine | <i>pinus glabra</i> | mulberry sp. | <i>morus</i> sp. |
| longleaf pine | <i>pinus palustris</i> | water tupelo | <i>nyssa aquatica</i> |
| table mountain pine | <i>pinus pungens</i> | blackgum | <i>nyssa sylvatica</i> |
| | | | <i>nyssa sylvatica</i> var. |
| pitch pine | <i>pinus rigida</i> | swamp tupelo | <i>biflora</i> |
| pond pine | <i>pinus serotina</i> | eastern hophornbeam | <i>ostrya virginiana</i> |
| eastern white pine | <i>pinus strobus</i> | sourwood | <i>oxydendrum arboreum</i> |
| loblolly pine | <i>pinus taeda</i> | redbay | <i>persea borbonia</i> |
| Virginia pine | <i>pinus virginiana</i> | sycamore | <i>platanus occidentalis</i> |
| baldcypress | <i>taxodium distichum</i> | cottonwood | <i>populus</i> sp. |
| | <i>taxodium distichum</i> var | | |
| pondcypress | <i>nutans</i> | bigtooth aspen | <i>populus grandidentata</i> |
| hemlock | <i>tsuga</i> sp. | black cherry | <i>prunus serotina</i> |
| Florida maple | <i>acer barbatum</i> | white oak | <i>quercus alba</i> |
| boxelder | <i>acer negundo</i> | scarlet oak | <i>quercus coccinea</i> |
| | | | <i>quercus falcata</i> var. |
| red maple | <i>acer rubrum</i> | souther red oak | <i>falcata</i> |
| silver maple | <i>acer saccharinum</i> | cherrybark oak | <i>quercus falcata</i> |
| sugar maple | <i>acer saccharum</i> | turkey oak | <i>quercus laevis</i> |
| buckeye/horsechestnut | <i>aesculus</i> sp. | laurel oak | <i>quercus laurifolia</i> |
| birch sp. | <i>betula</i> sp. | overcup oak | <i>quercus lyrata</i> |
| sweet birch | <i>betula lenta</i> | blackjack oak | <i>quercus marilandica</i> |
| american | | | |
| hornbeam/musclewood | <i>carpinus caroliniana</i> | swamp chestnut oak | <i>quercus michauxii</i> |
| hickory sp. | <i>carya</i> sp. | chinkapin oak | <i>quercus muehlenbergii</i> |
| catalpa | <i>catalpa</i> sp. | water oak | <i>quercus nigra</i> |
| hackberry sp. | <i>celtis</i> sp. | chestnut oak | <i>quercus prinus</i> |
| eastern redbud | <i>cercis canadensis</i> | northern red oak | <i>quercus rubra</i> |
| flowering dogwood | <i>cornus florida</i> | shumard oak | <i>quercus shumardii</i> |
| common persimmon | <i>diospyros virginiana</i> | post oak | <i>quercus stellata</i> |
| american beech | <i>fagus grandifolia</i> | black oak | <i>quercus velutina</i> |
| ash sp. | <i>fraxinus</i> sp. | live oak | <i>quercus virginiana</i> |
| white ash | <i>fraxinus americana</i> | back locust | <i>robinia pseudoacacia</i> |
| black ash | <i>fraxinus nigra</i> | willow | <i>salix</i> sp. |
| green ash | <i>fraxinus pennsylvanica</i> | sassafras | <i>sassafras albidum</i> |
| honeylocust | <i>gleditsia triacanthos</i> | basswood | <i>tilia</i> sp. |
| loblolly-bay | <i>gordonia lasianthus</i> | elm sp. | <i>ulmus</i> sp. |
| silverbell | <i>halesia</i> sp. | winged elm | <i>ulmus alata</i> |
| american holly | <i>ilex opaca</i> | american elm | <i>ulmus americana</i> |
| butternut | <i>juglans cinerea</i> | slippery elm | <i>ulmus rubra</i> |
| black walnut | <i>juglans nigra</i> | other softwoods | |
| sweetgum | <i>liquidambar styraciflua</i> | other hardwoods | |
| yellow-poplar | <i>liriodendron tulipifera</i> | other species | |

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 sp. | 2 | magnolia sp. | 2 |
| redcedar | 3 | cucumbertree | 2 |
| spruce | 2 | southern magnolia | 2 |
| sand pine | 1 | sweetbay | 2 |
| shortleaf pine | 1 | bigleaf magnolia | 2 |
| slash pine | 1 | apple sp. | 2 |
| spruce pine | 1 | mulberry sp. | 2 |
| longleaf pine | 1 | water tupelo | 3 |
| table mountain pine | 1 | blackgum | 3 |
| pitch pine | 1 | swamp tupelo | 3 |
| Pond pine | 1 | eastern hophornbeam | 2 |
| eastern white pine | 1 | sourwood | 2 |
| loblolly pine | 1 | redbay | 2 |
| Virginia pine | 1 | sycamore | 2 |
| baldcypress | 3 | cottonwood | 1 |
| pondcypress | 3 | bigtooth aspen | 1 |
| hemlock | 2 | black cherry | 2 |
| Florida 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/horsechestnut | 2 | laurel oak | 2 |
| birch sp. | 1 | overcup oak | 2 |
| sweet birch | 1 | blackjack oak | 3 |
| american hornbeam | 2 | swamp chestnut oak | 2 |

| Species | Snag class | Species | Snag class |
|-------------------|-------------------|------------------|-------------------|
| hickory sp. | 3 | chinkapin oak | 3 |
| catalpa | 2 | water oak | 3 |
| hackberry sp. | 2 | chestnut oak | 2 |
| eastern redbud | 2 | northern red oak | 2 |
| flowering dogwood | 2 | shumard oak | 2 |
| common persimmon | 3 | post oak | 3 |
| american beech | 2 | black oak | 2 |
| ash sp. | 2 | live oak | 2 |
| White ash | 2 | black locust | 3 |
| Black ash | 2 | willow | 1 |
| Green ash | 2 | sassafras | 2 |
| honeylocust | 3 | basswood | 1 |
| loblolly-bay | 2 | elm sp. | 1 |
| silverbell | 2 | winged elm | 1 |
| american holly | 2 | american elm | 1 |
| butternut | 2 | slippery elm | 1 |
| Black walnut | 2 | other softwoods | 1 |
| sweetgum | 2 | other hardwoods | 2 |
| yellow-poplar | 2 | other species | 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.

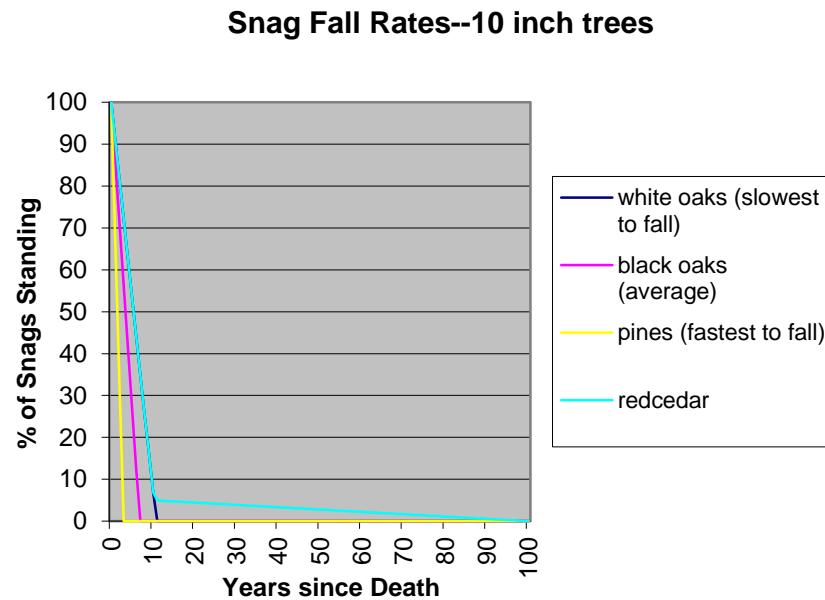


Figure 4.16.1 - Snag fall rates for 10 inch trees.

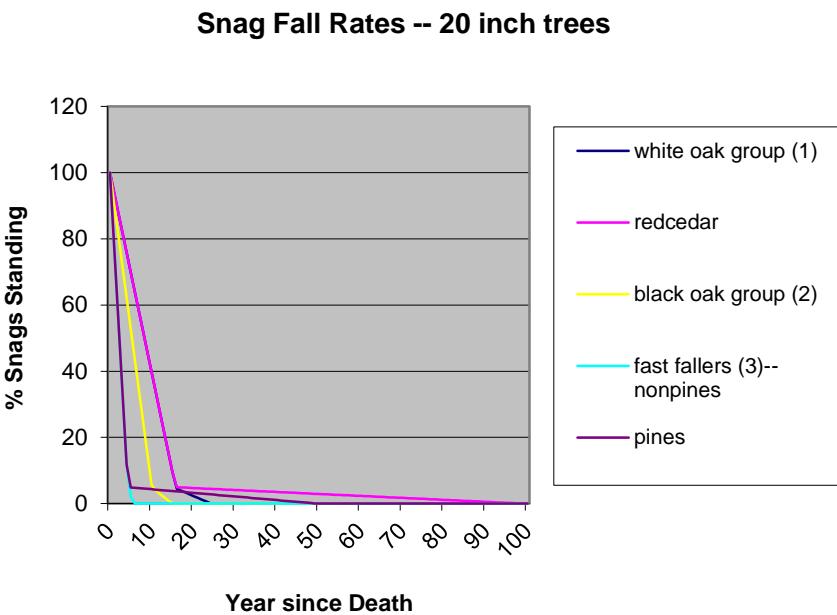


Figure 4.16.2 - Snag fall rates for 20 inch trees.

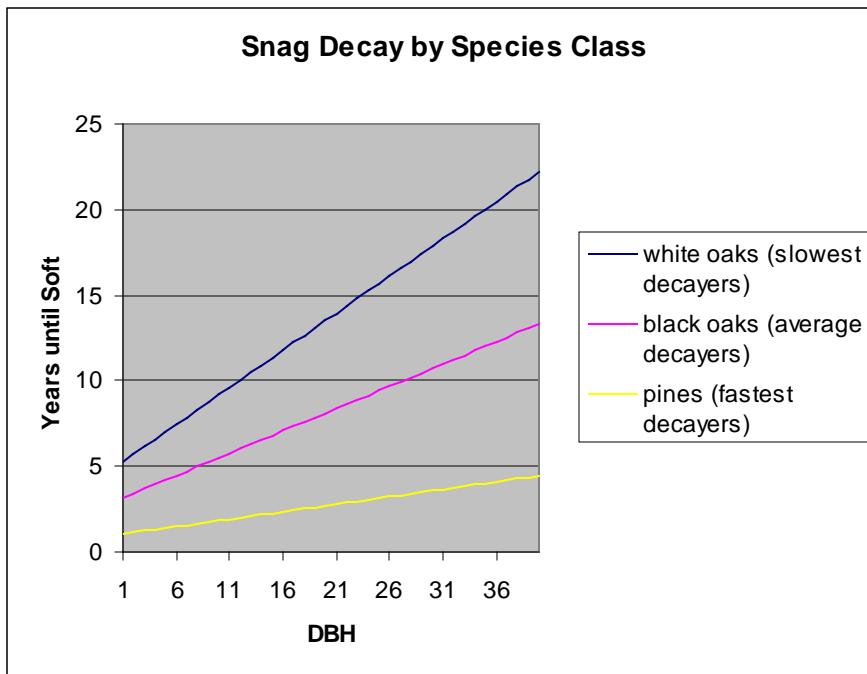


Figure 4.16.3 - The number of years until soft for various diameter snags.

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 Boles: 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/ft³) used in the SN-FFE variant.

| Species | Ibs/cuft | Species used | Species | Ibs/cuft | Species used |
|-----------------------|----------|--------------------|---------------------|----------|--------------|
| fir sp. | 20.6 | balsam fir | magnolia sp. | 27.4 | cuckbertree |
| redcedar | 27.4 | | cuckbertree | 27.4 | |
| spruce | 23.1 | red spruce | southern magnolia | 28.7 | |
| sand pine | 28.7 | | sweetbay | 27.4 | cuckbertree |
| shortleaf pine | 29.3 | | bigleaf magnolia | 27.4 | cuckbertree |
| slash pine | 33.7 | | apple sp. | 34.9 | black oak |
| spruce pine | 25.6 | | mulberry sp. | 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 | | eastern 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 | | sycamore | 28.7 | |
| baldcypress | 26.2 | | cottonwood | 23.1 | |
| pondcypress | 26.2 | baldcypress | bigtooth aspen | 22.5 | |
| hemlock | 23.7 | | black cherry | 29.3 | |
| Florida 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/horsechestnut | 34.9 | blackoak | laurel oak | 34.9 | |
| birch sp. | 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 | |
| hickory sp. | 39.9 | shagbark/mockernut | chinkapin oak | 37.4 | white oak |
| catalpa | 34.9 | black oak | water oak | 34.9 | |
| hackberry sp. | 30.6 | | chestnut oak | 35.6 | |
| eastern redbud | 34.9 | black oak | northern red oak | 34.9 | |
| flowering dogwood | 34.9 | black oak | shumard oak | 34.9 | black oak |
| common persimmon | 34.9 | black oak | post oak | 37.4 | |
| American beech | 34.9 | | black oak | 34.9 | |
| ash sp. | 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 sp. | 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 softwoods | 27.4 | redcedar |
| sweetgum | 28.7 | | other hardwoods | 34.9 | black oak |
| yellow-poplar | 24.9 | | other species | 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 Northeastern 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 ($\text{Vol} = 0.0015*D*D*H$) 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 categories 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 sp. | 8 | 5 | magnolia sp. | 1 | 4 |
| redcedar | 5 | 1 | cucumbertree | 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 sp. | 1 | 4 |
| spruce pine | 2 | 6 | mulberry sp. | 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 | eastern hophornbeam | 1 | 4 |
| eastern white pine | 2 | 6 | sourwood | 1 | 5 |
| loblolly pine | 3 | 6 | redbay | 1 | 5 |
| Virginia pine | 3 | 6 | sycamore | 1 | 5 |
| baldcypress | 1 | 1 | cottonwood | 1 | 5 |
| pondcypress | 1 | 1 | bigtooth aspen | 1 | 5 |
| hemlock | 4 | 5 | black cherry | 1 | 4 |
| Florida 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/horsechestnut | 1 | 5 | laurel oak | 1 | 4 |
| birch sp. | 1 | 5 | overcup oak | 1 | 3 |
| sweet birch | 1 | 5 | blackjack oak | 1 | 2 |
| American hornbeam | 1 | 4 | swamp chestnut oak | 1 | 3 |
| hickory sp. | 1 | 2 | chinkapin oak | 1 | 3 |
| catalpa | 1 | 4 | water oak | 1 | 3 |
| hackberry sp. | 1 | 4 | chestnut oak | 1 | 3 |
| eastern redbud | 1 | 5 | northern red oak | 1 | 4 |
| flowering dogwood | 1 | 5 | shumard oak | 1 | 4 |
| common persimmon | 1 | 4 | post oak | 1 | 3 |
| American beech | 1 | 4 | black oak | 1 | 4 |
| ash sp. | 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 sp. | 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 softwoods | 2 | 5 |
| sweetgum | 1 | 5 | other hardwoods | 1 | 5 |
| yellow-poplar | 1 | 4 | other species | 1 | 5 |

Table 4.16.7 - Years until all snag crown material of certain sizes has fallen by crown fall class

| Crown fall class | Foliage | Snag Crown Material Time to 100% Fallen (years) | | | | |
|-----------------------------|----------------|--|----------------|-------------|-------------|--------------|
| | | <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 |
| White Pine | 101-105 | 0.10 | 0.50 | 1.68 | 0.55 | 0.64 | 0.07 | 4.02 |
| Longleaf – slash pine | 141, 142 | 0.10 | 0.66 | 0.98 | 0.12 | 0.29 | 0.26 | 6.38 |
| Loblolly – shortleaf pine | 160s | 0.14 | 0.72 | 1.54 | 0.25 | 0.44 | 0.33 | 4.90 |
| Eastern redcedar | 181, 402 | 0.24 | 1.24 | 2.72 | 0.36 | 0.97 | 0.33 | 3.82 |
| 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 sp. | 0.052 | | magnolia sp. | 0.039 | |
| redcedar | 0.038 | | cucumbertree | 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 sp. | 0.043 | |
| spruce pine | 0.035 | | mulberry sp. | 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 | | eastern hop hornbeam | 0.037 | |
| eastern white pine | 0.045 | | sourwood | 0.036 | |
| loblolly pine | 0.052 | | red bay | 0.038 | |
| Virginia pine | 0.033 | | sycamore | 0.033 | |
| baldcypress | 0.025 | | cottonwood | 0.04 | |
| pondcypress | 0.042 | | bigtooth aspen | 0.039 | |
| hemlock | 0.039 | | black cherry | 0.03 | |
| Florida 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/horsechestnut | 0.036 | Ohio buckeye | laurel oak | 0.036 | |
| birch sp. | 0.033 | | overcup oak | 0.039 | |
| sweet birch | 0.03 | | blackjack oak | 0.037 | |
| American hornbeam | 0.03 | | swamp chestnut oak | 0.046 | |
| hickory sp. | 0.04 | shagbark hickory | chinkapin oak | 0.042 | |
| catalpa | 0.037 | | water oak | 0.036 | |
| hackberry sp. | 0.036 | sugarberry | chestnut oak | 0.049 | |
| eastern redbud | 0.035 | | northern red oak | 0.042 | |

| Species | Multiplier (V_{sp}) | Species used | Species | Multiplier (V_{sp}) | Species used |
|-------------------|--|---------------------|-----------------|--|---------------------|
| flowering dogwood | 0.041 | | shumard oak | 0.037 | |
| common persimmon | 0.041 | | post oak | 0.044 | |
| american beech | 0.025 | | black oak | 0.045 | |
| ash sp. | 0.042 | | live oak | 0.043 | |
| white ash | 0.042 | | black locust | 0.049 | |
| black ash | 0.035 | | willow | 0.04 | black willow |
| green ash | 0.039 | | sassafras | 0.035 | |
| honeylocust | 0.038 | | basswood | 0.038 | American basswood |
| loblolly-bay | 0.038 | | elm sp. | 0.039 | |
| silverbell | 0.038 | | winged elm | 0.031 | |
| American holly | 0.042 | | American elm | 0.031 | |
| butternut | 0.041 | | slippery elm | 0.032 | |
| black walnut | 0.041 | | other softwoods | 0.038 | redcedar |
| sweetgum | 0.036 | | other hardwoods | 0.045 | black oak |
| yellow-poplar | 0.041 | | other species | 0.045 | black oak |

4.16.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.16.12). 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 | |
| 0.25 – 1 | | 0.11 | |
| 1 – 3 | 0.11 | 0.09 | |
| 3 – 6 | | | 0.02 |
| 6 – 12 | 0.11 | 0.07 | |
| > 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 species | 4 | magnolia species | 4 |
| redcedar species | 2 | cucumbertree | 4 |
| spruce species | 4 | southern magnolia | 4 |
| sand pine | 1 | sweetbay | 4 |
| shortleaf pine | 1 | bigleaf magnolia | 4 |
| slash pine | 1 | apple species | 3 |
| spruce pine | 1 | mulberry species | 2 |
| longleaf pine | 1 | water tupelo | 2 |
| table mountain pine | 1 | blackgum/black tupelo | 2 |
| pitch pine | 1 | swamp tupelo | 2 |
| pond pine | 1 | eastern hophornbeam | 3 |
| eastern white pine | 1 | sourwood | 4 |
| loblolly pine | 1 | redbay | 4 |
| Virginia pine | 1 | sycamore | 4 |
| baldcypress | 3 | cottonwood species | 4 |
| pondcypress | 3 | bigtooth aspen | 4 |
| hemlock species | 4 | black cherry | 2 |
| Florida 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/horsechestnut species | 4 | laurel oak | 3 |
| birch species | 4 | overcup oak | 3 |
| sweet birch | 4 | blackjack oak | 2 |
| American hornbeam | 3 | swamp chestnut oak | 3 |
| hickory species | 4 | chinkapin oak | 2 |
| catalpa | 2 | water oak | 2 |
| hackberry species | 4 | chestnut oak | 3 |
| eastern redbud | 3 | northern red oak | 3 |
| flowering dogwood | 3 | Shumard oak | 3 |
| common persimmon | 2 | post oak | 2 |
| American beech | 4 | black oak | 3 |
| ash species | 4 | live oak | 2 |
| white ash | 4 | black locust | 2 |
| black ash | 4 | willow species | 4 |
| green ash | 4 | sassafras | 2 |
| honeylocust | 2 | basswood species | 4 |
| loblolly-bay | 4 | elm species | 4 |
| silverbell | 4 | winged elm | 4 |
| American holly | 3 | American elm | 4 |
| butternut | 4 | slippery elm | 4 |
| black walnut | 2 | other softwoods | 1 |
| sweetgum | 4 | other hardwoods | 4 |

| Species | Decay Rate Class | Species | Decay Rate Class |
|---------------|------------------|---------------|------------------|
| yellow-poplar | 4 | other species | 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.

| Size Class | Moisture Group | | | |
|------------------------|----------------|----------|-----|-----|
| | 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.

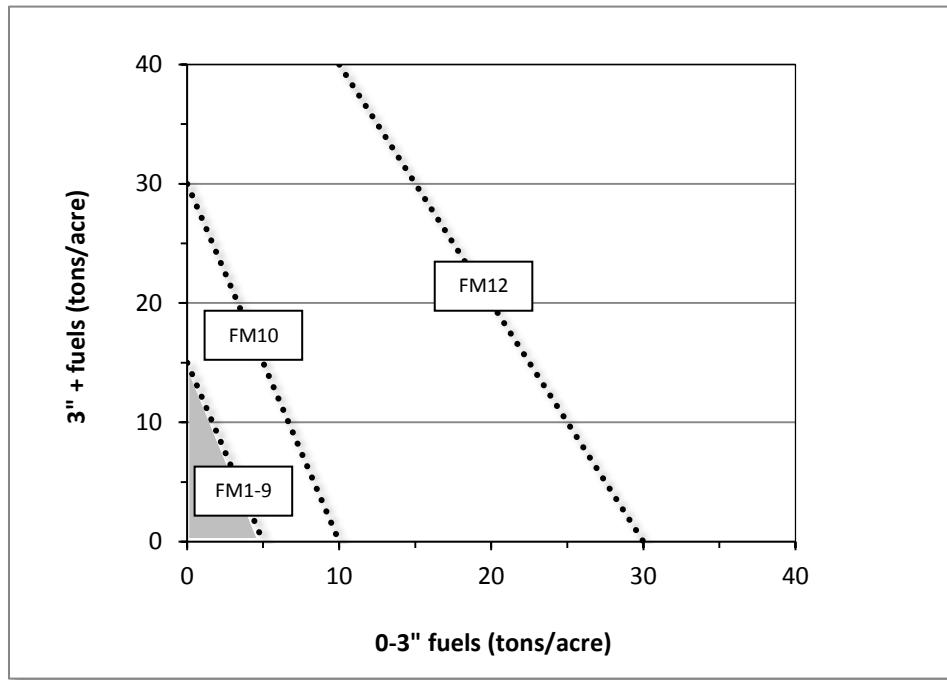


Figure 4.16.4 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in section 2.4.8. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines.

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 0-3" fuel <=5 tons and 3"+ moisture >20% 0-3" fuel <= 5 tons and 3"+ moisture <= 20% | 5 8 9 |
| Pine and Bottomland | 3"+ moisture >20% | 8 |
| Hardwoods | 3"+ moisture <= 20% | 9 |
| Pine-Bluestem | | 2 |
| Oak Savannah | | 2 |
| Eastern Redcedar | Avg. ht. of redcedar > 6 ft. Avg. ht. of redcedar <= 6 ft. | 4 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 softwoods’ and ‘other hardwoods’ 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 | <i>Pinus albicaulis</i> | |
| limber pine | <i>Pinus flexilis</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| singleleaf pinyon | <i>Pinus monophylla</i> | = UT singleleaf pinyon |
| blue spruce | <i>Picea pungens</i> | = TT Engelmann spruce |
| quaking aspen | <i>Populus tremuloides</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | = CI ponderosa pine |
| Utah juniper | <i>Juniperus osteosperma</i> | = UT Utah juniper |
| Rocky Mountain juniper | <i>Juniperus scopulorum</i> | = UT Rocky Mtn juniper |
| bigtooth maple | <i>Acer grandidentatum</i> | = SO bigleaf maple |
| Rocky Mountain maple | <i>Acer glabrum</i> | = UT quaking aspen |
| narrowleaf cottonwood | <i>Populus angustifolia</i> | = UT narrowleaf cottonwood |
| curlleaf mountain-mahogany | <i>Cercocarpus ledifolius</i> | = UT curlleaf mtn mahogany |
| other softwoods | | = TT whitebark pine |
| other hardwoods | | = 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 |
| curlleaf mountain-mahogany | 24 | 90 | 30 | 32 |
| other softwoods | 59 | 90 | — | 29 |
| other hardwoods | 6 | 5 | — | 29 |

¶ This value applies 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 |
| curlleaf mountain-mahogany | 1.00 | 1.00 | 1.0 |
| other softwoods | 0.41 | — | 0.9 |
| other hardwoods | 4.00 | — | 0.9 |

¶ This value applies 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 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 |
| curlleaf mountain-mahogany | 21.8 |
| other softwoods | 22.5 |
| other hardwoods | 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) |
| curlleaf mountain-mahogany | aspen; Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| other softwoods | whitebark pine; Brown (1978) |
| other hardwoods | 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 |
| curlleaf mountain-mahogany | 1 | 1 | 5 | 5 | 15 |
| other softwoods | 3 | 2 | 5 | 5 | 15 |
| other hardwoods | 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 I 0.40 | 0.10 1.00 | Use lodgepole pine |

| 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 Cl 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 | |
| curlleaf mtn-mahogany | E | 0.25 | 0.25 | Use quaking aspen, Ottmar and others 2000b |
| | I | 0.18 | 1.32 | |
| other softwoods | E | 0.20 | 0.10 | Use whitebark pine |
| | I | 0.40 | 1.00 | |
| other hardwoods | 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 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |

| 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 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| singleleaf pinyon | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| blue spruce | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| quaking aspen | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Engelmann spruce | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| subalpine fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| ponderosa pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| Utah juniper | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rocky Mtn juniper | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| bigtooth maple | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Rocky Mtn maple | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| narrowleaf cottonwood | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| curlleaf mtn-mahogany | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| other softwoods | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| other hardwoods | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |

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 |
| curlleaf mountain-mahogany | 0.044 |
| other softwoods | 0.030 |
| other hardwoods | 0.038 |

4.17.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.17.10). 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 | | |
| 0.25 – 1 | 0.054 | |
| 1 – 3 | 0.041 | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.0068 | |
| > 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 |
| curlleaf mountain-mahogany | 4 |
| other softwoods | 4 |
| other hardwoods | 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.

| Size Class | Moisture Group | | | |
|------------------------|----------------|-----|-------|-----|
| | 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.

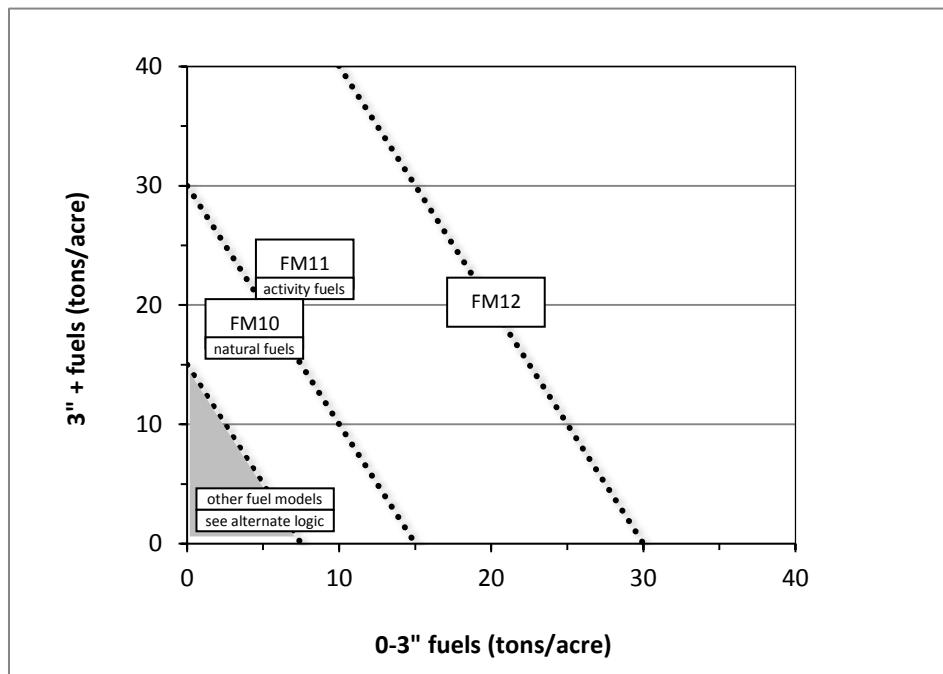
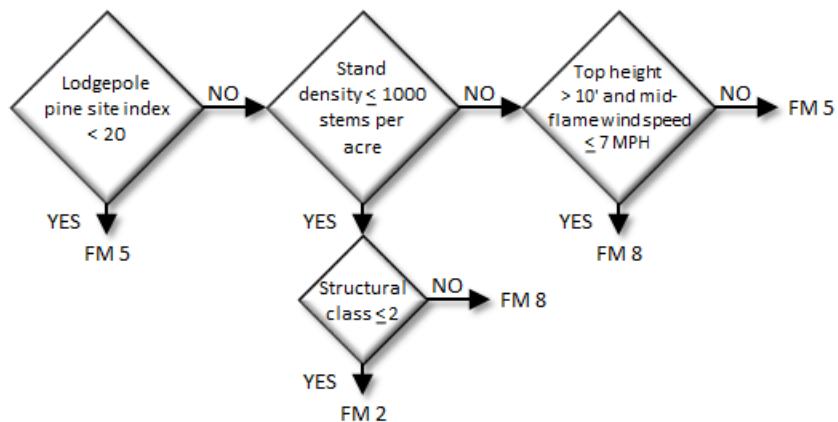
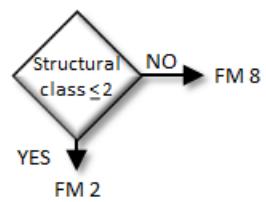
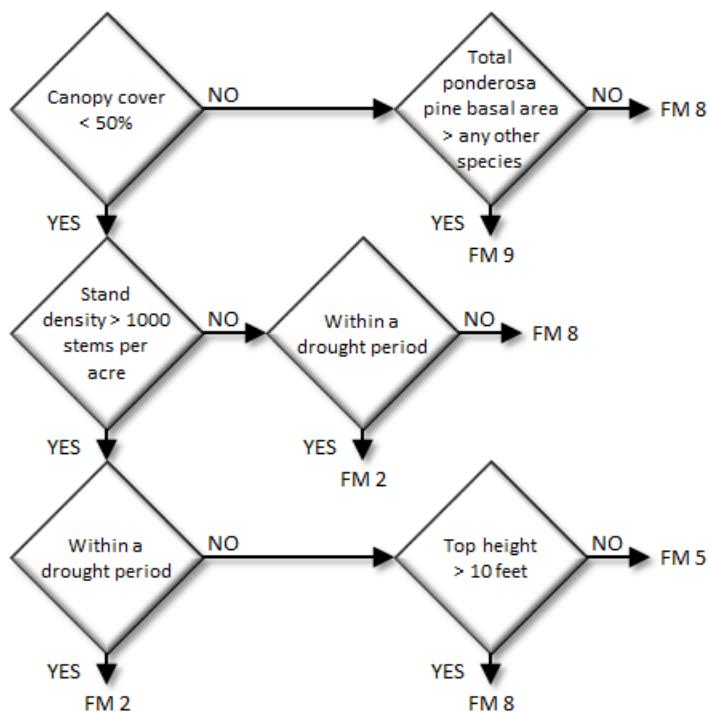
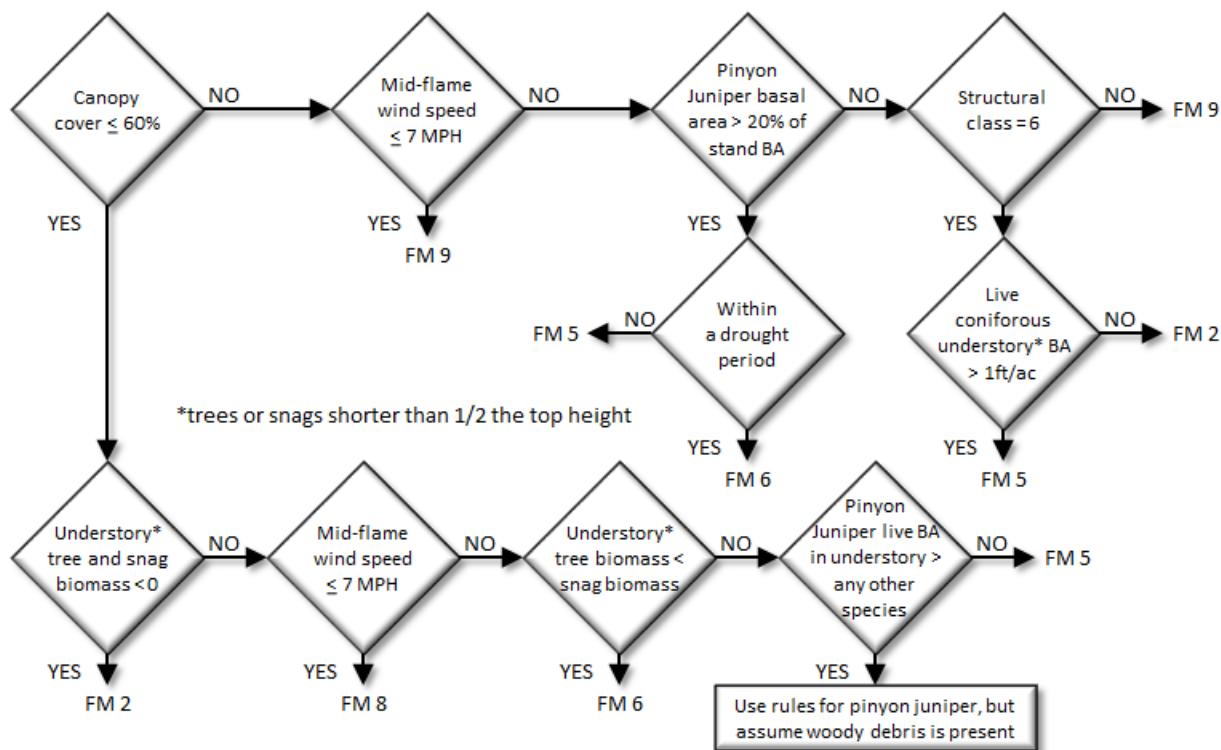


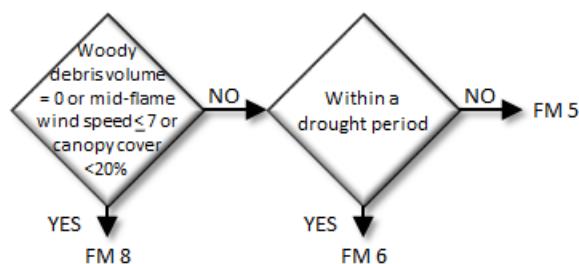
Figure 4.17.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.17.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

Lodgepole Pine Cover Type**Spruce Fir Cover Type****Mixed Conifer Cover Type**

Ponderosa Pine Cover Type



Pinyon Juniper Cover Type



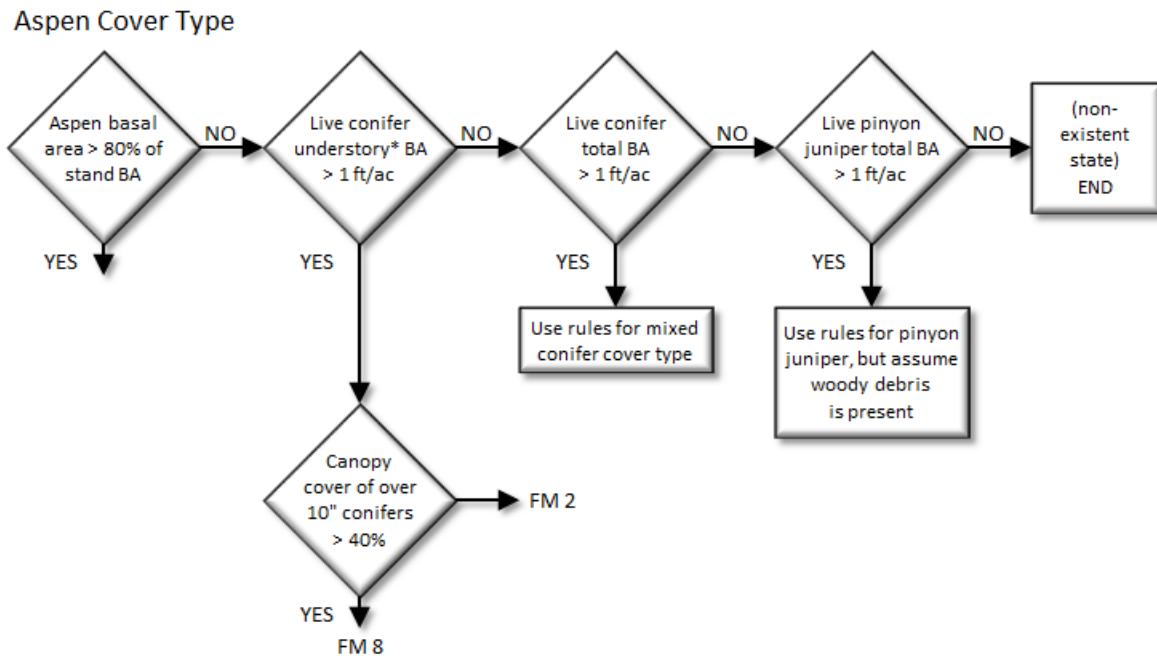


Figure 4.17.2 - Logic for modeling fire at “low” fuel loads in the TT-FFE variant.

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 softwoods’ and ‘other hardwoods’ 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 | <i>Pinus albicaulis</i> | |
| limber pine | <i>Pinus flexilis</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| white fir | <i>Abies concolor</i> | |
| blue spruce | <i>Picea pungens</i> | |
| quaking aspen | <i>Populus tremuloides</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Engelmann spruce | <i>Picea engelmannii</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| common pinyon | <i>Pinus edulis</i> | = common pinyon |
| western juniper | <i>Juniperus occidentalis</i> | = western juniper |
| Gambel oak | <i>Quercus spp.</i> | = western juniper |
| singleleaf pinyon | <i>Pinus monophylla</i> | = western juniper |
| Rocky Mountain juniper | <i>Juniperus scopulorum</i> | = western juniper |
| Utah juniper | <i>Juniperus osteosperma</i> | = western juniper |
| Great Basin bristlecone pine | <i>Pinus longaeva</i> | = CR bristlecone pine |
| narrowleaf cottonwood | <i>Populus angustifolia</i> | = CR cottonwoods |
| Fremont cottonwood | <i>Populus fremontii</i> | = CR cottonwoods |
| curlleaf mountain-mahogany | <i>Cercocarpus ledifolius</i> | = SO curlleaf mtn mah |
| bigtooth maple | <i>Acer grandidentatum</i> | = SO bigleaf maple |
| boxelder | <i>Acer negundo</i> | = CR cottonwoods |
| other softwoods | | = whitebark pine |
| other hardwoods | | = 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 |
| curlleaf mountain-mahogany | 31 | 90 | 30 | 39 |
| bigtooth maple | 31 | 90 | 30 | 39 |
| boxelder | 8 | 5 | — | 35 |
| other softwoods | 31 | 150 | 310 | 35 |
| other hardwoods | 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 |

| Species | Snag Fall | Height loss | Hard-to-Soft |
|------------------------------|------------------|--------------------|---------------------|
| western juniper | 1.0 | 0.0978 | 0.9 |
| Gambel oak | 2.5 | 1.494 | 0.9 |
| singleleaf pinyon | 1.0 | 0.0978 | 0.9 |
| 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 |
| curlleaf mountain-mahogany | 1.0 | 1.0 | 1.0 |
| bigtooth maple | 1.0 | 1.0 | 1.0 |
| boxelder | 4.0 | — | 0.9 |
| other softwoods | 1.0 | 0.0978 | 0.9 |
| other hardwoods | 2.5 | 1.494 | 0.9 |

§ This value applies 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 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/ft³) 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 |

| Species | Density (lb/ft ³) |
|------------------------------|----------------------------------|
| Great Basin bristlecone pine | 23.7 |
| narrowleaf cottonwood | 19.3 |
| Fremont cottonwood | 19.3 |
| curlleaf mountain-mahogany | 21.8 |
| bigtooth maple | 27.4 |
| boxelder | 19.3 |
| other softwoods | 22.5 |
| other hardwoods | 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) |
| curlleaf 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 softwoods | whitebark pine; Brown (1978) |
| other hardwoods | 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.

| Species | Live | Dead | | | |
|----------------|---------|---------|--------|---------|------|
| | Foliage | Foliage | <0.25" | 0.25–1" | > 1" |
| whitebark pine | 3 | 2 | 10 | 15 | 15 |

| Species | Live | | Dead | | |
|------------------------------|---------|---------|--------|---------|------|
| | Foliage | Foliage | <0.25" | 0.25-1" | > 1" |
| limber pine | 3 | 2 | 10 | 15 | 15 |
| Douglas-fir | 5 | 2 | 10 | 15 | 15 |
| white fir | 7 | 2 | 10 | 15 | 15 |
| 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 |
| curlleaf mountain-mahogany | 1 | 1 | 5 | 5 | 15 |
| bigtooth maple | 1 | 1 | 5 | 5 | 15 |
| boxelder | 1 | 1 | 10 | 10 | 10 |
| other softwoods | 3 | 2 | 10 | 15 | 15 |
| other hardwoods | 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 | |

| Species | | Herbs | Shrubs | Notes |
|------------------------------|---|--------------|---------------|--|
| subalpine fir | E | 0.15 | 0.20 | |
| | I | 0.30 | 2.00 | |
| ponderosa pine | E | 0.20 | 0.25 | |
| | 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 | |
| curlleaf 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 softwoods | E | 0.20 | 0.10 | Use whitebark pine |
| | I | 0.40 | 1.00 | |
| other hardwoods | 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.

| 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 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| limber pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | | | | | | | | 10.0 |

| Species | Size Class (in) | | | | | | | |
|------------------------------|-----------------|----------|-------|-------|--------|------|--------|------|
| | < 0.25 | 0.25 – 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 | Litter | Duff |
| white fir | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| blue spruce | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| quaking aspen | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| lodgepole pine | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| Engelmann spruce | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| subalpine fir | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| ponderosa pine | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| common pinyon | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| western juniper | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| Gambel oak | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| singleleaf pinyon | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| Rocky Mountain juniper | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| Utah juniper | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| Great Basin bristlecone pine | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| narrowleaf cottonwood | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| Fremont cottonwood | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| curlleaf mountain-mahogany | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| bigtooth maple | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 10.0 |
| boxelder | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| other softwoods | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| other hardwoods | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |

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 |
| curlleaf mountain-mahogany | 0.044 |
| bigtooth maple | 0.024 |
| boxelder | 0.038 |
| other softwoods | 0.030 |
| other hardwoods | 0.045 |

4.18.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.18.10). 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 | |
| 0.25 – 1 | | |
| 1 – 3 | 0.041 | |
| 3 – 6 | | 0.02 |
| 6 – 12 | 0.0068 | |
| > 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 **FUELDECAY** 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 |
| curlleaf mountain-mahogany | 4 |
| bigtooth maple | 4 |
| boxelder | 4 |
| other softwoods | 4 |
| other hardwoods | 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.

| Size Class | Moisture Group | | | |
|------------------------|----------------|-----|-------|-----|
| | 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.

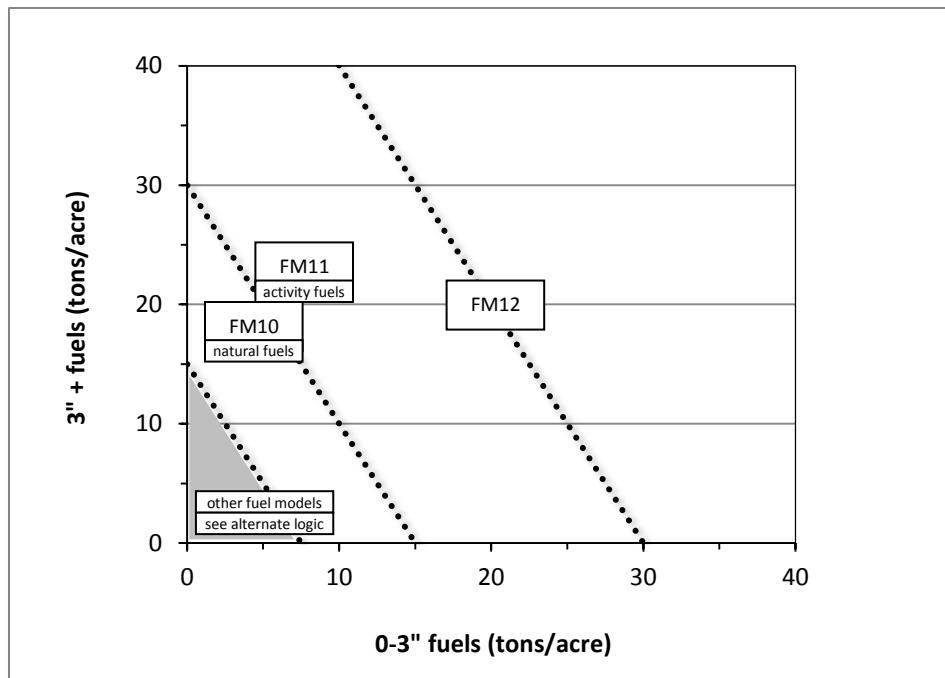
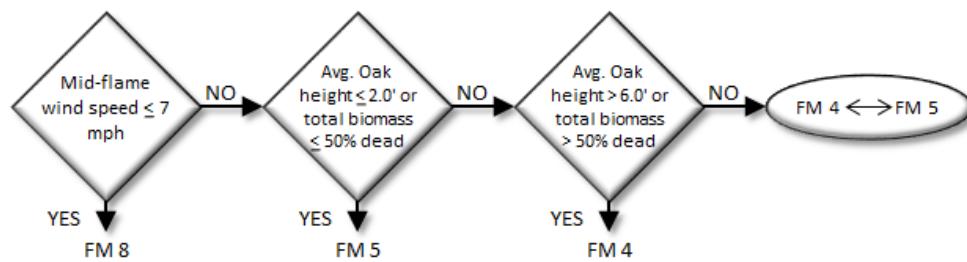
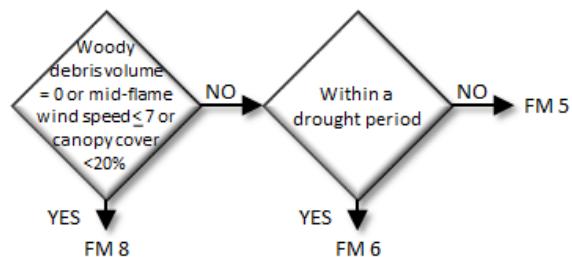


Figure 4.18.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.18.2. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further details).

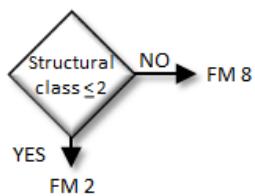
Oak Brush Cover Type



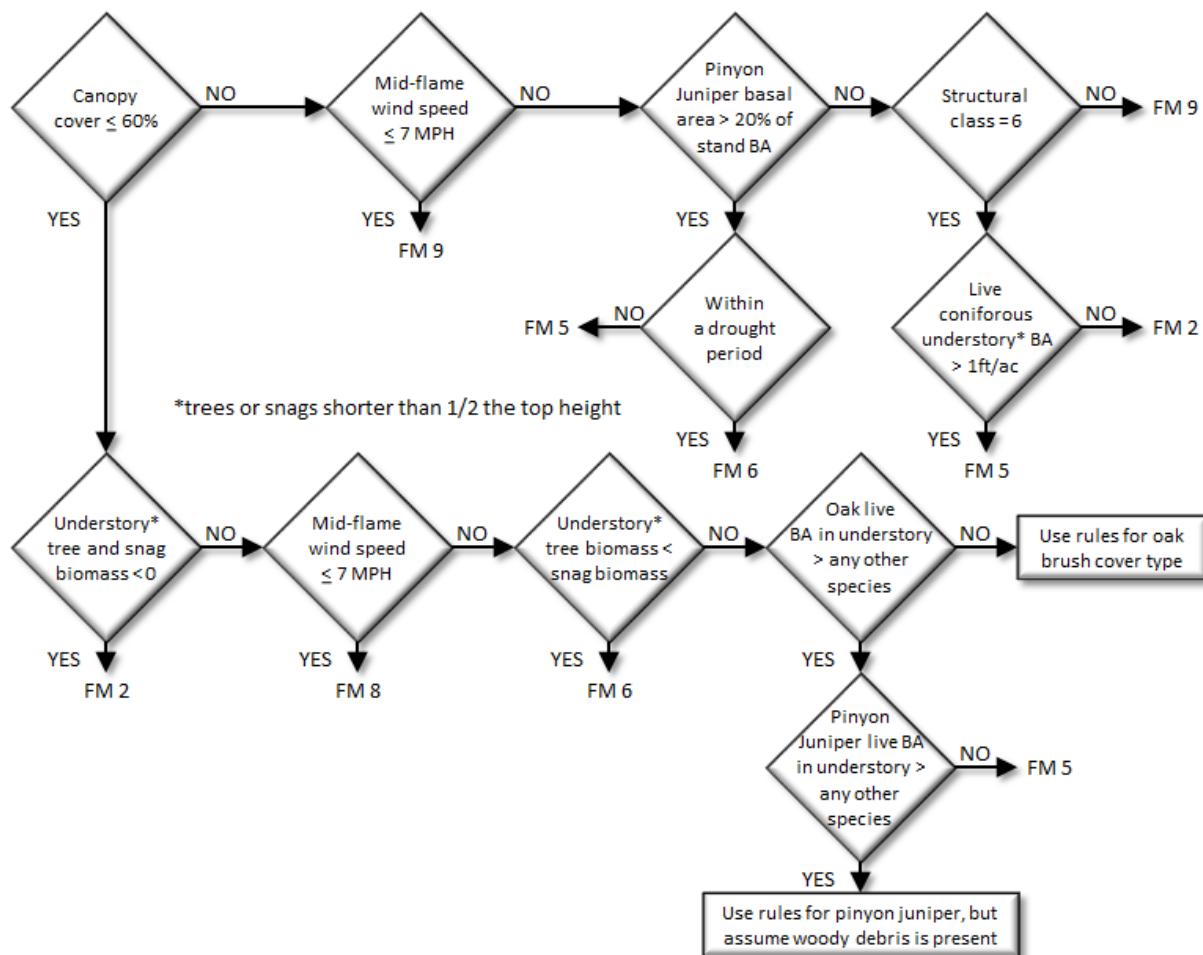
Pinyon Juniper Cover Type

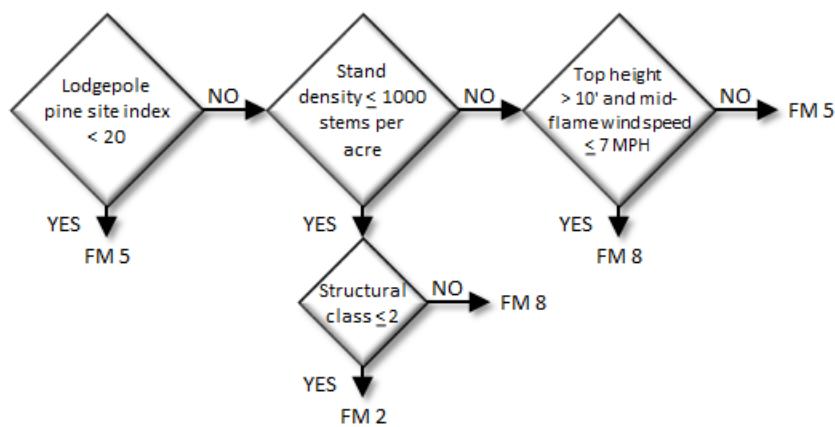
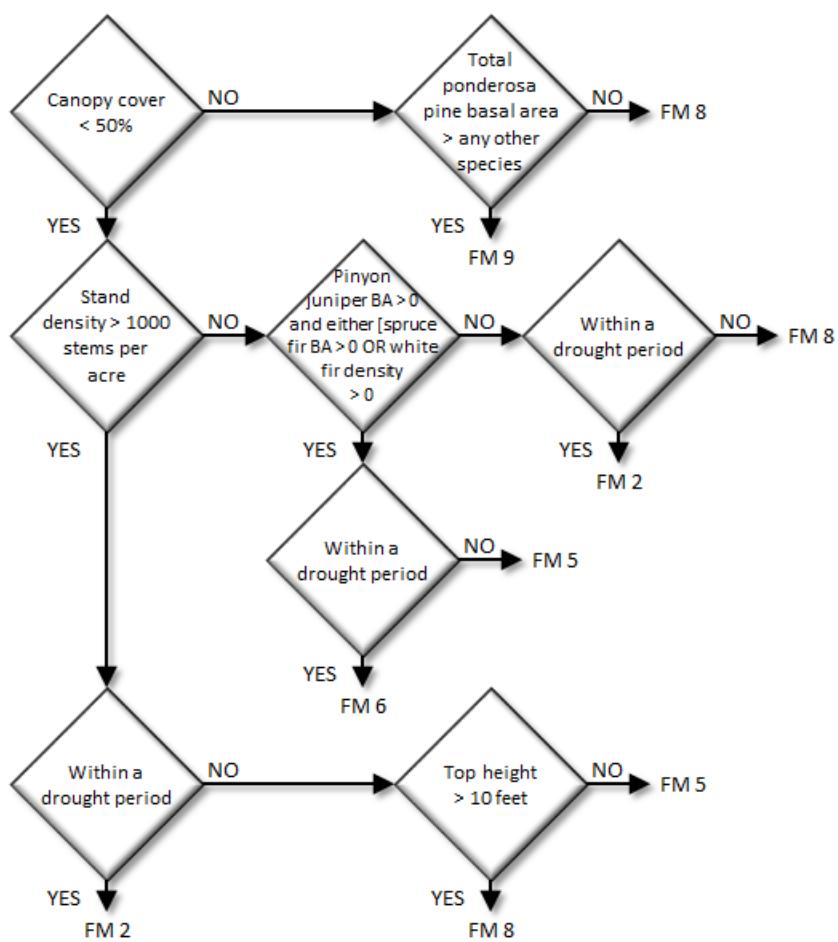


Spruce Fir Cover Type



Ponderosa Pine Cover Type



Lodgepole Pine Cover Type**Mixed Conifer Cover Type**

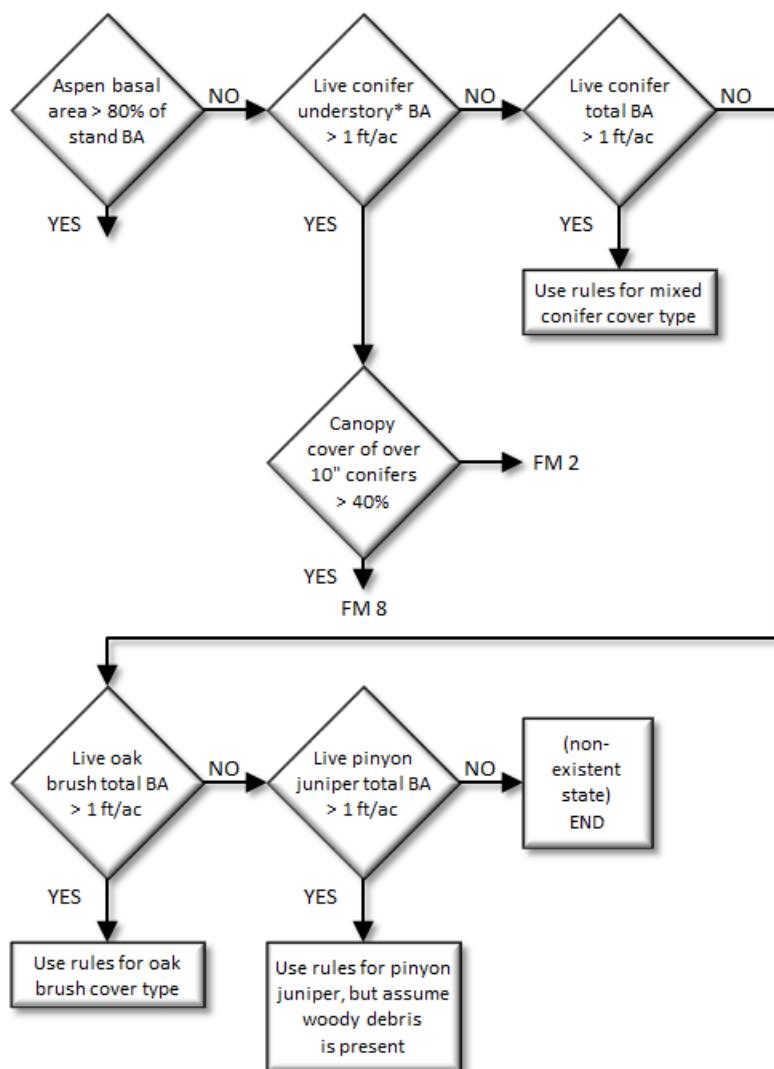
Aspen Cover Type

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 37 tree species shown in Table 4.19.1. One additional category, ‘other species’, 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 | <i>Abies amabilis</i> | |
| white fir | <i>Abies concolor</i> | |
| grand fir | <i>Abies grandis</i> | |
| subalpine fir | <i>Abies lasiocarpa</i> | |
| California red fir / Shasta red fir | <i>Abies magnifica</i> | |
| noble fir | <i>Abies procera</i> | |
| Alaska cedar / western larch | <i>Callitropsis nootkatensis / Larix occidentalis</i> | |
| incense-cedar | <i>Calocedrus decurrens</i> | = <i>Libocedrus decurrens</i> |
| Engelmann spruce / Sitka spruce | <i>Picea engelmannii / Picea sitchensis</i> | |
| lodgepole pine | <i>Pinus contorta</i> | |
| Jeffrey pine | <i>Pinus jeffreyi</i> | |
| sugar pine | <i>Pinus lambertiana</i> | |
| western white pine | <i>Pinus monticola</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| coast redwood | <i>Sequoia sempervirens</i> | |
| western redcedar | <i>Thuja plicata</i> | |
| western hemlock | <i>Tsuga heterophylla</i> | |
| mountain hemlock | <i>Tsuga mertensiana</i> | |
| bigleaf maple | <i>Acer macrophyllum</i> | |
| red alder | <i>Alnus rubra</i> | |
| white alder / Pacific madrone | <i>Alnus rhombifolia / Arbutus menziesii</i> | |
| paper birch | <i>Betula papyrifera</i> | |
| giant chinquapin / tanoak | <i>Chrysolepis chrysophylla / Lithocarpus densiflorus</i> | |
| quaking aspen | <i>Populus tremuloides</i> | |
| black cottonwood | <i>Populus trichocarpa</i> | |
| Oregon white oak / California black oak | <i>Quercus garryana / Quercus kelloggii</i> | |
| western juniper | <i>Juniperus occidentalis</i> | |
| subalpine larch | <i>Larix lyallii</i> | |
| whitebark pine | <i>Pinus albicaulis</i> | |
| knobcone pine | <i>Pinus attenuata</i> | |
| Pacific yew | <i>Taxus brevifolia</i> | |
| Pacific dogwood | <i>Cornus nuttallii</i> | |
| hawthorn species | <i>Crataegus spp.</i> | |
| bitter cherry | <i>Prunus emarginata</i> | |
| willow species | <i>Salix spp.</i> | |
| other species | | = 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/fmfc/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 ft³) used in the WC-FFE variant.

| Species | Density (lbs/ft ³) | Species | Density (lbs/ft ³) |
|-------------------------------------|-----------------------------------|---|-----------------------------------|
| Pacific silver fir | 24.9 | bigleaf maple | 27.4 |
| white fir | 23.1 | red alder | 23.1 |
| grand fir | 21.8 | white alder / Pacific madrone | 36.2 |
| subalpine fir | 19.3 | paper birch | 29.9 |
| California red fir / Shasta red fir | 22.5 | giant chinquapin / tanoak | 36.2 |
| noble fir | 23.1 | quaking aspen | 21.8 |
| Alaska cedar / western larch | 26.2 | black cottonwood | 19.3 |
| incense-cedar | 21.8 | Oregon white oak / California black oak | 37.4 |
| Engelmann spruce / Sitka 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 species | 27.4 |
| coast redwood | 21.2 | bitter cherry | 29.3 |
| western redcedar | 19.3 | willow species | 22.5 |
| western hemlock | 26.2 | | |

| Species | Density (lbs/ft ³) | Species | Density (lbs/ft ³) |
|------------------|-----------------------------------|---------------|-----------------------------------|
| mountain hemlock | 26.2 | other species | 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) |
| grand fir | Brown and Johnston (1976) |
| Subalpine fir | Brown and Johnston (1976) |
| California red fir / Shasta red fir | subalpine fir; Brown and Johnston (1976) |
| noble fir | grand fir; Brown and Johnston (1976) |
| Alaska cedar / western larch | western larch; Brown and Johnston (1976) |
| incense-cedar | based on western redcedar; Brown and Johnston (1976) |
| Engelmann spruce / | Brown and Johnston (1976) |
| Sitka spruce | |
| 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) |
| coast 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 / Pacific madrone | madrone; Snell and Little (1983) |
| paper birch | Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| giant chinquapin / tanoak | 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) |
| California black oak | |
| 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 species | Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| bitter cherry | Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| willow species | Jenkins et. al. (2003); Loomis and Roussopoulos (1978) |
| other species | 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.

| Species | Live | | Dead | | |
|-------------------------------------|---------|---------|--------|---------|------|
| | 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 / Shasta red fir | 7 | 2 | 5 | 5 | 15 |
| noble fir | 7 | 2 | 5 | 5 | 15 |
| Alaska cedar / western larch | 5 | 2 | 5 | 5 | 20 |
| incense-cedar | 5 | 1 | 5 | 5 | 20 |
| Engelmann spruce / Sitka 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 |
| coast 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 / Pacific madrone | 1 | 1 | 10 | 15 | 15 |
| paper birch | 1 | 1 | 10 | 15 | 15 |
| giant chinquapin / tanoak | 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 |
| California black oak | | | | | |
| 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 species | 1 | 1 | 10 | 15 | 15 |
| bitter cherry | 1 | 1 | 10 | 15 | 15 |
| willow species | 1 | 1 | 10 | 15 | 15 |
| other species | 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 |

| Species | | Herbs | Shrubs | Notes |
|---|---|--------------|---------------|--|
| | I | 0.30 | 2.00 | |
| white fir | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | Use grand fir |
| grand fir | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | |
| subalpine fir | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | Use grand fir |
| California red fir / Shasta red fir | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | Use grand fir |
| noble fir | E | 0.15 | 0.10 | |
| | I | 0.30 | 2.00 | Use grand fir |
| Alaska cedar / western larch | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use western redcedar |
| incense-cedar | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| Engelmann spruce / Sitka 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 | |
| | I | 0.25 | 0.10 | Use ponderosa pine |
| sugar pine | E | 0.20 | 0.25 | |
| | I | 0.25 | 0.10 | Use ponderosa pine |
| 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 | |
| coast redwood | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| 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 | |
| | I | 0.30 | 2.00 | Use grand fir |
| bigleaf maple | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| red alder | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| white alder / Pacific madrone | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| paper birch | E | 0.20 | 0.20 | |
| | I | 0.40 | 2.00 | Use Douglas-fir |
| giant chinquapin / tanoak | 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 / California black 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 | |
| | I | 0.40 | 2.00 | Use western larch |

| Species | | Herbs | Shrubs | Notes |
|------------------|---|--------------|---------------|---|
| 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 species | 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 species | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and others 2000b |
| | I | 0.18 | 1.32 | |
| other species | 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.

| Species | Size Class (in) | | | | | | | |
|-------------------------------------|------------------------|----------|-------|-------|--------|------|--------|------|
| | < 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 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| white fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| grand fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| subalpine fir | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| California red fir / Shasta red fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| noble fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| Alaska cedar / western larch | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| incense-cedar | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| Engelmann spruce / Sitka spruce | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| lodgepole pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 12.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Jeffrey pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |

| Species | Size Class (in) | | | | | | | |
|--|-----------------|----------|-------|-------|--------|------|--------|------|
| | < 0.25 | 0.25 – 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 | Litter | Duff |
| sugar pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| western white pine | E | 1.0 | 1.0 | 1.6 | 10.0 | 10.0 | 10.0 | 0.8 |
| | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 6.0 | 12.0 |
| ponderosa pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.8 |
| Douglas-fir | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| coast redwood | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| western redcedar | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| western hemlock | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 10.0 | 1.0 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 6.0 | 0.5 |
| mountain hemlock | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| bigleaf maple | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| red alder | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 5.0 | 0.8 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 1.4 | 3.0 | 0.4 |
| white alder / Pacific madrone | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| paper birch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| giant chinquapin / tanoak | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| quaking aspen | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| black cottonwood | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| Oregon white oak / California black oak | E | 0.7 | 0.7 | 0.8 | 1.2 | 1.2 | 0.5 | 1.4 |
| | I | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.0 | 0.5 |
| western juniper | E | 0.1 | 0.2 | 0.4 | 0.5 | 0.8 | 1.0 | 0.1 |
| | I | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| subalpine larch | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| whitebark pine | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| knobcone pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 12.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Pacific yew | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| Pacific dogwood | E | 2.2 | 2.2 | 5.2 | 15.0 | 20.0 | 15.0 | 1.0 |
| | I | 1.6 | 1.6 | 3.6 | 6.0 | 8.0 | 6.0 | 0.5 |
| hawthorn species | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| bitter cherry | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| willow species | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| other species | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |

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 / Pacific madrone | 0.060 |
| subalpine fir | 0.041 | paper birch | 0.027 |
| California red fir / Shasta red fir | 0.039 | giant chinquapin / tanoak | 0.045 |
| noble fir | 0.045 | quaking aspen | 0.044 |
| Alaska cedar / western larch | 0.022 | black cottonwood | 0.044 |
| incense-cedar | 0.081 | Oregon white oak / California black oak | 0.029 |
| Engelmann spruce / Sitka spruce | 0.036 | western juniper | 0.025 |
| lodgepole pine | 0.028 | subalpine larch | 0.050 |
| Jeffrey pine | 0.068 | whitebark pine | 0.030 |
| sugar pine | 0.072 | knobcone pine | 0.030 |
| western white pine | 0.035 | Pacific yew | 0.025 |
| ponderosa pine | 0.063 | Pacific dogwood | 0.062 |
| Douglas-fir | 0.063 | hawthorn species | 0.038 |
| coast redwood | 0.081 | bitter cherry | 0.062 |
| western redcedar | 0.035 | willow species | 0.041 |
| western hemlock | 0.040 | other species | 0.044 |
| mountain hemlock | 0.040 | | |

4.19.5 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 (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 | | | | |
| | 0.25 – 1 | 0.117 | 0.138 | 0.165 | 0.223 |
| | 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 | | | | |
| | 0.25 – 1 | 0.060 | 0.071 | 0.085 | 0.116 |
| | 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 | | | | |
| | 0.25 – 1 | 0.069 | 0.081 | 0.097 | 0.154 |
| | 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 | | | | |
| | 0.25 – 1 | 0.083 | 0.098 | 0.117 | 0.159 |
| | 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 | | | | |
| | 0.25 – 1 | 0.052 | 0.061 | 0.073 | 0.098 |
| | 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 | | | | |
| | 0.25 – 1 | 0.057 | 0.067 | 0.080 | 0.108 |
| | 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 | | | | |
| | 0.25 – 1 | 0.060 | 0.071 | 0.085 | 0.116 |
| | 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 |
| | 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 / Pacific madrone | 4 |
| subalpine fir | 3 | paper birch | 4 |
| California red fir/Shasta red fir | 3 | giant chinquapin / tanoak | 3 |
| noble fir | 3 | quaking aspen | 4 |
| Alaska cedar / western larch | 1 | black cottonwood | 4 |
| incense-cedar | 1 | Oregon white oak / California black oak | 3 |
| Engelmann spruce / Sitka spruce | 2 | | |
| lodgepole pine | 2 | western juniper | 1 |
| Jeffrey pine | 3 | subalpine larch | 1 |
| sugar pine | 1 | whitebark pine | 1 |
| western white pine | 1 | knobcone pine | 2 |
| ponderosa pine | 3 | Pacific yew | 1 |
| Douglas-fir | 1 | Pacific dogwood | 4 |
| coast redwood | 1 | hawthorn species | 4 |
| western redcedar | 1 | bitter cherry | 4 |
| western hemlock | 2 | willow species | 4 |
| mountain hemlock | 2 | other species | 4 |

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.

| Size Class | Moisture Group | | | |
|------------------------|-----------------------|------------|--------------|------------|
| | 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 |
|-------------------|--------|-------------------|--------|-------------------|--------|-------------------|--------|
| 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.

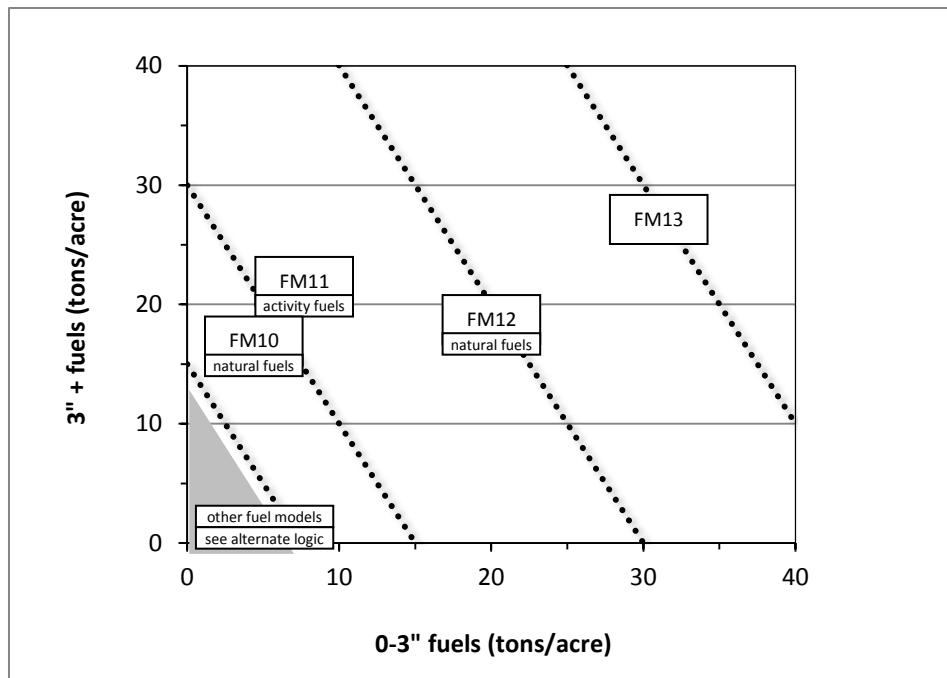


Figure 4.19.1 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.19.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description section 4.8 for further details).

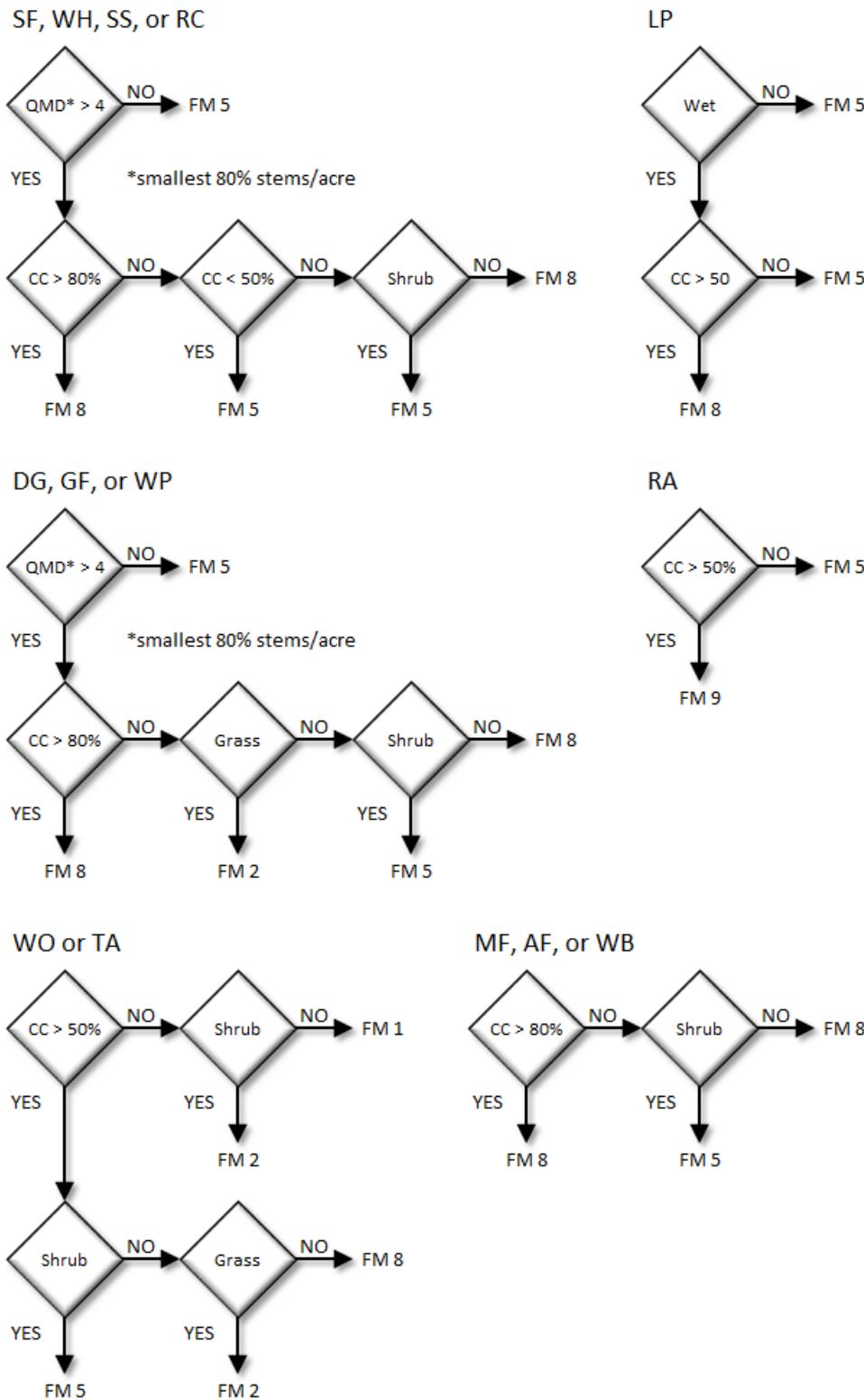


Figure 4.19.2 - Fuel models for the WC-FFE variant.

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 hardwoods’ and ‘other softwoods’ 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 | <i>Pinus lambertiana</i> | |
| Douglas-fir | <i>Pseudotsuga menziesii</i> | |
| white fir | <i>Abies concolor</i> | |
| giant sequoia | <i>Sequoiadendron giganteum</i> | = <i>Sequoia gigantea</i> |
| incense-cedar | <i>Calocedrus decurrens</i> | = <i>Libocedrus decurrens</i> |
| Jeffrey pine | <i>Pinus jeffreyi</i> | |
| California red fir | <i>Abies magnifica</i> | |
| ponderosa pine | <i>Pinus ponderosa</i> | |
| lodgepole pine | <i>Pinus contorta</i> | use CA lodgepole pine |
| whitebark pine | <i>Pinus albicaulis</i> | use CA/SO whitebark pine |
| western white pine | <i>Pinus monticola</i> | use CA/SO western white pine |
| singleleaf pinyon | <i>Pinus monophylla</i> | use <i>Pinus</i> sp (as done in UT) |
| Pacific silver fir | <i>Abies amabilis</i> | use SO Pacific silver fir |
| knobcone pine | <i>Pinus attenuata</i> | use CA knobcone pine |
| foxtail pine | <i>Pinus balfouriana</i> | use CA knobcone pine |
| Coulter pine | <i>Pinus coulteri</i> | use CA Coulter pine |
| limber pine | <i>Pinus flexilis</i> | use CA knobcone pine |
| Monterey pine | <i>Pinus radiata</i> | use CA Monterey pine |
| Gray or California foothill pine | <i>Pinus sabiniana</i> | use CA gray pine |
| Washoe pine | <i>Pinus washoensis</i> | use CA knobcone pine |
| Great Basin bristlecone pine | <i>Pinus longaeva</i> | use UT bristlecone pine |
| bigcone Douglas-fir | <i>Pseudotsuga macrocarpa</i> | use Douglas-fir |
| redwood | <i>Sequoia sempervirens</i> | use giant sequoia |
| mountain hemlock | <i>Tsuga mertensiana</i> | use CA/SO mountain hemlock |
| western juniper | <i>Juniperus occidentalis</i> | use CA western juniper |
| Utah juniper | <i>Juniperus osteosperma</i> | use CA western juniper |
| California juniper | <i>Juniperus californica</i> | use CA western juniper |
| California live oak | <i>Quercus agrifolia</i> | use CA California live oak |
| canyon live oak | <i>Quercus chrysolepis</i> | use CA canyon live oak |
| blue oak | <i>Quercus douglasii</i> | use CA blue oak |
| California black oak | <i>Quercus kelloggii</i> | |
| California white oak / valley oak | <i>Quercus lobata</i> | use CA valley oak |
| interior live oak | <i>Quercus wislizeni</i> | use CA interior live oak |
| tanoak | <i>Lithocarpus densiflorus</i> | |
| giant chinquapin | <i>Chrysolepis chrysophylla</i> | use CA/SO giant chinquapin |
| quaking aspen | <i>Populus tremuloides</i> | use CA/SO quaking aspen |
| California-laurel | <i>Umbellularia californica</i> | use CA California-laurel |
| Pacific madrone | <i>Arbutus menziesii</i> | use CA/NC Pacific madrone |
| Pacific dogwood | <i>Cornus nuttallii</i> | use CA Pacific dogwood |
| bigleaf maple | <i>Acer macrophyllum</i> | use CA/SO bigleaf maple |
| curlleaf mountain-mahogany | <i>Cercocarpus ledifolius</i> | use SO curlleaf mtn-mahogany |
| other softwoods | | use lodgepole pine |
| other hardwoods | | 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 | — |
| Gray or 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 | — |
| California white oak / 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 | — |
| curlleaf mountain-mahogany | 31 | 90 | 30 | 39 |
| other softwoods | 25 | 100 | 30 | — |
| other hardwoods | 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 | — |
| Gray or 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 | — |
| California white oak / 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 | — |
| curlleaf mountain-mahogany | 1.000 | 1.00 | 1.0 |
| other softwoods | 1.235 | 1.00 | — |
| other hardwoods | 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 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 oven-dry 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/ft³) 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 |
| Gray or 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 |
| California white oak / 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 |
| curlleaf mountain-mahogany | 21.8 |
| other softwoods | 23.7 |
| 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 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) |
| Gray or 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 |
| California white oak / 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 |
| curlleaf mountain-mahogany | aspen; Jenkins et. al. (2003), Loomis and Roussopoulos (1978) |
| other softwoods | lodgepole pine (Brown and Johnston 1976) |
| other hardwoods | 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 |
| Gray or 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 |
| California white oak / 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 |
| curlleaf mountain-mahogany | 1 | 1 | 10 | 15 | 15 |
| other softwoods | 3 | 3 | 10 | 15 | 15 |
| other hardwoods | 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 | |
| gray or 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 | use CA western juniper, Ottmar |

| Species | | Herbs | Shrubs | Notes |
|-----------------------------------|---|--------------|---------------|------------------------------------|
| | I | 0.10 | 2.06 | and others (1998) |
| Utah juniper | E | 0.14 | 0.35 | use CA western juniper, Ottmar |
| | I | 0.10 | 2.06 | and others (1998) |
| California juniper | E | 0.14 | 0.35 | use CA western juniper, Ottmar |
| | I | 0.10 | 2.06 | and others (1998) |
| California live oak | E | 0.23 | 0.22 | use CA California live oak: Gambel |
| | I | 0.55 | 0.35 | oak, Ottmar and others (2000b) |
| canyon live oak | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and |
| | I | 0.18 | 2.00 | others 2000b (modified) |
| blue oak | E | 0.23 | 0.22 | use CA blue oak: Gambel oak, |
| | I | 0.55 | 0.35 | Ottmar and others (2000b) |
| California black oak | E | 0.23 | 0.22 | Gambel oak, CR-FFE, Ottmar and |
| | I | 0.55 | 0.35 | others (2000b) |
| California white oak \ valley oak | E | 0.23 | 0.22 | use CA California white / valley |
| | I | 0.55 | 0.35 | oak: Gambel oak, Ottmar and |
| | | | | others (2000b) |
| interior live oak | E | 0.23 | 0.22 | use CA interior live oak: Gambel |
| | I | 0.55 | 0.35 | oak, Ottmar and others (2000b) |
| tanoak | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and |
| | I | 0.18 | 2.00 | others 2000b (modified) |
| giant chinquapin | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and |
| | I | 0.18 | 2.00 | others 2000b (modified) |
| 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 | |
| curlleaf mountain-mahogany | E | 0.25 | 0.25 | Use quaking aspen - Ottmar and |
| | I | 0.18 | 1.32 | others 2000b |
| other softwoods | E | 0.20 | 0.10 | lodgepole pine, NI-FFE |
| | I | 0.40 | 1.00 | |
| other hardwoods | E | 0.23 | 0.22 | use California black oak: Gambel |
| | I | 0.55 | 0.35 | oak, 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 4.20.8). 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 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| white fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| giant sequoia | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| incense-cedar | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Jeffrey pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| California red fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| ponderosa pine | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| lodgepole pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| whitebark pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| western white pine | E | 1.0 | 1.0 | 1.6 | 10.0 | 10.0 | 10.0 | 0.8 |
| | I | 0.6 | 0.6 | 0.8 | 6.0 | 6.0 | 6.0 | 0.4 |
| singleleaf pinyon | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Pacific silver fir | E | 0.7 | 0.7 | 3.0 | 7.0 | 7.0 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 2.0 | 2.8 | 2.8 | 0.0 | 0.3 |
| knobcone pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| foxtail pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| Coulter pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| limber pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| Monterey pine | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| gray or California foothill pine | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| Washoe pine | E | 0.7 | 0.7 | 1.6 | 2.5 | 2.5 | 0.0 | 1.4 |
| | I | 0.1 | 0.1 | 0.2 | 0.5 | 0.5 | 0.0 | 0.5 |
| Great Basin bristlecone pine | E | 0.2 | 0.8 | 2.3 | 1.4 | 3.0 | 0.0 | 0.5 |
| | I | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| bigcone Douglas-fir | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| redwood | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| mountain hemlock | E | 1.1 | 1.1 | 2.2 | 10.0 | 10.0 | 0.0 | 0.6 |
| | I | 0.7 | 0.7 | 1.6 | 4.0 | 4.0 | 0.0 | 0.3 |
| western juniper | E | 0.1 | 0.2 | 0.4 | 0.5 | 0.8 | 1.0 | 0.1 |
| | I | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Utah juniper | E | 0.1 | 0.2 | 0.4 | 0.5 | 0.8 | 1.0 | 0.1 |
| | I | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| California juniper | E | 0.1 | 0.2 | 0.4 | 0.5 | 0.8 | 1.0 | 0.1 |
| | I | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 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 |
| | I | 0.1 | 0.1 | 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 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| blue oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| California black oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 2.9 | 0.0 |
| California white oak / valley oak | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 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 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| tanoak | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| giant chinquapin | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| quaking aspen | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| California-laurel | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Pacific madrone | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| Pacific dogwood | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| bigleaf maple | E | 0.9 | 0.9 | 1.6 | 3.5 | 3.5 | 0.0 | 0.6 |
| | I | 0.5 | 0.5 | 1.0 | 1.4 | 1.4 | 0.0 | 0.3 |
| curlleaf mountain-mahogany | E | 0.2 | 0.6 | 2.4 | 3.6 | 5.6 | 0.0 | 1.4 |
| | I | 0.1 | 0.4 | 5.0 | 2.2 | 2.3 | 0.0 | 0.8 |
| other softwoods | E | 0.9 | 0.9 | 1.2 | 7.0 | 8.0 | 0.0 | 0.6 |
| | I | 0.6 | 0.7 | 0.8 | 2.8 | 3.2 | 0.0 | 0.3 |
| other hardwoods | E | 0.3 | 0.7 | 1.4 | 0.2 | 0.1 | 0.0 | 3.9 |
| | I | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |

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 |
| Gray or 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 |
| California white oak / 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 |
| curlleaf mountain-mahogany | 0.044 |
| other softwoods | 0.028 |
| other hardwoods | 0.030 |

4.20.5 Decay Rate

Decay of down material is simulated by applying loss rates by size class as described in section 2.4.5 (Table 4.20.10). 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 |
| Gray or 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 |
| California white oak / 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 |
| curlleaf mountain-mahogany | 4 |
| other softwoods | 4 |
| other hardwoods | 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.

| Size Class | Moisture Group | | | |
|-------------------------|----------------|-----|-------|-----|
| | 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 class 3 (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.

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.

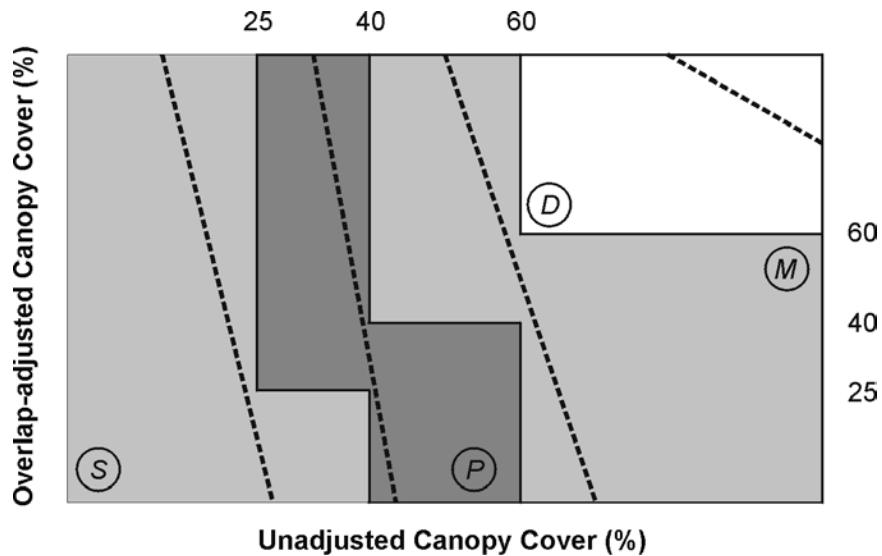


Figure 4.20.1 - Two measures of canopy cover, unadjusted and overlap-adjusted percent canopy cover, are used to derive weighted estimates of the four CWHR density classes. (S = sparse, P = open, M = moderate and D = dense)

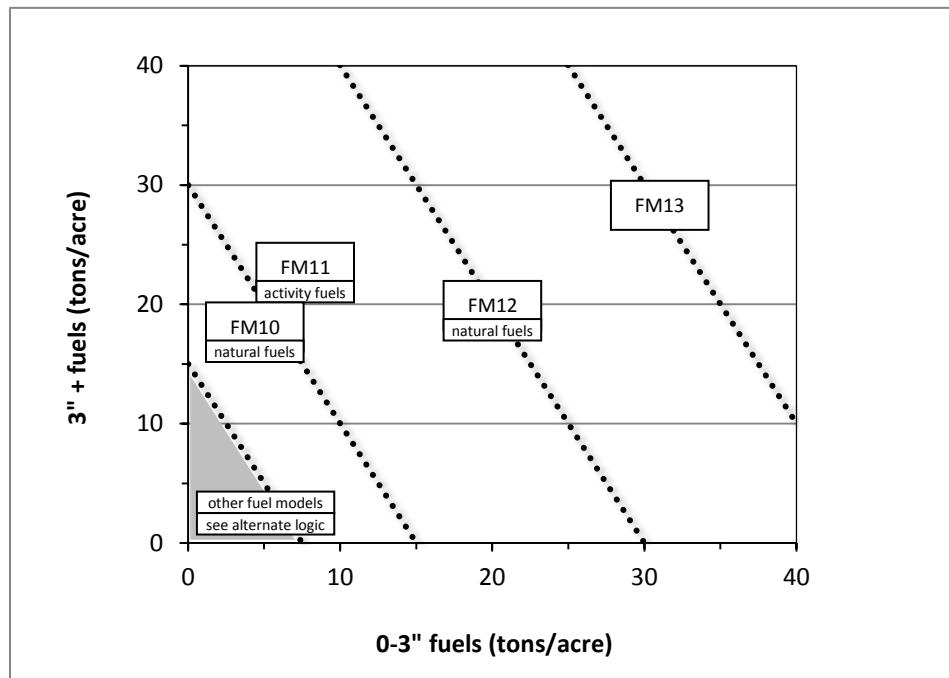


Figure 4.20.2 - If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.20.15. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see section 2.4.8 for further 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 | | | |
|-----------------------|---|---|---|---|---|----|----|----|---|----|----|---|---|----|----|---|----|
| 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 |
| Pine – west side | 9 | 5 | 5 | 9 | 9 | 26 | 26 | 25 | 9 | 26 | 26 | 8 | 8 | 26 | 26 | 8 | 8 |
| Red fir | 8 | 8 | 8 | 8 | 8 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| White fir – east side | 8 | 8 | 8 | 8 | 8 | 11 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| White fir – west side | 8 | 5 | 5 | 8 | 8 | 11 | 11 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Douglas-fir | 8 | 5 | 5 | 8 | 8 | 5 | 5 | 8 | 8 | 11 | 11 | 9 | 8 | 11 | 11 | 9 | 8 |
| Giant sequoia | 8 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Jeffrey pine | 9 | 9 | 9 | 9 | 9 | 2 | 2 | 2 | 9 | 2 | 2 | 2 | 9 | 2 | 2 | 2 | 9 |
| Hardwoods | 8 | 5 | 5 | 9 | 9 | 11 | 11 | 11 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Lodgepole pine | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Pine mixed – conifer | 9 | 5 | 5 | 9 | 9 | 26 | 26 | 25 | 9 | 26 | 26 | 8 | 8 | 26 | 26 | 8 | 8 |
| Fir mixed – conifer | 8 | 9 | 9 | 8 | 8 | 26 | 26 | 11 | 8 | 5 | 5 | 8 | 8 | 5 | 5 | 8 | 8 |
| Other softwood | 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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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-storyed 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, whichever 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 TPA_i be number of trees per acre represented for sample tree i and let X_i 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 λ_i 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 H_j, 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, $H_j = \infty$.

Next, T_j , 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).

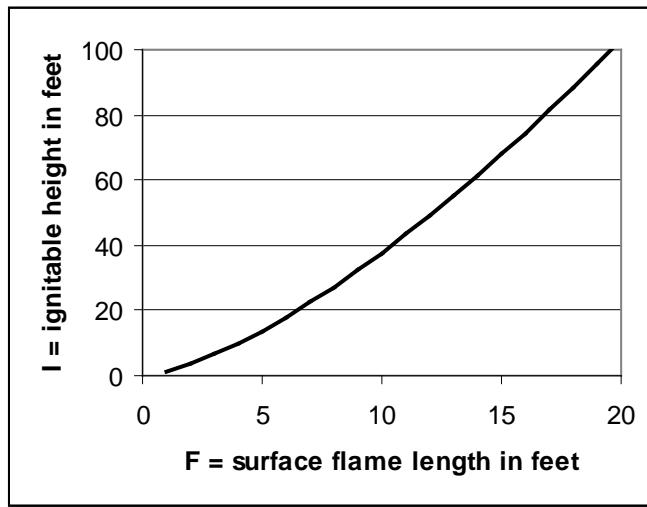


Figure A.2.1 - The relationship between surface flame length (F) and the height off the ground that flame can ignite (I).

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 H_j between 0.0 and 3.0. When values of H_j 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 H_j 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.

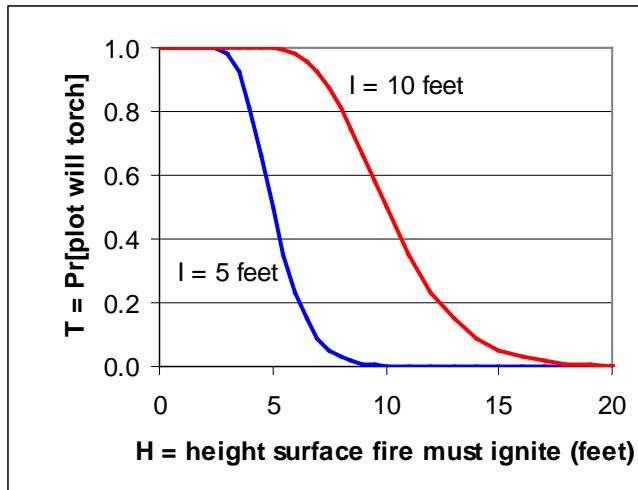


Figure A.2.2 - The probability that plot j will torch (T_j) is illustrated for two values of average ignition height (I). H_j is the height the surface fire must be able to ignite (feet) and is a function of the vertical crown structure on virtual plot j.

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 T_j is known for each plot, P-Torch ($\text{Pr}[\text{Torch}]$) 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:

$$\text{Pr}[\text{Torch}] = \sum_{i=1}^N T_i \times \frac{1}{N}$$

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.

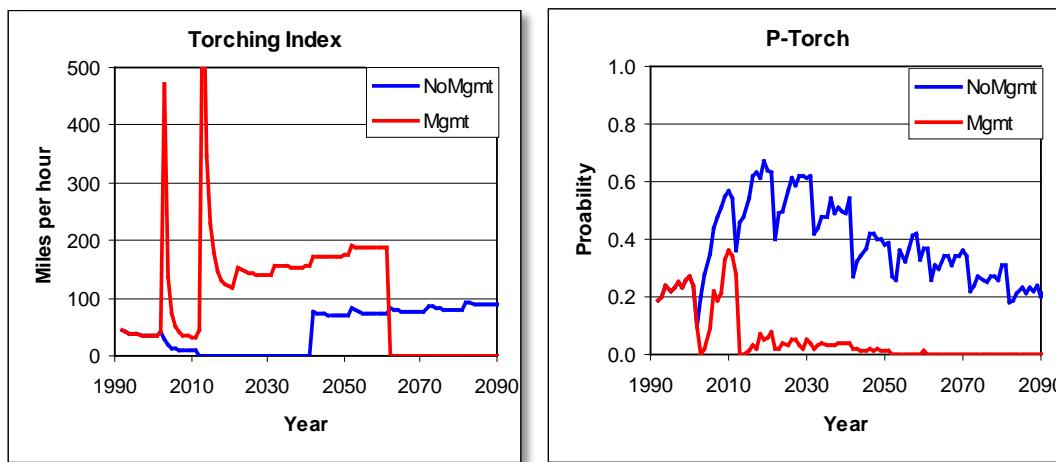


Figure A.3.1 - TI and P-Torch for stand 3024006. Both indices indicate that prescribed fire reduced the hazard of torching, but TI showed that the hazard greatly increased in 2062 when a few understory trees caused the CBH to drop to zero. P-Torch more realistically indicates that those trees do not 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.

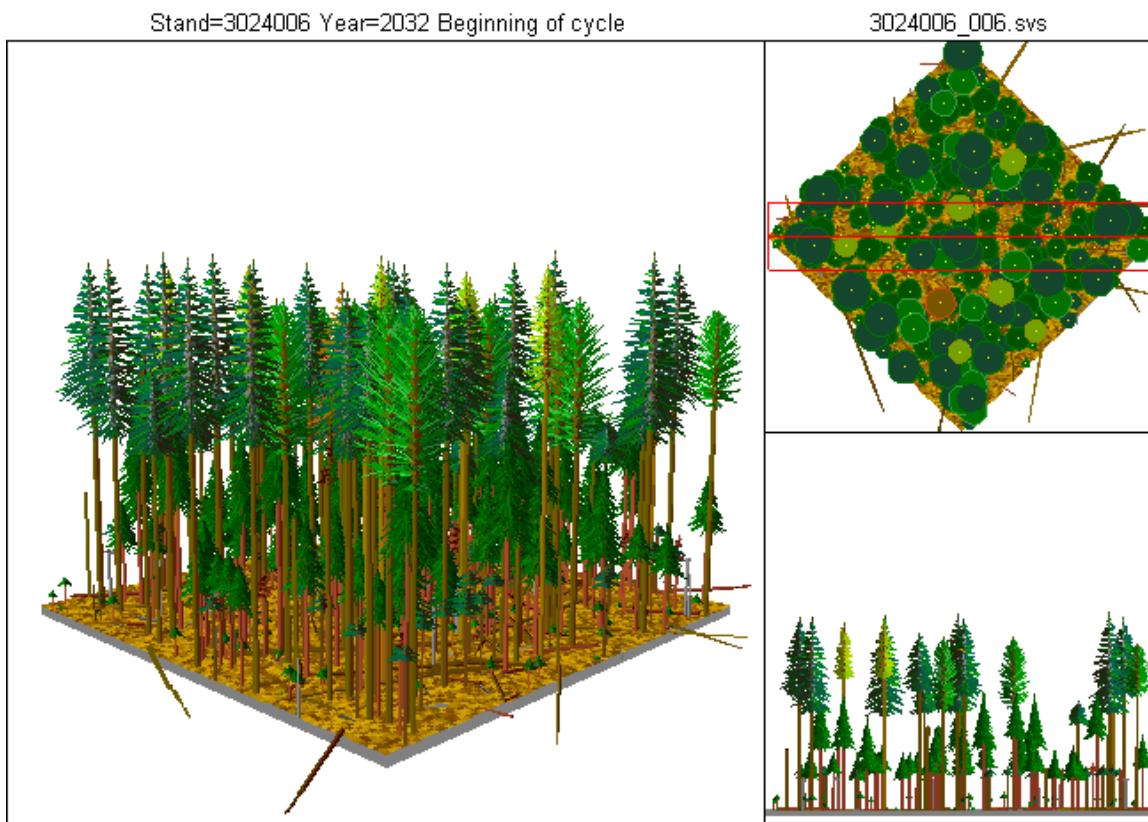


Figure A.3.2 - Example stand 3024006 shown at year 2032 without management using SVS (McGaughey 1997; <http://www.fs.fed.us/pns/svs>).

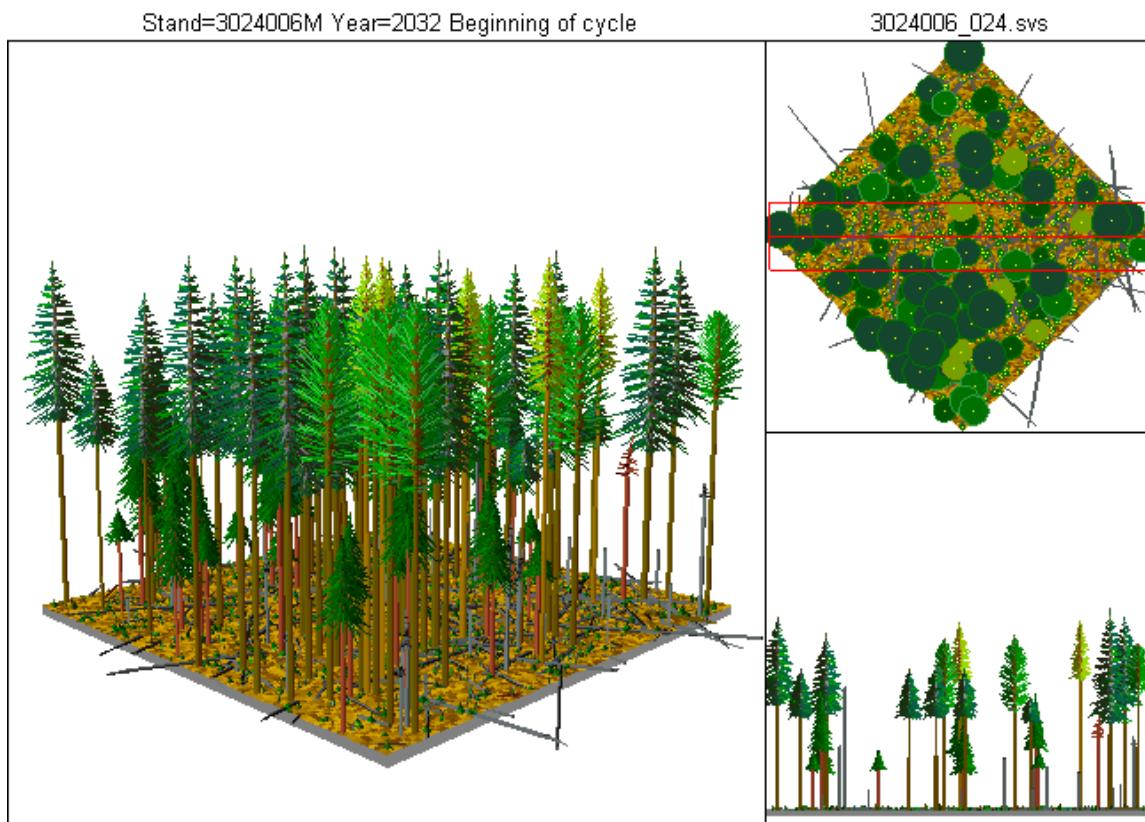


Figure A.3.3 - Example stand 30240006 shown at year 2032 with prescribed fires in 2002 and 2012.

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 stand's 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).

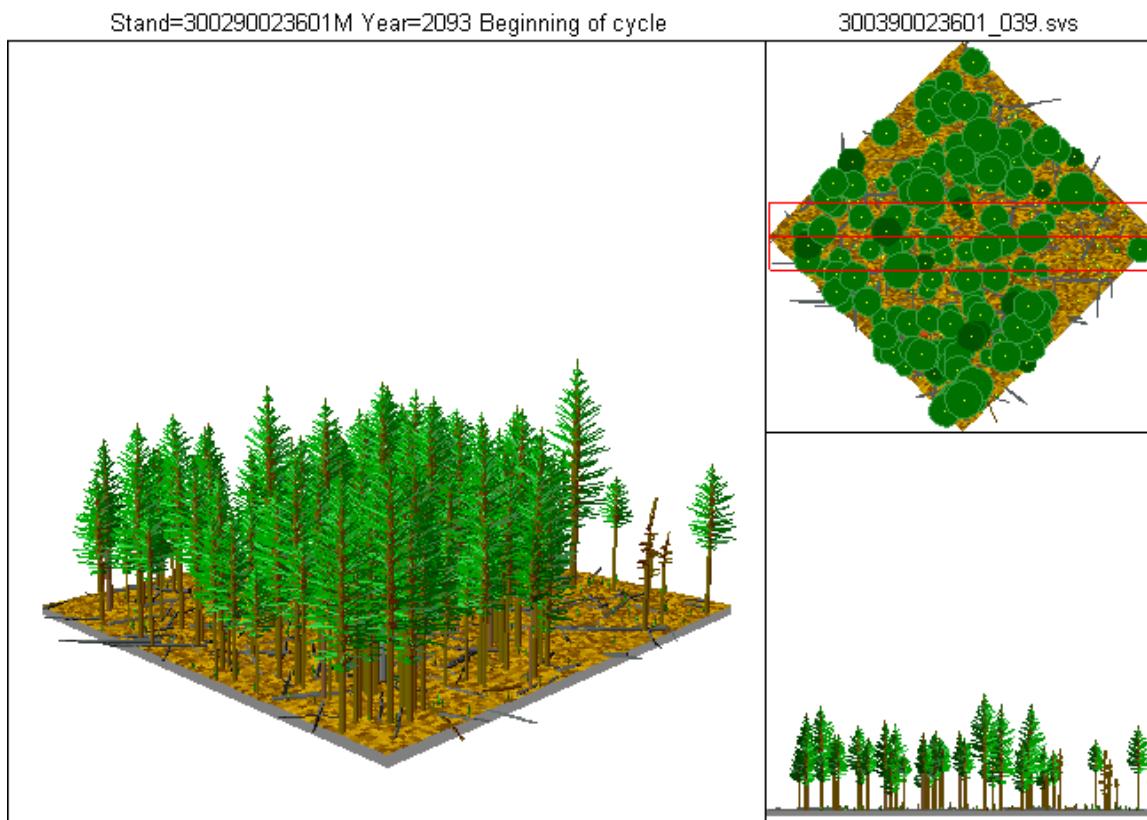


Figure A.3.4 - Stand 300290023601 at year 2093, after repeated prescribed surface fires. The appearance of this stand is about the same as it would be without the repeated prescribed fires and it is also about the same as it looks after an additional fire burns in year 2093 in severe fire conditions.

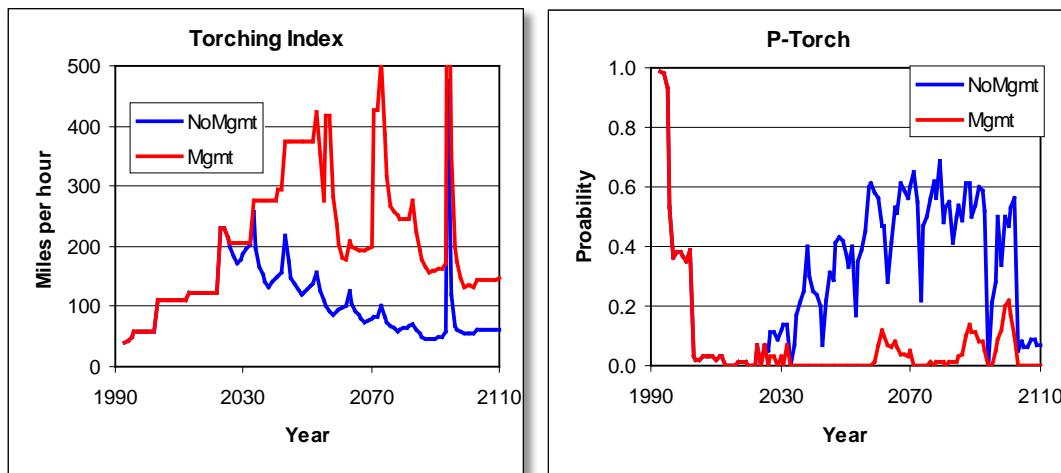
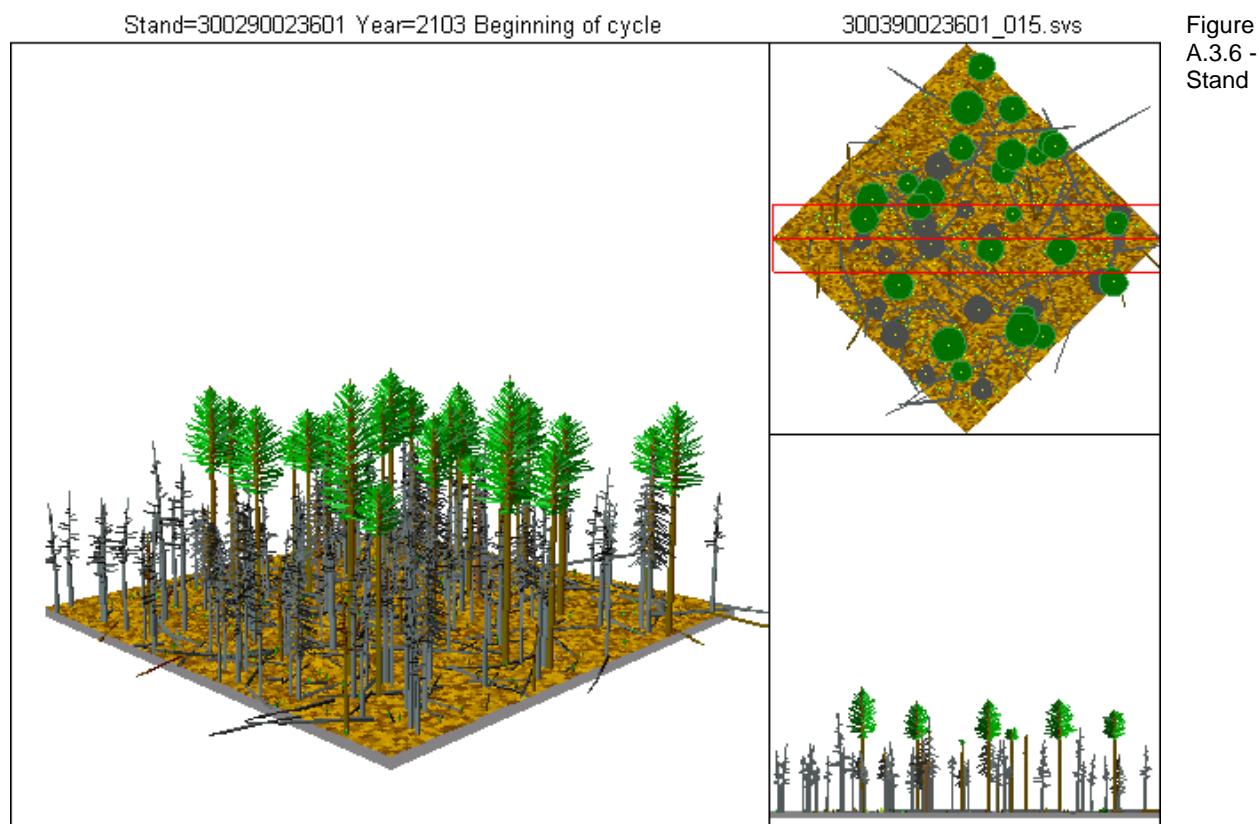


Figure A.3.5 - TI and P-Torch for stand 300290023601. Both indices indicate that the hazard of torching is high in the beginning and that a series of prescribed fire reduced the hazard. The saw-tooth appearance of the lines is partly due to spikes in fine fuels loads caused by simulated fires but mostly caused by modeling artifacts related to the way fuels are modeled in FFE.



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 (FDL) 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:

$$\begin{aligned} TFL &= \text{total fuel load (t/ac)} \\ BD &= \text{fuelbed bulk density (lb/ft}^3\text{)} \end{aligned}$$

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:

$$\begin{aligned} BD_{live} &= \text{bulk density of the live fuel component of the fuelbed} \\ BD_{dead} &= \text{bulk density of the dead fuel component of the fuelbed} \end{aligned}$$

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:

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

where:

FDL = 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/ft³, 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/ft³); 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 a fuelbed contains no fine fuel load—just 10- and 100-hr timelag class dead particles—then the fuel type is set to TL/SB.)

Fire-carrying Fuel Type Selection Guide

- 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 \leq 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 \leq 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 |
| Southeast 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 | | | | | | | | | | | | | | |
|--------------------------------|---|-------------------------|------------------|-------|--------|---------------------------------|--------|--------|------------------------------|-------------------------------------|------------------------------|------------------------------|------------------------------|-------|
| Fuel model Code | Name | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | | Fuel model number | SAV Ratio (1/ft) | | | Fuel Load (lb/ft ²) | | | Fuel bed depth (ft) | Dead fuel extinction moisture | SAV Ratio Live Herb | Fuel Load Live Herb | Fuel Load Live Herb | |
| | | | 1-hr | 10-hr | 100-hr | Live woody | 1-hr | 10-hr | 100-hr | Live woody | | | | |
| - | 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 | | | | | | | | | | | | |
|-----------------|---|--------------------------------|------------------|-------|--------|---------------------------------|-------|-------|--------|---------------------|-------------------------------|-----------|---------------------|-------|
| Fuel model Code | Name | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | | Fuel model number | SAV Ratio (1/ft) | | | Fuel Load (lb/ft ²) | | | | Fuel bed depth (ft) | Dead fuel extinction moisture | SAV Ratio | Fuel Load Live Herb | |
| | | | 1-hr | 10-hr | 100-hr | Live woody | 1-hr | 10-hr | 100-hr | Live woody | | | | |
| 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: lodgepole 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.

6 – Maxwell, W.G. and F.R. Ward. 1976. Photo series for quantifying forest residues in the ponderosa pine type, ponderosa pine and associated species type, lodgepole pine type. Gen. Tech. Rep. PNW-52. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 73 p.

7 – Blonski, K.S. and J.L. Schramel. 1981. Photo series for quantifying natural forest residues: southern Cascades, northern Sierra Nevada. Gen. Tech. Rep. PSW-56. Berkeley, CA: U.S.

Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 145 p.

Also published by the National Wildfire Coordinating Group as PMS 818 / NFES 1872

8 – Maxwell, W.G. and F.R. Ward. 1980. Photo series for quantifying natural forest residues in common vegetation types of the Pacific Northwest. Gen. Tech. Rep. PNW-105. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 230 p.

9 – Ottmar, R.D. and C.C. Hardy. 1989. Stereo photo series for quantifying forest residues in coastal Oregon forests: second-growth Douglas-fir-western hemlock type, western hemlock-Stika spruce type, and red alder type. Gen. Tech. Rep. PNW-GTR-231. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 67 p.

11 – Maxwell, W.G. 1982. Photo series for quantifying forest residues in the black hills, ponderosa pine type, spruce type. A-89-6-82. U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 80 p.

12 – 1997?. Photo series for quantifying forest residues in the southwestern region: data compiled from Black Hills Ponderosa Pine and Spruce Type, 1990; GTR-PNW-105, 1980; GTR-PNW-52, 1976; GTR-PSW-56, 1981. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 227 p.

Also published by the National Wildfire Coordinating Group as PMS 822 / NFES 1395

13 – Maxwell, W.G. and F.R. Ward. 1976. Photo series for quantifying forest residues in the coastal Douglas-fir-hemlock type, coastal Douglas-fir-hardwood type. Gen. Tech. Rep. PNW-51. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 73 p.

Also published by the National Wildfire Coordinating Group as PMS 819 / NFES 1870

14 – Ottmar, R.D., R.E. Vihnanek, and C.S. Wright. 1998. Stereo photo series for quantifying natural fuels. Volume I: mixed-conifer with mortality, western juniper, sagebrush, and grassland types in the interior Pacific Northwest. PMS 830. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 73 pp.

15 – Ottmar, R.D., R.E. Vihnanek, and C.S. Wright. 1998. Stereo photo series for quantifying natural fuels. Volume I: mixed-conifer with mortality, western juniper, sagebrush, and grassland types in the interior Pacific Northwest. PMS 830. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 73 pp.

16 – Ottmar, R.D. and R.E. Vihnanek. 1998. Stereo photo series for quantifying natural fuels. Volume II: black spruce and white spruce types in Alaska. PMS 831. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 65 pp.

and

Ottmar, R.D. and R.E. Vihnanek. 2002. Stereo photo series for quantifying natural fuels. Volume IIa: hardwoods with spruce in Alaska. PMS 836. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 41 pp.

- 17 – Ottmar, R.D., R.E. Vihnanek, and C.S. Wright. 2000. Stereo photo series for quantifying natural fuels. Volume III: Lodgepole pine, quaking aspen, and gambel oak types in the Rocky Mountains. PMS 832. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 85 pp.
- 18 – Ottmar, R.D. and R.E. Vihnanek. 1999. Stereo photo series for quantifying natural fuels. Volume V: midwest red and white pine, northern tallgrass prairie, and mixed oak types in the Central and Lake States. PMS 834. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 99 p.
- and
- Ottmar, R.D., R.E. Vihnanek, and C.S. Wright. 2002. Stereo photo series for quantifying natural fuels. Volume Va: jack pine in the Lake States. PMS 837. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 49 p.
- 19 – Ottmar, R.D. and R.E. Vihnanek. 2000. Stereo photo series for quantifying natural fuels. Volume VI: longleaf pine, pocosin, and marshgrass types in the Southeast United States. PMS 835. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 56 p.
- and
- Ottmar, R.D., R.E. Vihnanek, and J.W. Mathey. 2003. Stereo photo series for quantifying natural fuels. Volume VIa: sandhill, sand pine scrub, and hardwoods with white pine types in the Southeast United States. PMS 838. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 78 p.
- 20 – Maxwell, W.G. 1990. Photo series for quantifying forest residues in the black hills, ponderosa pine type, spruce type. A-89-1-90. U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 80 p.
- 21 – Ottmar, R.D., R.E. Vihnanek, and J.C. Regelbrugge. 2000. Stereo photo series for quantifying natural fuels. Volume IV: pinyon-juniper, sagebrush, and chaparral types in the Southwestern United States. PMS 833. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 97 pp.
- 22 – Wright, Clinton S., R.D. Ottmar, R.E. Vihnanek, and D.R. Weise. 2002. Stereo photo series for quantifying natural fuels: grassland, shrubland, woodland, and forest types in Hawaii. Gen. Tech. Rep. PNW-GTR-545. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 91 p.
- 23 – Ottmar, R.D., C.C. Hardy, and R.E. Vihnanek. 1990. Stereo photo series for quantifying forest residues in the Douglas-fir-hemlock type of the Willamette National Forest. Gen. Tech. Rep. PNW-GTR-258. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 63 p.
- 24 – Lynch, C.M. and L.J. Horton. 1983. Photo series for quantifying forest residues in loblolly pine, Eastern white pine, pitch pine, Virginia pine. NA-FR-25. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry. 69 p.
- 25 – Wilcox, F., J. McCarty, and B. Bungard. 1982. Photo series for quantifying forest residues in the northern hardwood type, oak-hickory type. NA-FR-22. Broomall, PA: U.S. Department of

Agriculture, Forest Service, Northeastern Area, State and Private Forestry, and Pennsylvania Department of Environmental Resources, Bureau of Forestry. 43 p.

26 – Scholl, E.R. and T.A. Waldrop. 1999. Photos for estimating fuel loadings before and after prescribed burning in the upper coastal plain of the southeast. Gen. Tech. Rep. SRS-26. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 25 p.

27 – Ottmar, R.D., R.E. Vihnanek, C.S. Wright, and D.L. Olsen. 2004. Stereo photo series for quantifying natural fuels. Volume VII: Oregon white oak, California deciduous oak, and mixed-conifer with shrub types in the Western United States. PMS 839. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 75 p.

28 – Maxwell, W.G. and F.R. Ward. 1979. Photo series for quantifying forest residues in the sierra mixed conifer type, sierra true fir type. Gen. Tech. Rep. PNW-95. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 79 p.

29 – Sanders, B.M. and D.H. Van Lear. 1988. Photos for estimating residue loadings before and after burning in Southern Appalachian mixed pine-hardwood clearcuts. Gen. Tech. Rep. SE-49. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 21 p.

30 – Wade, D.D., J.K. Forbus, and J.M. Saveland. 1993. Photo series for estimating post-hurricane residues and fire behavior in southern pine. Gen. Tech. Rep. SE-82. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 19 p.

31 – Blank, R.W. 1982. Stereo photos for evaluating jack pine slash fuels. Gen. Tech. Rep. NC-77. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 23 p.

32 – Popp, J.B. and J.E. Lundquist. 2006. Photos series for quantifying forest residues in managed lands of the Medicine Bow National Forest. Gen. Tech. Rep. RMRS-GTR-172. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 105 p.

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 | Ref | Char Code | Int Code | Ref | Char Code | Int Code |
|-----|-----------|----------|-----|------------|----------|-----|-----------|----------|
| 1 | 3A | 11 | 9 | 5RAPOST04 | 25 | 19 | LLP04 | 11 |
| 1 | 13A | 12 | 9 | 5RAPOST05 | 26 | 19 | LLP05 | 12 |
| 1 | 6A | 13 | 11 | 1PP1TH | 1 | 19 | LLP06 | 13 |
| 1 | 18A | 14 | 11 | 2PP1TH | 2 | 19 | LLP07 | 14 |
| 1 | 10A | 15 | 11 | 3PP1TH | 3 | 19 | LLP08 | 15 |
| 1 | 7A | 16 | 11 | 4PP1TH | 4 | 19 | LLP09 | 16 |
| 1 | 19A | 17 | 11 | 5PP1TH | 5 | 19 | LLP10 | 17 |
| 1 | 11A | 18 | 11 | 6PP1TH | 6 | 19 | PW01 | 18 |
| 1 | 5A | 19 | 11 | 7PP1TH | 7 | 19 | PW02 | 19 |
| 1 | 8A | 20 | 11 | 1PP2PC | 8 | 19 | SH01 | 20 |
| 1 | 16A | 21 | 11 | 2PP2PC | 9 | 19 | SH02 | 21 |
| 1 | 15A | 22 | 11 | 3PP2PC | 10 | 19 | SH03 | 22 |
| 2 | 24 | 1 | 11 | 4PP2PC | 11 | 19 | SH04 | 23 |
| 2 | 18 | 2 | 11 | 5PP2PC | 12 | 19 | SH05 | 24 |
| 2 | 23 | 3 | 11 | 1PP3PC | 13 | 19 | SH06 | 25 |
| 2 | 33A | 4 | 11 | 2PP3PC | 14 | 19 | SH07 | 26 |
| 2 | 30A | 5 | 11 | 3PP3PC | 15 | 19 | SH08 | 27 |
| 2 | 32A | 6 | 11 | 1PP3CC | 16 | 19 | SH09 | 28 |
| 2 | 17 | 7 | 11 | 2PP3CC | 17 | 19 | SH10 | 29 |
| 2 | 31A | 8 | 11 | 1PPSP3PC | 18 | 19 | SH11 | 30 |
| 2 | 29A | 9 | 11 | 2PPSP3PC | 19 | 19 | SPS01 | 31 |
| 2 | 72 | 10 | 11 | 3PPSP3PC | 20 | 19 | SPS02 | 32 |
| 2 | 76 | 11 | 11 | 1SP3PC | 21 | 19 | SPS03 | 33 |
| 2 | 69 | 12 | 11 | 2SP3PC | 22 | 19 | SPS04 | 34 |
| 2 | 80 | 13 | 11 | 1PP1 | 23 | 20 | 1PP1TH | 1 |
| 2 | 70 | 14 | 11 | 1PP2 | 24 | 20 | 2PP1TH | 2 |
| 2 | 64 | 15 | 11 | 2PP2 | 25 | 20 | 3PP1TH | 3 |
| 2 | 79 | 16 | 11 | 1PP3 | 26 | 20 | 4PP1TH | 4 |
| 2 | 75 | 17 | 12 | 1PP1TH(BH) | 1 | 20 | 5PP1TH | 5 |
| 2 | 73 | 18 | 12 | 2PP1TH(BH) | 2 | 20 | 6PP1TH | 6 |
| 2 | 77 | 19 | 12 | 3PP1TH(BH) | 3 | 20 | 7PP1TH | 7 |
| 2 | 84 | 20 | 12 | 4PP1TH(BH) | 4 | 20 | 1PP2PC | 8 |
| 2 | 74 | 21 | 12 | 5PP1TH(BH) | 5 | 20 | 2PP2PC | 9 |
| 2 | 78 | 22 | 12 | 6PP1TH(BH) | 6 | 20 | 3PP2PC | 10 |
| 2 | 68 | 23 | 12 | 7PP1TH(BH) | 7 | 20 | 4PP2PC | 11 |
| 2 | 31 | 24 | 12 | 1PP2PC | 8 | 20 | 5PP2PC | 12 |
| 2 | 36A | 25 | 12 | 2PP2PC | 9 | 20 | 1PP3PC | 13 |
| 2 | 71 | 26 | 12 | 3PP2PC | 10 | 20 | 2PP3PC | 14 |
| 2 | 14 | 27 | 12 | 4PP2PC | 11 | 20 | 3PP3PC | 15 |
| 2 | 88 | 28 | 12 | 5PP2PC | 12 | 20 | 1PP3CC | 16 |
| 2 | 13 | 29 | 12 | 1PP3PC | 13 | 20 | 2PP3CC | 17 |

| Ref | Char Code | Int Code | Ref | Char Code | Int Code | Ref | Char Code | Int Code |
|-----|-----------|----------|-----|--------------|----------|-----|-----------|----------|
| 2 | 9 | 30 | 12 | 2PP3PC | 14 | 20 | 1PPSP3PC | 18 |
| 2 | 89 | 31 | 12 | 3PP3PC | 15 | 20 | 2PPSP3PC | 19 |
| 2 | 5 | 32 | 12 | 1PP3CC | 16 | 20 | 3PPSP3PC | 20 |
| 2 | 29 | 33 | 12 | 2PP3CC | 17 | 20 | 1SP3PC | 21 |
| 2 | 30 | 34 | 12 | 1PPSP3PC | 18 | 20 | 2SP3PC | 22 |
| 2 | 56 | 35 | 12 | 2PPSP3PC | 19 | 20 | 1PP1 | 23 |
| 2 | 33 | 36 | 12 | 3PPSP3PC | 20 | 20 | 1PP2 | 24 |
| 2 | 91 | 37 | 12 | 1SP3PC | 21 | 20 | 2PP2 | 25 |
| 2 | 7 | 38 | 12 | 2SP3PC | 22 | 20 | 1PP3 | 26 |
| 2 | 32 | 39 | 12 | 1PP1(BH) | 23 | 21 | PJ01 | 1 |
| 2 | 8 | 40 | 12 | 1PP2(BH) | 24 | 21 | PJ02 | 2 |
| 2 | 28 | 41 | 12 | 2PP2(BH) | 25 | 21 | PJ03 | 3 |
| 2 | 43 | 42 | 12 | 1PP3(BH) | 26 | 21 | PJ04 | 4 |
| 2 | 14A | 43 | 12 | 1AZPPSPPRE01 | 27 | 21 | PJ05 | 5 |
| 2 | 39A | 44 | 12 | 1AZPPSPPRE02 | 28 | 21 | PJ06 | 6 |
| 2 | 41A | 45 | 12 | 1AZPPSPPRE03 | 29 | 21 | PJ07 | 7 |
| 2 | 49 | 46 | 12 | 1AZPPSPPRE04 | 30 | 21 | PJ08 | 8 |
| 2 | 28A | 47 | 12 | 1MC2 | 31 | 21 | PJ09 | 9 |
| 2 | 27A | 48 | 12 | 2MC2 | 32 | 21 | PJ10 | 10 |
| 2 | 12A | 49 | 12 | 3MC2 | 33 | 21 | PJ11 | 11 |
| 2 | 37A | 50 | 12 | 1MC3 | 34 | 21 | PJ12 | 12 |
| 2 | 42A | 51 | 12 | 2MC3 | 35 | 21 | PJ13 | 13 |
| 2 | 38A | 52 | 12 | 3MC3 | 36 | 21 | PJ14 | 14 |
| 2 | 86 | 53 | 12 | 1PP&Assoc3 | 37 | 21 | SWSB01 | 15 |
| 2 | 43A | 54 | 12 | 2PP&Assoc3 | 38 | 21 | SWSB02 | 16 |
| 2 | 34 | 55 | 12 | 3PP&Assoc3 | 39 | 21 | SWSB03 | 17 |
| 2 | 40A | 56 | 12 | 4PP&Assoc3 | 40 | 21 | SWSB04 | 18 |
| 2 | 42 | 57 | 12 | 5PP&Assoc3 | 41 | 21 | SWSB05 | 19 |
| 2 | 48 | 58 | 12 | 1PP&Assoc4 | 42 | 21 | SWSB06 | 20 |
| 2 | 95 | 59 | 12 | 2PP&Assoc4 | 43 | 21 | SWSB07 | 21 |
| 3 | 2 | 1 | 12 | 3PP&Assoc4 | 44 | 21 | SWSB08 | 22 |
| 3 | 26A | 2 | 12 | 1PP1 | 45 | 21 | SWSB09 | 23 |
| 3 | 1 | 3 | 12 | 2PP1 | 46 | 21 | SWSB10 | 24 |
| 3 | 35A | 4 | 12 | 3PP1 | 47 | 21 | SWSB11 | 25 |
| 3 | 82 | 5 | 12 | 1PP2(PNW105) | 48 | 22 | HIF01 | 1 |
| 3 | 85 | 6 | 12 | 2PP2(PNW105) | 49 | 22 | HIF02 | 2 |
| 3 | 25A | 7 | 12 | 3PP2(PNW105) | 50 | 22 | HIF03 | 3 |
| 3 | 34A | 8 | 12 | 4PP2(PNW105) | 51 | 22 | HIF04 | 4 |
| 3 | 45A | 9 | 12 | 1PP3(PNW105) | 52 | 22 | HIF05 | 5 |
| 3 | 47A | 10 | 12 | 2PP3(PNW105) | 53 | 22 | HIF06 | 6 |
| 3 | 87 | 11 | 12 | 3PP3(PNW105) | 54 | 22 | HIF07 | 7 |

| Ref | Char Code | Int Code | Ref | Char Code | Int Code | Ref | Char Code | Int Code |
|-----|-----------|----------|-----|--------------|----------|-----|------------|----------|
| 3 | 83 | 12 | 12 | 4PP3(PNW105) | 55 | 22 | HIF08 | 8 |
| 3 | 92 | 13 | 12 | 5PP3 | 56 | 22 | HIF09 | 9 |
| 3 | 53 | 14 | 12 | 6PP3 | 57 | 22 | HIG01 | 10 |
| 3 | 41 | 15 | 12 | 7PP3 | 58 | 22 | HIG02 | 11 |
| 3 | 49A | 16 | 12 | 8PP3 | 59 | 22 | HIG03 | 12 |
| 3 | 98 | 17 | 12 | 1PP4(PNW105) | 60 | 22 | HIG04 | 13 |
| 3 | 61 | 18 | 12 | 2PP4(PNW105) | 61 | 22 | HIG05 | 14 |
| 3 | 60 | 19 | 12 | 3PP4(PNW105) | 62 | 22 | HIG06 | 15 |
| 3 | 6 | 20 | 12 | 4PP4 | 63 | 22 | HIG07 | 16 |
| 3 | 55 | 21 | 12 | 1JU2 | 64 | 22 | HIG08 | 17 |
| 3 | 48A | 22 | 12 | 2JU2 | 65 | 22 | HIG09 | 18 |
| 3 | 11 | 23 | 12 | 1PP4PC | 66 | 22 | HIG10 | 19 |
| 3 | 46A | 24 | 12 | 2PP4PC | 67 | 22 | HIG11 | 20 |
| 3 | 27 | 25 | 12 | 3PP4PC | 68 | 22 | HIG12 | 21 |
| 3 | 81 | 26 | 12 | 4PP4PC | 69 | 22 | HIG13 | 22 |
| 3 | 45 | 27 | 12 | 5PP4PC | 70 | 22 | HIS01 | 23 |
| 3 | 1A | 28 | 12 | 1PP1TH | 71 | 22 | HIS02 | 24 |
| 3 | 40 | 29 | 12 | 2PP1TH | 72 | 22 | HIS03 | 25 |
| 3 | 39 | 30 | 12 | 3PP1TH | 73 | 22 | HIS04 | 26 |
| 3 | 35 | 31 | 12 | 4PP1TH | 74 | 22 | HIS05 | 27 |
| 3 | 2A | 32 | 12 | 5PP1TH | 75 | 22 | HIS06 | 28 |
| 3 | 26 | 33 | 12 | 6PP1TH | 76 | 22 | HIS07 | 29 |
| 3 | 24A | 34 | 12 | 1PP2 | 77 | 22 | HIW01 | 30 |
| 3 | 44 | 35 | 12 | 2PP2 | 78 | 22 | HIW02 | 31 |
| 3 | 37 | 36 | 12 | 3PP2 | 79 | 22 | HIW03 | 32 |
| 3 | 21 | 37 | 12 | 4PP2 | 80 | 22 | HIW04 | 33 |
| 3 | 21A | 38 | 12 | 1PP3 | 81 | 22 | HIW05 | 34 |
| 3 | 90 | 39 | 12 | 2PP3 | 82 | 22 | HIW06 | 35 |
| 3 | 54 | 40 | 12 | 3PP3 | 83 | 22 | HIW07 | 36 |
| 3 | 36 | 41 | 12 | 4PP3 | 84 | 23 | 1DFWHPRE01 | 1 |
| 3 | 22A | 42 | 12 | 1PP4 | 85 | 23 | 1DFWHPRE02 | 2 |
| 3 | 50 | 43 | 12 | 2PP4 | 86 | 23 | 1DFWHPRE03 | 3 |
| 3 | 58 | 44 | 12 | 3PP4 | 87 | 23 | 1DFWHPRE04 | 4 |
| 3 | 19 | 45 | 12 | 3WF2 | 88 | 23 | 1DFWHPRE05 | 5 |
| 3 | 57 | 46 | 12 | 4WF3 | 89 | 23 | 1DFWHPRE06 | 6 |
| 3 | 96 | 47 | 12 | 3WF3 | 90 | 23 | 1DFWHPRE07 | 7 |
| 3 | 23A | 48 | 13 | 1DF4CC | 1 | 23 | 1DFWHPRE08 | 8 |
| 3 | 46 | 49 | 13 | 2DF4CC | 2 | 23 | 1DFWHPRE09 | 9 |
| 3 | 97 | 50 | 13 | 3DF4CC | 3 | 23 | 1DFWHPRE10 | 10 |
| 3 | 20 | 51 | 13 | 4DF4CC | 4 | 23 | 1DFWHPRE11 | 11 |
| 3 | 59 | 52 | 13 | 5DF4CC | 5 | 23 | 1DFWHPRE12 | 12 |

| Ref | Char Code | Int Code | Ref | Char Code | Int Code | Ref | Char Code | Int Code |
|-----|-----------|----------|-----|-----------|----------|-----|-------------|----------|
| 3 | 44A | 53 | 13 | 6DF4CC | 6 | 23 | 1DFWHPRE13 | 13 |
| 3 | 93 | 54 | 13 | 7DF4CC | 7 | 23 | 1DFWHPRE14 | 14 |
| 3 | 47 | 55 | 13 | 8DF4CC | 8 | 23 | 1DFWHPRE15 | 15 |
| 3 | 4 | 56 | 13 | 9DF4CC | 9 | 23 | 1DFWHPRE16 | 16 |
| 3 | 22 | 57 | 13 | 10DF4CC | 10 | 23 | 1DFWHPRE17 | 17 |
| 3 | 51 | 58 | 13 | 1DF4PC | 11 | 23 | 1DFWHPRE18 | 18 |
| 3 | 62 | 59 | 13 | 2DF4PC | 12 | 23 | 1DFWHPRE19 | 19 |
| 3 | 12 | 60 | 13 | 3DF4PC | 13 | 23 | 2DFWHPOST01 | 20 |
| 3 | 20A | 61 | 13 | 4DF4PC | 14 | 23 | 2DFWHPOST02 | 21 |
| 3 | 94 | 62 | 13 | 5DF4PC | 15 | 23 | 2DFWHPOST03 | 22 |
| 3 | 10 | 63 | 13 | 6DF4PC | 16 | 23 | 2DFWHPOST04 | 23 |
| 3 | 3 | 64 | 13 | 7DF4PC | 17 | 23 | 2DFWHPOST05 | 24 |
| 3 | 38 | 65 | 13 | 8DF4PC | 18 | 23 | 2DFWHPOST06 | 25 |
| 3 | 52 | 66 | 13 | 9DF4PC | 19 | 23 | 2DFWHPOST07 | 26 |
| 5 | 1WH1TH | 1 | 13 | 1DF3PC | 20 | 24 | 1LL2N | 1 |
| 5 | 2WH1TH | 2 | 13 | 2DF3PC | 21 | 24 | 2LL2H | 2 |
| 5 | 3WH1TH | 3 | 13 | 3DF3PC | 22 | 24 | 3LL3N | 3 |
| 5 | 4WH1TH | 4 | 13 | 4DF3PC | 23 | 24 | 4LL2H | 4 |
| 5 | 5WH1TH | 5 | 13 | 5DF3PC | 24 | 24 | 5LL1P | 5 |
| 5 | 6WH1TH | 6 | 13 | 6DF3PC | 25 | 24 | 6LL3H | 6 |
| 5 | 1GF1TH | 7 | 13 | 1DF1TH | 26 | 24 | 7LL3H | 7 |
| 5 | 2GF1TH | 8 | 13 | 2DF1TH | 27 | 24 | 8LL3N | 8 |
| 5 | 3GF1TH | 9 | 13 | 3DF1TH | 28 | 24 | 9LL3H | 9 |
| 5 | 4GF1TH | 10 | 13 | 4DF1TH | 29 | 24 | 1WP3N | 10 |
| 5 | 1WC1TH | 11 | 13 | 1DFHD4CC | 30 | 24 | 2WP2P | 11 |
| 5 | 2WC1TH | 12 | 13 | 2DFHD4CC | 31 | 24 | 3WP3N | 12 |
| 5 | 3WC1TH | 13 | 13 | 3DFHD4CC | 32 | 24 | 4WP3H | 13 |
| 5 | 4WC1TH | 14 | 13 | 4DFHD4CC | 33 | 24 | 5WP3H | 14 |
| 5 | 5WC1TH | 15 | 13 | 5DFHD4CC | 34 | 24 | 6WP2H | 15 |
| 5 | 6WC1TH | 16 | 13 | 6DFHD4CC | 35 | 24 | 7WP3N | 16 |
| 5 | 7WC1TH | 17 | 13 | 7DFHD4CC | 36 | 24 | 1PP1N | 17 |
| 6 | 1PP4CC | 1 | 13 | 1DFHD4PC | 37 | 24 | 2PP2N | 18 |
| 6 | 2PP4CC | 2 | 13 | 2DFHD4PC | 38 | 24 | 3PP1N | 19 |
| 6 | 1PP4PC | 3 | 13 | 3DFHD4PC | 39 | 24 | 4PP1N | 20 |
| 6 | 2PP4PC | 4 | 13 | 4DFHD4PC | 40 | 24 | 5PP2N | 21 |
| 6 | 3PP4PC | 5 | 13 | 5DFHD4PC | 41 | 24 | 6PP2N | 22 |
| 6 | 4PP4PC | 6 | 13 | 6DFHD4PC | 42 | 24 | 7PP3H | 23 |
| 6 | 5PP4PC | 7 | 14 | BG01 | 1 | 24 | 1VP2N | 24 |
| 6 | 1PP1TH | 8 | 14 | BG02 | 2 | 24 | 2VP2N | 25 |
| 6 | 2PP1TH | 9 | 14 | BG03 | 3 | 24 | 3VP3N | 26 |
| 6 | 3PP1TH | 10 | 14 | BG04 | 4 | 24 | 4VP2N | 27 |

| Ref | Char Code | Int Code | Ref | Char Code | Int Code | Ref | Char Code | Int Code |
|-----|--------------|----------|-----|-----------|----------|-----|-----------|----------|
| 6 | 4PP1TH | 11 | 14 | MC01 | 5 | 25 | 1A21N | 1 |
| 6 | 5PP1TH | 12 | 14 | MC02 | 6 | 25 | 2A22N | 2 |
| 6 | 6PP1TH | 13 | 14 | MC03 | 7 | 25 | 3B21N | 3 |
| 6 | 1PP&ASSOC4PC | 14 | 14 | MC04 | 8 | 25 | 4A22N | 4 |
| 6 | 2PP&ASSOC4PC | 15 | 14 | MC05 | 9 | 25 | 5B12N | 5 |
| 6 | 3PP&ASSOC4PC | 16 | 14 | MC06 | 10 | 25 | 6A12N | 6 |
| 6 | 4PP&ASSOC4PC | 17 | 14 | MC07 | 11 | 25 | 7B22N | 7 |
| 6 | 5PP&ASSOC4PC | 18 | 14 | MC08 | 12 | 25 | 8A22N | 8 |
| 6 | 6PP&ASSOC4PC | 19 | 14 | MC09 | 13 | 25 | 9A11N | 9 |
| 6 | 7PP&ASSOC4PC | 20 | 14 | MC10 | 14 | 25 | 10A22CC | 10 |
| 6 | 8PP&ASSOC4PC | 21 | 14 | MC11 | 15 | 25 | 11B22CC | 11 |
| 6 | 1LP3CC | 22 | 14 | MC12 | 16 | 25 | 12A22CC | 12 |
| 6 | 1LP3PC | 23 | 14 | MC13 | 17 | 25 | 13A22CC | 13 |
| 6 | 2LP3PC | 24 | 14 | MC14 | 18 | 25 | 14B23CC | 14 |
| 6 | 3LP3PC | 25 | 14 | MC15 | 19 | 26 | FC1PRE | 1 |
| 6 | 4LP3PC | 26 | 14 | MC16 | 20 | 26 | FC1POST | 2 |
| 6 | 5LP3PC | 27 | 14 | MC17 | 21 | 26 | FC2PRE | 3 |
| 7 | 1MP4 | 1 | 14 | SB01 | 22 | 26 | FC2POST | 4 |
| 7 | 2MP4 | 2 | 14 | SB02 | 23 | 26 | FC3PRE | 5 |
| 7 | 3MP4 | 3 | 14 | SB03 | 24 | 26 | FC3POST | 6 |
| 7 | 4MP4 | 4 | 14 | SB04 | 25 | 26 | FC4PRE | 7 |
| 7 | 5MP4 | 5 | 14 | WJ01 | 26 | 26 | FC4POST | 8 |
| 7 | 1MF4 | 6 | 14 | WJ02 | 27 | 26 | FC5PRE | 9 |
| 7 | 2MF4 | 7 | 14 | WJ03 | 28 | 26 | FC5POST | 10 |
| 7 | 3MF4 | 8 | 14 | WJ04 | 29 | 26 | FC6PRE | 11 |
| 7 | 4MF4 | 9 | 15 | BG01 | 1 | 26 | FC6POST | 12 |
| 7 | 5MF4 | 10 | 15 | BG02 | 2 | 26 | FC7PRE | 13 |
| 7 | 1PP2 | 11 | 15 | BG03 | 3 | 26 | FC7POST | 14 |
| 7 | 2PP2 | 12 | 15 | BG04 | 4 | 26 | FC8PRE | 15 |
| 7 | 3PP2 | 13 | 15 | MC01 | 5 | 26 | FC8POST | 16 |
| 7 | 4PP2 | 14 | 15 | MC02 | 6 | 27 | CDO01 | 1 |
| 7 | 1PP3 | 15 | 15 | MC03 | 7 | 27 | CDO02 | 2 |
| 7 | 2PP3 | 16 | 15 | MC04 | 8 | 27 | CDO03 | 3 |
| 7 | 3PP3 | 17 | 15 | MC05 | 9 | 27 | CDO04 | 4 |
| 7 | 4PP3 | 18 | 15 | MC06 | 10 | 27 | CDO05 | 5 |
| 7 | 1PP4 | 19 | 15 | MC07 | 11 | 27 | CDO06 | 6 |
| 7 | 2PP4 | 20 | 15 | MC08 | 12 | 27 | CDO07 | 7 |
| 7 | 3PP4 | 21 | 15 | MC09 | 13 | 27 | CDO08 | 8 |
| 7 | 1LP2 | 22 | 15 | MC10 | 14 | 27 | CDO09 | 9 |
| 7 | 2LP2 | 23 | 15 | MC11 | 15 | 27 | MCS01 | 10 |
| 7 | 3LP2 | 24 | 15 | MC12 | 16 | 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 | Ref | Char Code | Int Code | Ref | Char Code | Int Code |
|-----|------------|----------|-----|-----------|----------|-----|-----------|----------|
| 8 | 2HD2 | 10 | 16 | BS14 | 29 | 28 | 4TF4RC | 23 |
| 8 | 1DF2 | 11 | 16 | WS01 | 30 | 28 | 5TF4RC | 24 |
| 8 | 2DF2 | 12 | 16 | WS02 | 31 | 28 | 6TF4RC | 25 |
| 8 | 1DF3 | 13 | 16 | WS03 | 32 | 28 | 1TF4PC | 26 |
| 8 | 2DF3 | 14 | 16 | WS04 | 33 | 28 | 2TF4PC | 27 |
| 8 | 1DF4 | 15 | 16 | WS05 | 34 | 28 | 3TF4PC | 28 |
| 8 | 2DF4 | 16 | 16 | WS06 | 35 | 28 | 4TF4PC | 29 |
| 8 | 3DF4 | 17 | 16 | WS07 | 36 | 28 | 5TF4PC | 30 |
| 8 | 4DF4 | 18 | 16 | WS08 | 37 | 29 | 6A | 1 |
| 8 | 5DF4 | 19 | 16 | WS09 | 38 | 29 | 6B | 2 |
| 8 | 6DF4 | 20 | 16 | WS10 | 39 | 29 | 8A | 3 |
| 8 | 7DF4 | 21 | 16 | WS11 | 40 | 29 | 8B | 4 |
| 8 | 1SA1 | 22 | 16 | WS12 | 41 | 29 | 10A | 5 |
| 8 | 2SA1 | 23 | 17 | GO01 | 1 | 29 | 10B | 6 |
| 8 | 3SA1 | 24 | 17 | GO02 | 2 | 29 | 12A | 7 |
| 8 | 1SA2 | 25 | 17 | GO03 | 3 | 29 | 12B | 8 |
| 8 | 2SA2 | 26 | 17 | GO04 | 4 | 29 | 14A | 9 |
| 8 | 1SA3 | 27 | 17 | GO05 | 5 | 29 | 14B | 10 |
| 8 | 2SA3 | 28 | 17 | GO06 | 6 | 29 | 16A | 11 |
| 8 | 3SA3 | 29 | 17 | GO07 | 7 | 29 | 16B | 12 |
| 8 | 1SA4 | 30 | 17 | GO08 | 8 | 29 | 18A | 13 |
| 8 | 2SA4 | 31 | 17 | GO09 | 9 | 29 | 18B | 14 |
| 8 | 1MC2 | 32 | 17 | LP01 | 10 | 29 | 20A | 15 |
| 8 | 2MC2 | 33 | 17 | LP02 | 11 | 29 | 20B | 16 |
| 8 | 3MC2 | 34 | 17 | LP03 | 12 | 30 | 3D | 1 |
| 8 | 1MC3 | 35 | 17 | LP04 | 13 | 30 | 3Dpost | 2 |
| 8 | 2MC3 | 36 | 17 | LP05 | 14 | 30 | 2A | 3 |
| 8 | 3MC3 | 37 | 17 | LP06 | 15 | 30 | 2Apost | 4 |
| 8 | 1MC4 | 38 | 17 | LP07 | 16 | 30 | 3B | 5 |
| 8 | 2MC4 | 39 | 17 | LP08 | 17 | 30 | 3Bpost | 6 |
| 8 | 1LP1 | 40 | 17 | LP09 | 18 | 30 | 2C | 7 |
| 8 | 2LP1 | 41 | 17 | LP10 | 19 | 30 | 2Cpost | 8 |
| 8 | 3LP1 | 42 | 17 | LP11 | 20 | 30 | 2D | 9 |
| 8 | 1LP2 | 43 | 17 | LP12 | 21 | 30 | 2Dpost | 10 |
| 8 | 2LP2 | 44 | 17 | LP13 | 22 | 30 | 1A | 11 |
| 8 | 3LP2 | 45 | 17 | QA01 | 23 | 30 | 1Apost | 12 |
| 8 | 4LP2 | 46 | 17 | QA02 | 24 | 30 | 1C | 13 |
| 8 | 1LP3 | 47 | 17 | QA03 | 25 | 30 | 1Cpost | 14 |
| 8 | 2LP3 | 48 | 17 | QA04 | 26 | 30 | 1D | 15 |
| 8 | 3LP3 | 49 | 17 | QA05 | 27 | 30 | 1Dpost | 16 |
| 8 | 1PP&Assoc3 | 50 | 17 | QA06 | 28 | 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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