The Fire and Fuels Extension to the Forest Vegetation Simulator

Addendum to RMRS-GTR-116

This document outlines changes and additions that have been made to the Fire and Fuels Extension since the publication of the official FFE documentation (RMRS-GTR-116)

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The Authors

Add –

Stephanie A. Rebain is a Forester with the Forest Vegetation Simulator staff, USDA Forest Service, Fort Collins, CO. She has been involved with FFE since 2002. Her contributions include the development of the FFE for the Ozark, Lake States, and Northeast regions, leading FVS-FFE training sessions, and maintenance of the FFE code.

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Add the following people who were involved with the development of new variants or participated in a regional validation workshop:

Applegate, Vic
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Birdsey, Richard
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Burke, Earl
Bush, Renate
Caves, Tom
Duran, Lara
Dwyer, Dennis
Evans, David
Fieldhouse, Paul
Fryar, Roger
Gayton, Dyce
Geils, Brian
Hanson, Dan
Harnois, Mike
Harry, Lee
Hartman, George
Heath, Linda
Hoover, Coeli
Hoverman, Roger
Hutton, Diane
Johnson, Morris
Johnson, Steve
Journey, Mike
Kolacs, Jeremy
Lieser, Ed
Locke, Mike
Lundberg, Renee
Maffei, Helen
Martin, Fred
Mateyka, Mike
Mellen, Kim
Miedtke, Doug

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Negron, Jorge
Novak, Mark
Paddock, Erin
Ponder, Felix
Reed, Dave
Remus, Tom
Schantz, Rob
Shea, Julie
Shifley, Steve
Simpson, Mike
Smith, Jane
Smith, Jim
Spetich, Marty
Stock, Joyce
Stone, Jim
Tandy, Brian
Terrell, Bennie
Turner, Lauri
Underwood, Steve
Vickers, Gregg
Weyenberg, Scott
Woodall, Chris
Wright, Debi
Yanez, Leo
Young, Carol

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Section 2.3 Snag Submodel

The snag fall rate, snag decay, and snag height loss predictions were modified in the Region 6 variants of FFE, based on work by Kim Mellen, regional wildlife ecologist. Contact Stephanie Rebain (sarebain@fs.fed.us) for more information.

Section 2.3.7 Management

There is actually no base model SALVAGE keyword.

Table 2.7:

The correct default initial fuel loadings for the north Idaho variant are found in Table 4.8

Section 2.4.2 Initialization:

Dead surface fuel loads 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.

Section 2.4.3 Estimation of Tree Material:

Table 2.8 – The density values are incorrect. The current density values are in Appendix B.

When FFE uses Brown and Johnston's equations to calculation crown biomass, and the equation uses dominance position, a tree is considered dominant or co-dominant if it is above the 60th percentile in height (the tallest 40% of trees). If a tree is below the 60th percentile, it is assumed to be intermediate/suppressed. No linear interpolation is done.

Section 2.4.7 Canopy Fuels:

By default, the canopy fuels calculations are determined from estimates of foliage and fine branchwood (half of the 0-0.25" branchwood) of conifer trees at least 6 feet tall. Canopy base height is generally set when 30 lbs/acre/foot is reached. 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.

Section 2.4.8 Fire Behavior Fuel Models:

Table 2.13:

The Scott and Burgan fuel models (Scott and Burgan 2005) can also be selected within FFE and are used in the default fuel model selection logic in some variants. These should be added to the table.

The fire behavior fuel model can also be set by including this information in the StandInit table of an input FVS database.

Table 2.16:

Trampling and flailing values are reversed. The trampling category corresponds to a multiplier of 0.75 and the flailing category corresponds to a multiplier of 0.83.

Section 2.5.3 Controlling Fire Extent:

Correction to the default values mentioned for jackpot burns:

By default, in jackpot burning, 60 percent of the stand's fuel is in the burned part of the stand. These piles are assumed to be far enough from trees not to cause mortality.

Table 2.19:

The table heading incorrectly states that the wind speed is the mid-flame wind speed. The wind speed is actually the 20-ft wind speed (in miles per hour) at the time of the fire.

Section 2.5.5 Fire Effects:

The tree mortality equation presented is for surface fires. When crown fires are simulated, additional mortality is predicted based on the percent crowning predicted.

In the equation for P_{mort}, one coefficient is incorrect. The coefficient of 6.313 is actually 6.316.

When users set the percentage of the stand area 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 only applied to the tree records in the burned portion of the stand.

Section 2.5.7 Output:

The format of the potential fire report has changed. In addition to total flame length, surface fire flame length is now also reported for severe and moderate fires. The surface fire flame length is an estimate of the flame length assuming a surface fire. The total flame length is an estimate of the flame length that takes into account any crown fire behavior that is being predicted. Therefore, the two flame length estimates will be the same if a surface fire is predicted, but when a passive or active or conditional crown fire is predicted, the total flame length will be larger than the surface fire flame length. The type of fire is now reported as "A", "P", "S", or "C" for active, passive, surface, or conditional fires. A conditional fire is predicted when the wind speed is greater than the crowning index, but less than the torching index (Scott and Reinhardt 2001). The interpretation is that if a fire originates as a surface fire in the stand, it is expected to remain so. If a fire originates as an active crown fire in an adjacent stand, active crown fire will continue through the stand. FFE models conditional fires as conditional crown fires (i.e. the associated flame length and fire effects, such as mortality, assume a crown fire. P-torch, the proportion of small places where torching is possible, is also reported. See Appendix A for more information about P-torch.

A new soil heating report is available for output with the SOILHEAT keyword whenever a fire is simulated. The soil heating estimates match those in the FOFEM model. The soil heating output includes the temperature (°C) at various depths below the surface. Also output is the depth where the temperature exceeds 60 °C (often considered the lethal temperature for living organisms) and 275 °C.

Section 2.6 Discussion

This section is renumbered as Section 2.7

This following new section is inserted as a new Section 2.6

2.6 Carbon Submodel

2.6.1 Overview

Natural resource managers may be interested in the amount of carbon being sequested 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 modelling approach used by the 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 the 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 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 (Ludovici et. al. 2002) and can be adjusted by the model user with the CarbCalc keyword.

As Table 2.26 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.

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

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

Forest, DDW	✓		Dead Surface Fuel 0-3in Dead Surface Fuel >3in	▨
Belowground, Live	Jenkins method always used	✓	▨	*f(sp,dbh)*
Belowground, Dead		✓	▨	*f(sp,dbh)*

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

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, and optionally sent to an external database, using the database (DBS) extension and the DBS CARBRPTS keyword. 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 2.17) 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 2.27 (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 2.27 – Example Stand Carbon Report. This example reports conditions every 5 years using the default FFE-calculated biomass and default units. Note that changes to the various pools also include contributions from stand growth and mortality, as well as from stand management actions and fire disturbance. Two disturbances are shown in bold and highlighted with asterisks at the end of the report line. First, a harvest in 2010 reduces C in the aboveground live and merchantable categories. This harvest transfers some live belowground C in roots to dead root C, representing the roots of harvested trees. Second, further changes occur with a simulated fire in 2025, which consumes much of the C in surface fuel but has neglible effect upon the C held in standing wood. A corresponding extract from the All Fuels Report is shown below, for comparison.

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

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

Harvested Products Report: Using the CARBCUT keyword, the carbon content of the merchantable timber utilized from stand entries (including salvage harvests) can be followed over time and summarized to the main output, and optionally sent to an external database using the database (DBS) extension and the DBS CARBRPTS keyword. 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 CARBREPT 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-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 2.28 – Example Harvested Products Report. This example reports conditions every 5 years using the default FFE-calculated biomass and units. The result of a harvest in 2010 is shown in bold and highlighted with asterisks at the end of the report line. (see Table 2.27 for the corresponding Stand Carbon report). Note that the 34.3 tC/ac of merchantable removed carbon is less than the total carbon removed from the stand (38.1 tC/ac). The Total Carbon Stored category is the sum of the Products and Landfill; Total Carbon Removed is the sum of all four categories.

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

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

The format of the Harvested Products report follows the decay-fate categories of Smith and others (2006). 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 feet volume and total cubic feet 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 feet volume and does not include unmerchantable trees or the unmerchantable parts of merchantable trees. In eastern variants linked to the FFE, the total carbon (either standing or removed) in live trees is based on the merchantable cubic feet volume in pulpwood and crown biomass equations that predict unmerchantable biomass for a tree. The merchantable carbon reported is based on the merchantable cubic feet 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.

Chapter 3 – User’s Guide

Section 3.3, Initalization the Model:
FUELINIT keyword-
Two additional fields have been added to the FuelInit keyword, so that users can set the 1 and 10 hour fuels separately.
Field 8: Initial fuel load for the 0-0.25” class (tons/acre)
Field 9: Initial fuel load for the 0.25-1” class (tons/acre)

The initial fuel loadings can also be set within 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.

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)

When included with input FVS data, the photo series information should be specified in the StandInit table in columns labelled 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 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 keyword 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 keyword is processed.)

Photo series reference numbers and associated photo reference codes:

1 – **Fischer, W.C.** 1981. Photo guide for appraising downed woody fuels in Montana forests: grand fir-larch-Douglas-fir, western hemlock, western redcedar-western hemlock, and western redcedar cover types. Gen. Tech. Rep. INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 53 p.

2 – **Fischer, W.C.** 1981. Photo guide for appraising downed woody fuels in Montana forests: interior ponderosa pine, ponderosa pine-larch-Douglas-fir, larch-Douglas-fir, and interior Douglas-fir cover types. Gen. Tech. Rep. INT-97. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 133 p.

Also published by the National Wildfire Coordinating Group as PMS 820 / NFES 2293

3 – **Fischer, W.C.** 1981. Photo guide for appraising downed woody fuels in Montana forests: lodgdpole pine and Engelmann spruce-subalpine fir cover types. Gen. Tech. Rep. INT-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 143 p.

Also published by the National Wildfire Coordinating Group as PMS 821 / NFES 2294

5 – **Koski, W.H. and W.C. Fischer.** 1979. Photo series for appraising thinning slash in north Idaho: western hemlock, grand fir, and western redcedar timber types. Gen. Tech. Rep. INT-46. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 50 p.

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.

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and

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18	MO10	29	19	SH10	29
18	MO11	30	19	SH11	30
18	MP01	31	19	SPS01	31
18	MP02	32	19	SPS02	32
18	MP03	33	19	SPS03	33
18	MP04	34	19	SPS04	34
18	MP05	35	20	1PP1TH	1
18	MP06	36	20	2PP1TH	2
18	MP07	37	20	3PP1TH	3
18	MP08	38	20	4PP1TH	4
18	MP09	39	20	5PP1TH	5
18	MP10	40	20	6PP1TH	6
18	MP11	41	20	7PP1TH	7
18	MP12	42	20	1PP2PC	8
18	MP13	43	20	2PP2PC	9
19	HP01	1	20	3PP2PC	10
19	HP02	2	20	4PP2PC	11
19	HP03	3	20	5PP2PC	12
19	HP04	4	20	1PP3PC	13
19	HP05	5	20	2PP3PC	14
19	HP06	6	20	3PP3PC	15
19	HP07	7	20	1PP3CC	16
19	LLP01	8	20	2PP3CC	17
19	LLP02	9	20	1PPSP3PC	18
19	LLP03	10	20	2PPSP3PC	19
19	LLP04	11	20	3PPSP3PC	20
19	LLP05	12	20	1SP3PC	21
19	LLP06	13	20	2SP3PC	22
19	LLP07	14	20	1PP1	23
19	LLP08	15	20	1PP2	24
19	LLP09	16	20	2PP2	25
19	LLP10	17	20	1PP3	26
19	P-W01	18	21	PJ01	1
19	P-W02	19	21	PJ02	2
19	SH01	20	21	PJ03	3
19	SH02	21	21	PJ04	4
19	SH03	22	21	PJ05	5
19	SH04	23	21	PJ06	6

Ref	Char. code	Int. code
21	PJ07	7
21	PJ08	8
21	PJ09	9
21	PJ10	10
21	PJ11	11
21	PJ12	12
21	PJ13	13
21	PJ14	14
21	SWSB01	15
21	SWSB02	16
21	SWSB03	17
21	SWSB04	18
21	SWSB05	19
21	SWSB06	20
21	SWSB07	21
21	SWSB08	22
21	SWSB09	23
21	SWSB10	24
21	SWSB11	25
22	HI-F01	1
22	HI-F02	2
22	HI-F03	3
22	HI-F04	4
22	HI-F05	5
22	HI-F06	6
22	HI-F07	7
22	HI-F08	8
22	HI-F09	9
22	HI-G01	10
22	HI-G02	11
22	HI-G03	12
22	HI-G04	13
22	HI-G05	14
22	HI-G06	15
22	HI-G07	16
22	HI-G08	17
22	HI-G09	18
22	HI-G10	19
22	HI-G11	20
22	HI-G12	21
22	HI-G13	22
22	HI-S01	23
22	HI-S02	24

Ref	Char. code	Int. code
22	HI-S03	25
22	HI-S04	26
22	HI-S05	27
22	HI-S06	28
22	HI-S07	29
22	HI-W01	30
22	HI-W02	31
22	HI-W03	32
22	HI-W04	33
22	HI-W05	34
22	HI-W06	35
22	HI-W07	36
23	1DFWHPRE01	1
23	1DFWHPRE02	2
23	1DFWHPRE03	3
23	1DFWHPRE04	4
23	1DFWHPRE05	5
23	1DFWHPRE06	6
23	1DFWHPRE07	7
23	1DFWHPRE08	8
23	1DFWHPRE09	9
23	1DFWHPRE10	10
23	1DFWHPRE11	11
23	1DFWHPRE12	12
23	1DFWHPRE13	13
23	1DFWHPRE14	14
23	1DFWHPRE15	15
23	1DFWHPRE16	16
23	1DFWHPRE17	17
23	1DFWHPRE18	18
23	1DFWHPRE19	19
23	2DFWHPOST01	20
23	2DFWHPOST02	21
23	2DFWHPOST03	22
23	2DFWHPOST04	23
23	2DFWHPOST05	24
23	2DFWHPOST06	25
23	2DFWHPOST07	26
24	1LL2N	1
24	2LL2H	2
24	3LL3N	3
24	4LL2H	4
24	5LL1P	5

Ref	Char. code	Int. code
24	6LL3H	6
24	7LL3H	7
24	8LL3N	8
24	9LL3H	9
24	1WP3N	10
24	2WP2P	11
24	3WP3N	12
24	4WP3H	13
24	5WP3H	14
24	6WP2H	15
24	7WP3N	16
24	1PP1N	17
24	2PP2N	18
24	3PP1N	19
24	4PP1N	20
24	5PP2N	21
24	6PP2N	22
24	7PP3H	23
24	1VP2N	24
24	2VP2N	25
24	3VP3N	26
24	4VP2N	27
25	1A21N	1
25	2A22N	2
25	3B21N	3
25	4A22N	4
25	5B12N	5
25	6A12N	6
25	7B22N	7
25	8A22N	8
25	9A11N	9
25	10A22CC	10
25	11B22CC	11
25	12A22CC	12
25	13A22CC	13
25	14B23CC	14
26	FC1PRE	1
26	FC1POST	2
26	FC2PRE	3
26	FC2POST	4
26	FC3PRE	5
26	FC3POST	6
26	FC4PRE	7
26	FC4POST	8
26	FC5PRE	9
26	FC5POST	10
26	FC6PRE	11
26	FC6POST	12
26	FC7PRE	13
26	FC7POST	14
26	FC8PRE	15
26	FC8POST	16
27	CDO01	1
27	CDO02	2
27	CDO03	3
27	CDO04	4
27	CDO05	5
27	CDO06	6
27	CDO07	7
27	CDO08	8
27	CDO09	9
27	MCS01	10
27	MCS02	11
27	MCS03	12
27	MCS04	13
27	MCS05	14
27	MCS06	15
27	MCS07	16
27	MCS08	17
27	MCS09	18
27	MCS10	19
27	MCS11	20
27	WO01	21
27	WO02	22
27	WO03	23
27	WO04	24
27	WO05	25
27	WO06	26
27	WO07	27
27	WO08	28
27	WO09	29
27	WO10	30
28	1-MC-4-RC	1
28	2-MC-4-RC	2
28	3-MC-4-RC	3
28	1-MC-4-PC	4

Ref	Char. code	Int. code
28	2-MC-4-PC	5
28	3-MC-4-PC	6
28	4-MC-4-PC	7
28	5-MC-4-PC	8
28	6-MC-4-PC	9
28	7-MC-4-PC	10
28	8-MC-4-PC	11
28	1-MC-3-PC	12
28	2-MC-3-PC	13
28	3-MC-3-PC	14
28	4-MC-3-PC	15
28	5-MC-3-PC	16
28	6-MC-3-PC	17
28	7-MC-3-PC	18
28	8-MC-3-PC	19
28	1-TF-4-RC	20
28	2-TF-4-RC	21
28	3-TF-4-RC	22
28	4-TF-4-RC	23
28	5-TF-4-RC	24
28	6-TF-4-RC	25
28	1-TF-4-PC	26
28	2-TF-4-RC	27
28	3-TF-4-PC	28
28	4-TF-4-PC	29
28	5-TF-4-PC	30
29	1-preburn	1
29	1-postburn	2
29	2-preburn	3
29	2-postburn	4
29	3-preburn	5
29	3-postburn	6
29	4-preburn	7
29	4-postburn	8
29	5-preburn	9
29	5-postburn	10
29	6-preburn	11
29	6-postburn	12
29	7-preburn	13
29	7-postburn	14
29	8-preburn	15
29	8-postburn	16
30	3D-preburn	1
30	3D-postburn	2
30	2A-preburn	3
30	2A-postburn	4
30	3B-preburn	5
30	3B-postburn	6
30	2C-preburn	7
30	2C-postburn	8
30	2D-preburn	9
30	2D-postburn	10
30	1A-preburn	11
30	1A-postburn	12
30	1C-preburn	13
30	1C-postburn	14
30	1D-preburn	15
30	1D-postburn	16
31	1	1
31	2	2
31	3	3
31	4	4
31	5	5
31	6	6
31	7	7
31	8	8
31	9	9
31	10	10
32	1A	1
32	1B	2
32	1C	3
32	2A	4
32	2B	5
32	3A	6
32	3B	7
32	4A	8
32	4B	9
32	4C	10
32	5A	11
32	5B	12
32	5C	13
32	6A	14
32	6B	15
32	6C	16
32	7A	17
32	7B	18

Ref	Char. code	Int. code	Ref	Char. code	Int. code
32	7C	19	32	13A	30
32	8A	20	32	13B	31
32	9A	21	32	13C	32
32	9B	22	32	13D	33
32	10A	23	32	13E	34
32	10B	24	32	14A	35
32	10C	25	32	14B	36
32	11A	26	32	14C	37
32	12A	27	32	14D	38
32	12B	28	32	14E	39
32	12C	29			

Section 3.4.2, SIMFIRE keyword:
Wind speed is in miles per hour 20 feet above the vegetation, not 20 feet above the ground

Three additional fields have been added to the SimFire keyword.
Field 5: Mortality Code. 0 = Turn off FFE mortality predictions, 1 = FFE estimates mortality.
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.

The percentage of stand area burned affects many of the fire effects calculations, such as mortality, fuel consumption, smoke production, and mineral soil exposure.

Section 3.4.2, MOISTURE keyword:
To implement the new fuel models, the "live" surface fuel category needed to be split into two categories, one for live woody fuel and one for live herbaceous fuel. As a result, an 8th field was added to this keyword. Field 7 now represents the percent moisture for live woody fuel and field 8 represents the percent moisture for live herbaceous fuel.

Section 3.4.2, FlameAdj keyword:
One field has been added to the SimFire keyword.
Field 5: Scorch height (ft). If entered in addition to flame length and percent crowning, this sets the scorch height for the simulated fire. If left blank, the scorch height is estimated based on the flame length and percent crowning of the fire.

Section 3.4.3, PileBurn keyword:
Field 4: Percent of the affected area into which the fuel is concentrated (area which will be treated, i.e. footprint of piles).

Section 3.4.4, POTFMOIS keyword:
To implement the new fuel models, the "live" surface fuel category needed to be split into two categories, one for live woody fuel and one for live herbaceous fuel. As a result, an 8th field was added to this keyword. Field 7 now represents the percent moisture for live woody fuel and field 8 represents the percent moisture for live herbaceous fuel.

Section 3.4.4, New keywords:
The LS fuel model logic uses the season of the burn to determine the fuel model and in its fire-related mortality predictions. As a result, a new keyword, POTFSEAS, was created so that users can control the season of potential fires. The season of the fire does not affect other FFE variants.

POTFSEAS - controls the season of the burn for potential fire calculations. (Currently used in LS-FFE only.)
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 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 is 1.

The keyword POTFPAB was created so that users can control the percentage of the stand area that is assumed burned for potential fires, which is used in the fire effect calculations.

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%.

Section 3.4.5, DEFULMOD keyword:
Loadings should be entered in lbs/ft^2.

To implement the new fuel models, the “live” surface fuel category needed to be split into two categories, one for live woody fuel and one for live herbaceous fuel. As a result, two new fields were added to this keyword. Field 6 now represents the surface to volume ratio of the live woody fuel. Field 10 represents the loading for the live woody fuel. Field 13 represents the surface to volume ratio for the live herbaceous fuel. Field 14 represents the loading for the live herbaceous fuel.

Section 3.4.5, FUELMODL keyword:
The new fuel models (Scott and Burgan 2005) were added and can now be selected with the FuelModl keyword. These should be added to **Table 3.2.** The fuel model can also be set within the StandInit table of an input FVS database.

Section 3.4.5, new keywords:

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 new fuel models) or can choose to predict fire behavior from modelled fuel loads directly. The SAV 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 fm89. See Appendix C for more details on the new fuel model logic and the modelled loads option.

Field 1: Year or cycle in which the fire behavior calculations will be changed. Default = 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

FMODLIST - Adjust the fuel models available for selection in conjuction with the new fuel model logic (also see FireCalc keyword). Fuel models can either be turned "on" (they will be part of the potential fuel model pick list) or turned "off". See Appendix C for details on the new fuel model logic and 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 = 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

Section 3.4.6 Canopy fuels:

Add this section with the following description:
Estimates of canopy base height and canopy bulk density help determine whether a surface fire, passive crown fire, or active crown fire are simulated. By default, CBH and CBD are calculated as described in section 2.4.7. Users can alter these calculations with the CanCalc keyword.

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. Default is 0 = conifers only. 1 = all species.
Field 4: Cutoff value used in determining canopy base height. Default is 30 lbs/acre/foot

Table 3.6:

FUELMOVE is in section 3.7.3
FUELTRET is in section 3.7.3
PRUNE is in section 3.7.1
SALVAGE is in section 3.7.2
YARDLOSS is in section 3.7.1

Section 3.7.1, Yardloss keyword:

Description should say: Set the proportion of cut stems that are left in the stand and, of those, set the portion that are left down. Also specify the proportion of branchwood that is left from removed stems.

Description of fields should match the description in Suppose.
Field 2: Proportion of cut stems left in the stand.
Field 3: Proportion of left stems that are down.
Field 4: Proportion of branchwood left from removed stems. (Proportion of unmerchantable wood left from removed stems in the eastern variants.)

Section 3.7.2 Snag Management

An additional keyword, SALVSP, is now available:

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 calender year.
Field 2: Species or species group. Default is all.
Field 3: Whether the species listed in field 2 is to be cut or left in subsequent salvage operations. 0 = cut this species. 1 = leave this species. Default is 0.

Also, the Salvage keyword was recently modified. It now gets processed only at the beginning of each cycle, like the thinning keywords. So any time a Salvage keyword is set for mid-cycle, it will get moved up and will actually be done at the beginning of the cycle.

The following new section is inserted:

3.8 Carbon Accounting Keywords

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 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 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.

```
Line     |                           Column Ruler
Number   | ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
         | Keyword      Field 1   Field 2   Field 3   Field 4   Field 5   Field 6   Field 7
    1-11 | see figure 3.1
   FFE 1 | ThinBBA         2010       100
   FFE 2 | Fmin
   FFE 3 | SimFire         2025
   FFE 4 | CarbCalc                             0.1         6         6
```

```
  FFE 5   CarbRept                       5
  FFE 6   CarbCut                        5
  FFE 7   FuelOut                        5
  FFE 8   PotFire                        5
  FFE 9   End
  12-17   See figure 3.1
```

Figure 3.14 A keyword file to simulate a thin-from-below harvest followed by a fire. Keywords added to configure the algorithms, output units, decay rate and diameter breakpoints for carbon accounting, and to print the two carbon reports.

The following section number: Output Keywords is incremented from **3.8 to 3.9**. Tables in the Output Keywords section and later (currently Tables 3.14 – 3.17) will need to be incremented.

3.9 Output Keywords

Four additional output keywords, CanFProf, SoilHeat, CarbRept and CarbCut are now available. The following text is inserted following the SVIMAGES keyword. Figure 3.8 and Figure 3.15 should be updated to include examples of the 4 new keywords:

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 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.

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: Interval to output; default is 1 (every year).

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

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

CARBREPT Request the stand carbon 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: Interval to output; default is 1 (every year).

CARBCUT Request the harvested products 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: Interval to output; default is 1 (every year).

The following section, currently **3.9**, is incremented from 3.9 to **3.10**.

Section 3.10 Using the FVS Event Monitor:

The POTFLEN function returns the flame lengths reported in the potential fire report. If arg1 = 1, total flame length under severe conditions is returned. If arg1 = 2, total flame length under moderate conditions is returned. If arg1 = 3, surface fire flame length under severe conditions is returned. If arg1 = 4, surface fire flame length under moderate conditions is returned.

The SNAGS function was altered to accept an 8th argument. If the 8th argument is 0, values from the beginning of a cycle are returned. If the 8th argument is 1, post salvage and thinning values are returned.

Eight new FFE event monitor functions are available.

PotFMort(arg1) returns potential fire mortality.
Arg1 = 1 returns potential severe fire mortality in terms of % BA
Arg1 = 2 returns potential moderate fire mortality in terms of %BA
Arg1 = 3 returns potential severe fire mortality in terms of total cuft/acre
Arg1 = 4 returns potential moderate fire mortality in terms of total cuft/acre

FuelMods(arg1, arg2) returns the fuel models and associated weights being used.
Arg1 = 1, 2, 3, or 4 and controls which fuel model / weight is returned.
Arg2 = 1 returns the actual fuel model number
Arg2 = 2 returns the associated weight

SalvVol(arg1, arg2, arg3) returns salvage volume removed by species and diameter.
Arg1 = species (0 = all species)
Arg2 = the lower limit dbh in inches (greater than or equal to)
Arg3 = the upper limit dbh in inches (less than)

In the western variants, the volume is in terms of total cuft/acre; in the eastern variants, the volume is in merchantable cuft/acre.

When more than one salvage operation is done in a cycle, SalvVol returns the cumulative volume.

PotFType(arg1) returns potential fire type.
Arg1 = 1 returns potential severe fire type
Arg1 = 2 returns potential moderate fire type

The returned value is numeric as follows:
1 = surface fire
2 = passive crown fire
3 = active crown fire
4 = conditional crown fire

PotSRate(arg1) returns potential fire spread rate in feet/min.
Arg1 = 1 returns the potential severe fire spread rate assuming a surface fire
Arg1 = 2 returns the potential moderate fire spread rate assuming a surface fire
Arg1 = 3 returns the final potential severe fire spread rate (taking any crown fire activity into account)
Arg1 = 4 returns the final potential moderate fire spread rate (taking any crown fire activity into account)

PotReInt(arg1) returns potential fire reaction intensity in BTU/ft2/min.
Arg1 = 1 returns potential severe fire reaction intensity
Arg1 = 2 returns potential moderate fire reaction intensity

TreeBio(arg1, arg2, arg3, arg4, arg5, arg6, arg7, arg8) returns the biomass (dry weight tons per acre) of standing tree (live and/or dead) and the biomass of tree removed from the stand through harvest and/or salvage.

Arg1 = trees to include: (<0 = standing trees only; 0=removed trees only; >0 = both)
Arg2 = trees to include: (<0 = dead trees only; 0=live trees only; >0 = both)
Arg3 = tree portion to include: (<0 = tree stems only; 0=tree crowns only;
>0 = both; 2 = foliage (only for live standing trees))
Arg4 = species; 0 = ALL.
Arg5 = the lower diameter limit (ft); default is 0.
Arg6 = the upper diameter limit (ft); default is a large number.
Arg7 = the lower height limit (ft); default is 0.
Arg8 = the upper height limit (ft); default is a large number.

CarbStat(arg1) returns carbon stored in various pools, in whatever units are designated with the CarbCalc keyword. The following pools correspond exactly to those reported in the two existing FFE carbon reports.

Arg1 = 1 returns the total aboveground live tree carbon
Arg1 = 2 returns the merchantable aboveground live tree carbon
Arg1 = 3 returns the belowground live carbon (roots)
Arg1 = 4 returns the belowground dead carbon (roots of dead or cut trees)
Arg1 = 5 returns the standing dead carbon
Arg1 = 6 returns the down dead wood carbon
Arg1 = 7 returns the forest floor carbon
Arg1 = 8 returns the shrub and herb carbon
Arg1 = 9 returns the total stand carbon
Arg1 = 10 returns the total removed carbon
Arg1 = 11 returns the carbon released from fire
Arg1 = 12 returns the merchantable removed carbon in wood products
Arg1 = 13 returns the merchantable removed carbon in landfills
Arg1 = 14 returns the merchantable removed carbon emitted with energy capture
Arg1 = 15 returns the merchantable removed carbon emitted without energy capture
Arg1 = 16 returns the merchantable removed stored carbon (products + landfills)
Arg1 = 17 returns the merchantable removed carbon (all categories)

Chapter 4 – Variant Descriptions

Species Name Changes
The common names and codes for some species changed with the release of the western species translator. The following changes should be incorporated into the next version of the FFE documentation:

North Idaho, Eastern Montana, East Cascades, Central Idaho, Tetons, Blue Mountains – other changed to other species
Central Rockies – Rocky Mountain juniper was changed to juniper sp., cottonwoods changed to cottonwood species, oaks changed to oak species
Utah – oak changed to oak species, other changed to other species
Western Sierra – other conifers was changed to other softwoods, other hardwood changed to other hardwoods (part of the California black oak category), red fir changed to California red fir

Sections 4.1 Introduction
The Fire and Fuels Extension (FFE) has been developed for 19 of the Forest Vegetation Simulator (FVS) variants: Northern Idaho, Kookantl, Central Rockies, Utah, Eastern Montana, Western Sierra, Blue Mountains, Eastern Cascades, Central Idaho, Tetons, Southern Oregon/Northern California, Klamath Mountains, Inland California and Southern Cascades, Inland Empire, Southern, Pacific Northwest Coast Westside Cascades, Lake States, and Northeast. 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 document; however, all of the user keywords are described in the FFE Model Description (RMRS-GTR-116, chapter 2).

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 new variants of the Fire and Fuels Extension to FVS.

Sections 4.4.2, 4.8.2, 4.11.2 Snags:
The snag fall rate, snag decay, and snag height loss predictions were modified in the Region 6 variants of FFE, based on work by Kim Mellen, regional wildlife ecologist. Contact Stephanie Rebain (sarebain@fs.fed.us) for more information.

Sections 4.2.3, 4.3.3, 4.4.3, 4.5.3, 4.6.3, 4.7.3, 4.8.3, 4.9.3, 4.10.3, 4.11.3 Fuels:
Live Tree Bole:
The wood density values used (lbs/cuft factors) are based on the green specific gravity values in table 4-3a of The Wood Handbook (Forest Products Laboratory 1999).

Tables 4.4, 4.17, 4.30, 4.47, 4.59, 4.71, 4.86, 4.99, 4.114, 4.126 are incorrect.

The correct density values are listed in Appendix B.

Section 4.3.3 Fuels:
The live and dead surface fuel values for the "other" category in tables 4.20 and 4.21 were updated and taken from:

Ottmar, R.D., Vihnanek, R.E., and Wright, C.S. 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, Idaho: National Wildfire Coordinating Group, National Interagency Fire Center. 73 pp.

The "other" category in the EM variant is modeled as juniper and the following values are now used:

Species		Herbs	Shrubs	Notes
other	E	0.14	0.35	Ottmar photo series, Volume I
	I	0.10	2.06	

		Size Class (in)							
Species		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
other	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

Section 4.5.3 Fuels:
The live and dead surface fuel values for juniper, pinyon pine, and bristlecone pine in tables 4.50 and 4.51 were taken from:

Ottmar, R.D. and R.E. Vihnanek. 2000. Stereo photo series for quantifying natural fuels. Volume IV: pinyon-juniper, sagebrush, and chapparal types in the southwestern United States. PMS 833. Boise, Idaho: National Wildfire Coordinating Group, National Interagency Fire Center. 97 pp.

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.

Section 4.5.7 Fire Behavior Fuel Models
Figure 4.6 – Logic for modeling fire at "low" fuel loads in the CR-FFE variant:
For the ponderosa pine cover type, when crown cover is less than or equal to 60%, understory tree and snag biomass is greater than 0, and the midflame wind speed is less than 7 miles per hour, the fuel model selected was fuel model 8. This was changed to fuel model 5.

In older versions of CR-FFE, the default structure class parameters (percentage of tree height that must be exceeded to find a gap in the height distribution, diameter breakpoint between seedlings/saplings and pole-sized trees, diameter breakpoint between pole-sized trees and large older trees, minimum cover percent needed to qualify as a stratum, minimum trees/acre needed to classify as stand initiation, minimum percent of maximum stand density index to classify as stem exclusion) were used to determine structure class, which was then used to determine the appropriate fuel models for some cover types. However, if users selected the STRCLASS keyword, the parameters they input on this keyword were used instead. Based on input from a CR-FFE validation meeting in October 2004, new versions of CR-FFE use the following structure class parameters for the determination of fuel model:

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

These parameters are only assumed for the fuel model logic, so users can still enter the values they want on the STRCLASS keyword.

Also, the logic for some cover types at low fuel loads was changed.

For the pinyon juniper cover type, the fuel models are now based on canopy cover, with linear interpolation used when canopy cover is near the breakpoints below:
Canopy cover 0 – 30%: fm 2
Canopy cover 30 – 50%: fm 5
Canopy cover 50% and up: fm 6

For the spruce fir cover type, the fuel models are based on structure class:
structure class 0: fm 2
structure class 1: fm 2 (unless the qmd is greater than 1 inch, then fm 5 is used)
structure class 2: fm 8
structure classes 3 – 6: fm 10

For the lodgepole pine cover type, the fuel models are based on structure class:
structure class 0, 1, or 5: fm 5
structure class 2: fm 8
structure class 3, 4, or 6: fm 10

For the mixed conifer cover type, the fuel models logic is described below.
If the total ponderosa pine basal area is > any other species: fm 9
If ponderosa pine is not dominant then the following logic is used:
structure class 0: fm 2 (fm 1 if within a drought period)
structure class 1: fm 5 (fm 6 if within a drought period)
structure class 2: fm 8 (fm 6 if within a drought period)
structure class 3, 4, or 6: fm 10
structure class 5 and canopy cover < 50%: fm 2 (interpolation is used if canopy cover is close to 50%)
structure class 5 and canopy cover >= 50%: fm 8 (interpolation is used if canopy cover is close to 50%)

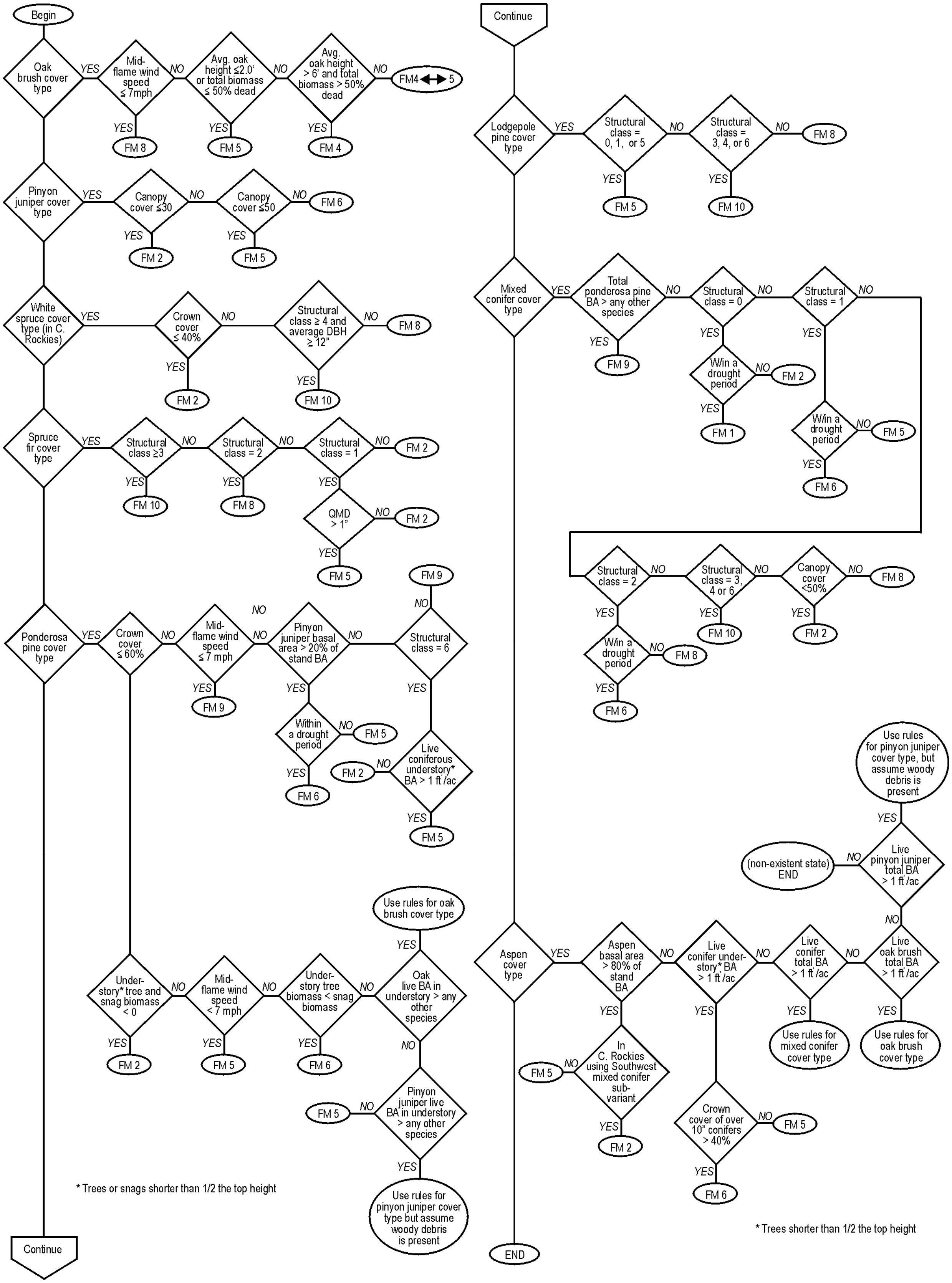


Figure 4.6 – Revised – Logic for modeling fire at "low" fuel loads in the CR-FFE variant

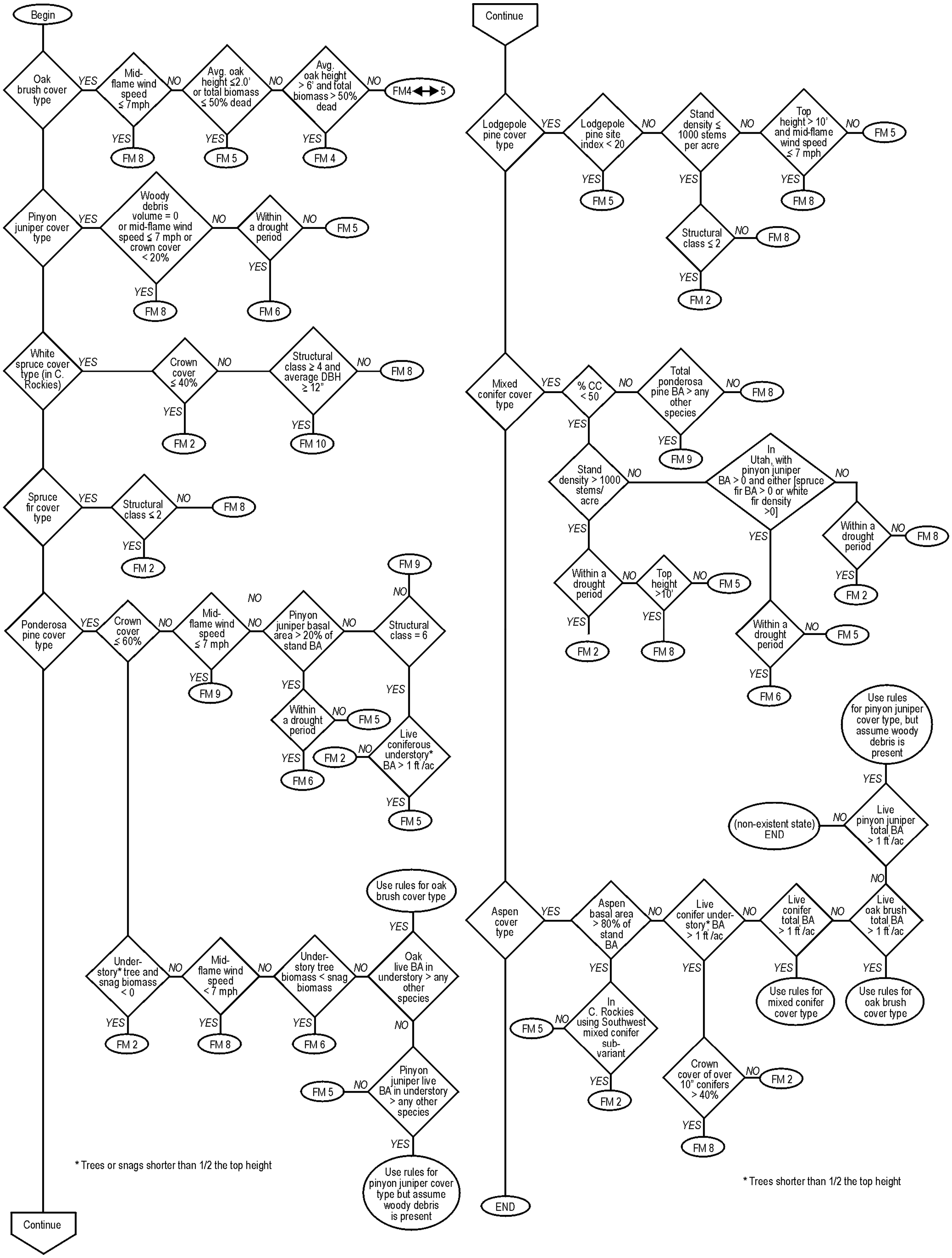
Section 4.6.3 Fuels:

The live and dead surface fuel values for juniper and pinyon pine in tables 4.62 and 4.63 were taken from:

Ottmar, R.D. and R.E. Vihnanek. 2000. Stereo photo series for quantifying natural fuels. Volume IV: pinyon-juniper, sagebrush, and chapparal types in the southwestern United States. PMS 833. Boise, Idaho: National Wildfire Coordinating Group, National Interagency Fire Center. 97 pp.

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.

Section 4.6.7 Fire Behavior Fuel Models



* Trees or snags shorter than 1/2 the top height

* Trees shorter than 1/2 the top height

Figure 4.8 – Revised – Logic for modeling fire at "low" fuel loads in the UT-FFE variant

Section 4.7.3 Fuels:

The values in Table 4.74 are incorrect for California black oak / other hardwoods. The correct live fuel loads are listed below.

Species		Herbs	Shrubs	Notes
California black oak / other hardwoods	E	0.23	0.22	
	I	0.55	0.35	

The values in Table 4.75 are incorrect for California black oak / other hardwoods. The correct dead fuel loads are listed below.

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
California black oak / other hardwoods	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0

Section 4.7.5 Decay Rate:

The values in Table 4.77 are incorrect. The correct decay rates are listed below. Also, the rates are not from Abbott and Crossley, but are based on the decay rates used in the Sierra Nevada Framework.

Table 4.77 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

Table 4.78 was modified to include R5 site classes 6 and 7, which get a decay rate multiplier of 0.5.

Section 4.7.7 Fire Behavior Fuel Models:

The following figure should also be included in section 4.7.7 Fire Behavior Fuel Models for the WS-FFE.

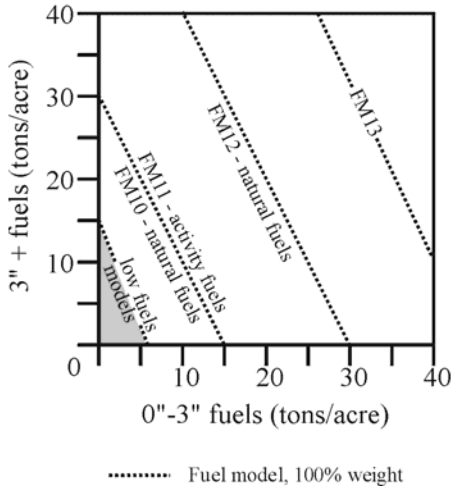
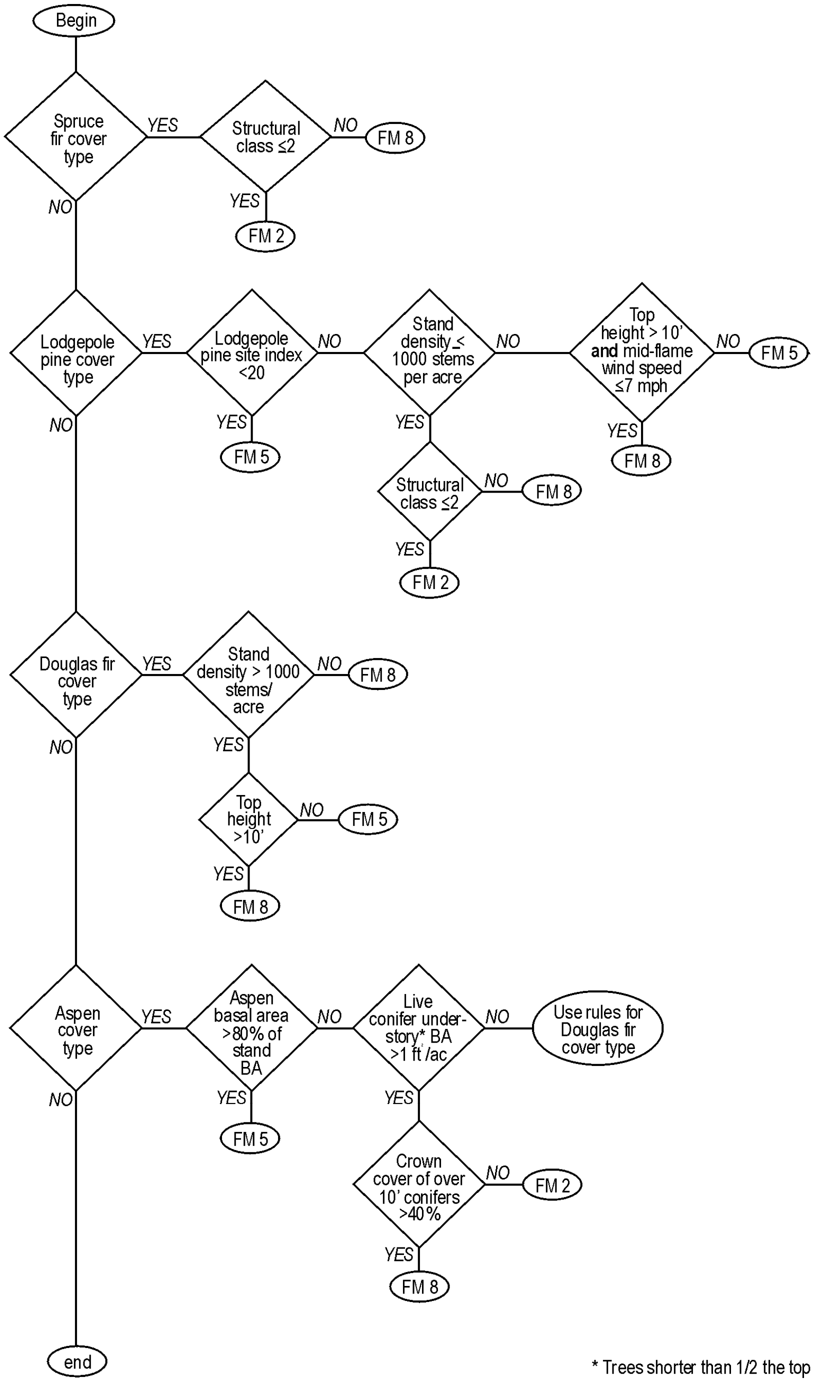


Figure 4.#. If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.82. Otherwise, flame length based on distance between the closest fuel models, identified by the dashed lines, and on recent management (see Model Description Section 4.8 for further details).

Section 4.10.7 Fire Behavior Fuel Models



* Trees shorter than 1/2 the top height

Figure 4.15 – Revised –Logic for modeling fire at "low" fuel loads in the TT-FFE variant

Section 4.11.3 Fuels:
The live and dead surface fuel values for the "other" category in tables 4.129 and 4.130 were updated and taken from:

Ottmar, R.D., Vihnanek, R.E., and Wright, C.S. 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, Idaho: National Wildfire Coordinating Group, National Interagency Fire Center. 73 pp.

The "other" category in the BM variant is modeled as juniper and the following values are now used:

Species		Herbs	Shrubs	Notes
other	E	0.14	0.35	Ottmar photo series, Volume I
	I	0.10	2.06	

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
other	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

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	*Pinus lambertiana*	
Douglas-fir	*Pseudotsuga menziesii*	
white fir	*Abies concolor*	
Pacific madrone	*Arbutus menziesii*	
incense-cedar	*Calocedrus decurrens*	= *Libocedrus decurrens*
California black oak	*Quercus kelloggii*	
tanoak	*Lithocarpus densiflorus*	
California red fir	*Abies magnifica*	
ponderosa pine	*Pinus ponderosa*	
other hardwoods		= *tanoak*
other softwoods		= *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 3 of the FFE Model Description.

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 Tables 4.12.2 and 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 (yr)	All Down (yr)	50% Height (yr)	Hard-to-Soft (yr)	Notes
sugar pine	25	100	20	–	All species: soft snags do not normally occur; height loss stops at 50% of original height
Douglas-fir	35	100	20	–	
white fir	35	100	20	–	
Pacific madrone	20	50	20	–	
incense-cedar	45	100	20	–	
California black oak	20	50	20	–	
tanoak	20	50	20	–	
California red fir	35	100	20	–	
ponderosa pine	25	100	20	–	
other hardwoods	20	50	20	–	
other softwoods	35	100	20	–	

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	Notes
sugar pine	1.24	1.49	–	All species: soft snags do not normally occur; height loss stops at 50% of original height
Douglas-fir	0.88	1.49	–	
white fir	0.88	1.49	–	
Pacific madrone	1.54	1.49	–	
incense-cedar	0.69	1.49	–	
California black oak	1.54	1.49	–	
tanoak	1.54	1.49	–	
California red fir	0.88	1.49	–	
ponderosa pine	1.24	1.49	–	
other hardwoods	1.54	1.49	–	
other softwoods	0.88	1.49	–	

Snag bole volume is determined using the base FVS model equations. The coefficients shown in 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 and others 2001) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in Section 4 of the FFE Model Description.

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 transferred to the FFE after being computed 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 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. Woody density (ovendry lbs/green ft^3) used in the NC-FFE variant.

Species	Density (lbs/ft^3)
sugar pine	21.2
Douglas-fir	28.7
white fir	23.1
Pacific madrone	36.2
incense-cedar	21.8
California black oak	34.9
tanoak	36.2
California red fir	22.5
ponderosa pine	23.7
other hardwoods	36.2
other softwoods	28.7

Tree Crown

As described in the Section 2 of the FFE Model Description, 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 used in the NC-FFE. Species mappings are done for species for which equations are not available.

Species	Species Mapping and Equation Source
sugar pine	western white pine; Brown and Johnston (1976)
Douglas-fir	Brown and Johnston (1976
white fir	grand fir; Brown and Johnston (1976)
Pacific madrone	Snell and Little (1983)
incense-cedar	based on western redcedar; Brown and Johnston (1976)
California black oak	Snell and Little (1983); Snell (1979)
tanoak	Snell and Little (1983), Snell (1979)
California red fir	grand fir; Brown and Johnston (1976)
ponderosa pine	Brown and Johnston (1976)
other conifers	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.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
sugar pine	3	3	10	15	15
Douglas-fir	5	3	10	15	15
white fir	7	3	10	15	15
Pacific madrone	1	1	10	15	15
incense-cedar	5	1	10	15	20
California black oak	1	1	10	15	15
tanoak	1	1	10	15	15
California red fir	7	3	10	15	15
ponderosa pine	3	3	10	10	10
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 by the FFE. 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 (Model Description, Section 4.2). 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 Gambel oak stands reported by Chojnacky (1992).

Table 4.12.7. Values (dry weight, tons/acre) for live fuels used in the NC-FFE. Biomass is linearly interpolated between the "initiating" (I) and "established"(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
sugar pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	1.00	
Douglas-fir	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
white fir	E	0.15	0.10	Grand fir, NI-FFE
	I	0.30	2.00	
Pacific madrone	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
Incense-cedar	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
California black oak	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
tanoak	E	0.25	0.25	aspen , CR-FFE
	I	0.18	2.00	
California red fir	E	0.15	0.10	grand fir, NI-FFE
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	NI-FFE
	I	0.25	1.00	
other softwoods	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
other hardwoods	E	0.25	0.25	aspen, CR-FFE
	I	0.18	2.00	

Dead Fuels

Initial default CWD 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 (Model Description, Section 4.2). Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.12.8). If tree canopy cover is <10 percent, the CWD 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. Initial fuel loads can be modified using the FUELINIT keyword.

Table 4.12.8. Canopy cover and cover type are used to assign default coarse woody debris (tons/acre) by size class for established (E) and initiating (I) stands.

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
sugar pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Pacific madrone	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
incense-cedar	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California black oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
Tanoak	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
California red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
ponderosa pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	15.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	7.0
other softwoods	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
other hardwoods	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6

4.12.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.12.9 are used to calculate single bark thickness (RMRS-GTR-116, 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 and others 2001).

Table 4.12.9. Species specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
sugar pine	0.072
Douglas-fir	0.063
white fir	0.048
Pacific madrone	0.060
incense-cedar	0.060
California black oak	0.030
tanoak	0.052
California red fir	0.039
ponderosa pine	0.063
other softwoods	0.063
other hardwoods	0.052

4.12.5 Decay Rate

Decay of down material is simulated by applying the loss rates shown in Table 4.12.10, as described in section 2.4.5 of the FFE documentation. Default decay rates are based on the decay rates used in the Sierra Nevada Framework.

Table 4.12.10. Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.025	0.02
0.25 – 1		
1 – 3		
3 – 6	0.0125	
6 – 12		
> 12		
Litter	0.5	
Duff	0.002	0.0

The default decay rates are modified by incorporating information from the R5 site class. The multipliers shown in Table 4.12.11 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
6	0.5
7	0.5

By default, the FFE decays all wood species at the rates shown in Table 4.12.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.12.12 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword.

Table 4.12.12. Default wood decay classes used in the NC-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant). Modified decay classes for madrone, California black oak, tanoak and other hardwoods were adopted at the California variants workshop (Stephanie Rebain, pers. comm., February 2003)

Species	Decay Class
sugar pine	4
Douglas-fir	3
white fir	4
madrone	3
incense-cedar	2
California black oak	2
tanoak	4
California 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 (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups shown in Table 4.12.13, or they can specify moisture conditions for each class using the MOISTURE keyword.

Table 4.12.13. Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1 hr.)	3	8	12	12
0.25 – 1.0 in. (10 hr.)	4	8	12	12
1.0 – 3.0 in. (100 hr.)	5	10	14	14
> 3.0 in. (1000+ hr.)	10	15	25	25
Duff	15	50	125	125
Live	70	110	150	150

4.12.7 Fire Behavior Fuel Models

Fire behavior fuel models (Anderson 1982) are determined in two steps: determination of cover classification and determination of dominant species. The first step uses tree cover attributes classified by the California Wildlife Habitat Relationships (CWHR) system (Mayer and Laudenslayer 1988) shown in Table 4.12.14. Following the approach used in the WS-FFE, the table classifies stands by their canopy cover and the size of the larger trees in the stand, predicting CWHR size class and CWHR density class[1] (the third and fourth columns). Mayer and Laudenslayer's class definitions were modified to 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.

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[1] 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.

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 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.

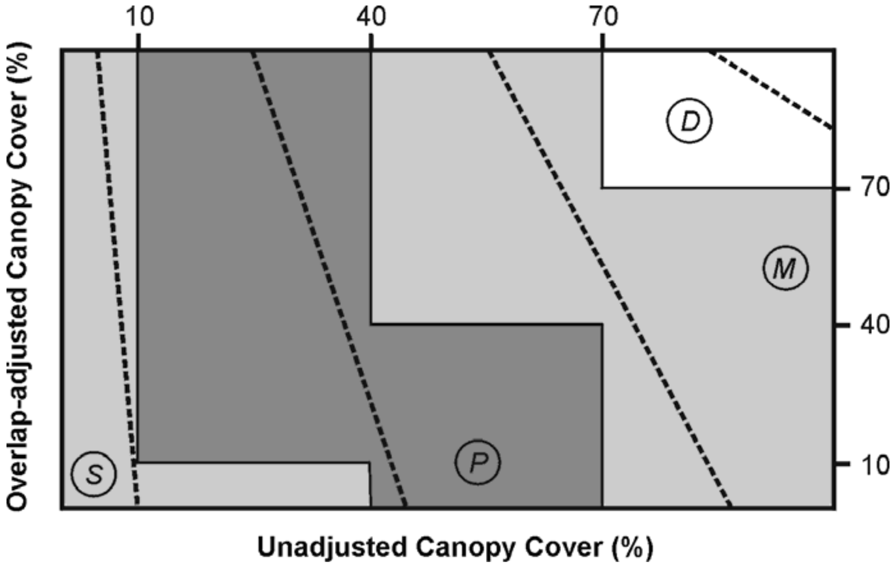

Figure 4.12.1 Two measures of canopy cover, unadjusted and overlap-adjusted percent canopy cover, are used to derive weighted estimates of the four CWHR density classes. (S = sparse, P = open, M = moderate and D = dense)

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 other softwoods 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 4.8 and Figure 4.5 of the FFE Model Description) 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 (Figure 4.12.2). Finally, in order to give Table 4.12.15 priority, FM10 is removed from the list of candidate models when FM11 has been selected from the table.

In some situations a thinning or disturbance may cause one of the selected fuel models to switch from FM8 or FM9 to FM5. When this happens, the transition to these brush fuel models is modified to simulate a delay in brush ingrowth. In the case where an FM8 or FM9 fuel model is predicted to change to FM5, the change is made over five years, gradually shifting from FM8 or FM9 to FM5.

Finally, flame length is calculated using the weights from above the appropriate fuel models. The FLAMEADJ keyword allows users to scale the calculated flame length or override the calculated flame length with a value they choose.

Table 4.12.15. Fire behavior fuels models for the NC-FFE are determined using forest type and CWHR class, as described in the text. The modeling logic allows one or more fuel models to be selected.

Size Class	1	2				3				4				5				6
Density Class		S	P	M	D	S	P	M	D	S	P	M	D	S	P	M	D	
Forest Type																		
Pine	5	6	6	6	6	2	2	9	9	2	2	2	9	2	2	9	9	10
Red fir	5	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
White fir – east side	5	5	5	8	8	11	11	11	8	8	8	8	8	8	8	8	8	10
White fir – west side	5	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
Douglas-fir	5	5	5	6	6	6	6	8	8	11	11	9	8	11	11	9	8	10
Hardwoods	5	5	5	6	6	11	11	11	9	9	9	9	9	9	9	9	9	10
Pine mixed – conifer	5	5	5	6	6	6	6	6	9	9	9	8	8	8	8	8	8	10
Fir mixed – conifer	5	5	5	6	6	6	6	6	8	6	6	8	8	6	6	8	8	10
Other softwoods	5	5	5	6	6	6	6	6	8	6	6	8	8	6	6	8	8	10

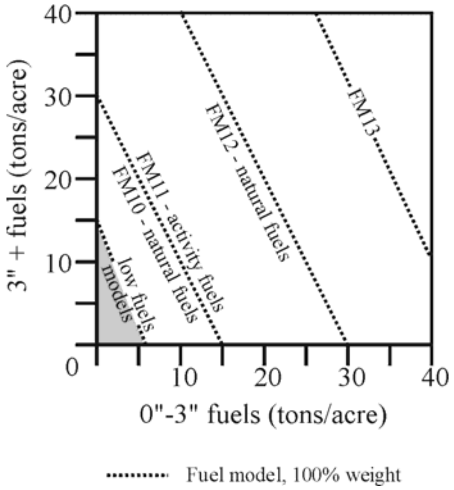

Figure 4.12.2. If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.12.15. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description Section 4.8 for further details).

4.13 Inland California and Southern Cascades (CA)

4.13.1 Tree Species

The Inland California and Southern Cascades variant models the 47 tree species shown in Table 4.13.1. Two additional categories, ‘other hardwoods’ and ‘other softwoods’, are modeled using California black oak and ponderosa pine, respectively.

Table 4.13.1. Tree species simulated by the Inland California and Southern Cascades variant.

Common Name	Scientific Name	Notes
Port-Orford-cedar	*Chamaecyparis lawsonia*	
incense-cedar	*Calocedrus decurrens*	= *Libocedrus decurrens*
western redcedar	*Thuja plicata*	
white fir	*Abies concolor*	
California red fir	*Abies magnifica magnifica*	
Shasta red fir	*Abies magnifica shastensis*	
Douglas-fir	*Pseudotsuga menziesii*	
western hemlock	*Tsuga heterophylla*	
mountain hemlock	*Tsuga mertensiana*	
whitebark pine	*Pinus albicaulis*	
knobcone pine	*Pinus attenuata*	
lodgepole pine	*Pinus contorta*	
Coulter pine	*Pinus coulteri*	
limber pine	*Pinus flexilis flexilis*	
Jeffrey pine	*Pinus jeffreyi*	
sugar pine	*Pinus lambertiana*	
western white pine	*Pinus monticola*	
ponderosa pine	*Pinus ponderosa*	
Monterey pine	*Pinus radiata*	
gray pine	*Pinus sabiniana*	
western juniper	*Juniperus occidentalis*	
Brewer spruce	*Picea breweriana*	
giant sequoia	*Sequoiadendron giganteum*	= *Sequoia gigantea*
Pacific yew	*Taxus brevifolia*	
coast live oak	*Quercus agrifolia*	
canyon live oak	*Quercus chrysolepsis*	
blue oak	*Quercus douglasii*	
Engelmann oak	*Quercus engelmanni*	
Oregon white oak	*Quercus garryana*	
California black oak	*Quercus kelloggii*	
valley white oak	*Quercus lobata*	

Common Name	Scientific Name	Notes
interior live oak	*Quercus wislizenii*	
bigleaf maple	*Acer macrophyllum*	
California buckeye	*Aesculus californica*	
red alder	*Alnus rubra*	
Pacific madrone	*Arbutus menziesii*	
giant chinkapin	*Chrysolepis chrysophylla*	
Pacific dogwood	*Cornus nuttallii*	
Oregon ash	*Fraxinus latifolia*	
walnut species	*Juglans spp.*	
tanoak	*Lithocarpus densiflorus*	
California sycamore	*Platanus racemosa*	
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus trichocarpus*	
willow species	*Salix spp.*	
California nutmeg	*Torreya californica*	
California-laurel	*Umbellularia californica*	
other softwoods		*= ponderosa pine*
other hardwoods		*= California black oak*

4.13.2 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 3 of the FFE Model Description.

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 Tables 4.13.2 and 4.13.3.

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 4.13.2. 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 4.13.3.

Species	95% Fallen (yr)	All Down (yr)	50% Height (yr)	Hard-to-Soft (yr)	Notes
Port-Orford-cedar	25	150	20	–	All species: soft snags do not normally occur; height loss stops at 50% of original height
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	–	
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 chinkapin	20	50	20	–	
Pacific dogwood	20	50	20	–	
Oregon ash	20	50	20	–	

Species	95% Fallen (yr)	All Down (yr)	50% Height (yr)	Hard-to-Soft (yr)	Notes
walnut species	20	50	20	–	
tanoak	20	50	20	–	
California sycamore	20	50	20	–	
quaking aspen	20	50	20	–	
black cottonwood	20	50	20	–	
willow species	20	50	20	–	
California nutmeg	20	50	20	–	
California-laurel	20	50	20	–	
other softwoods	25	100	20	–	
other hardwoods	20	50	20	–	

Table 4.13.3. Default snag fall, snag height loss and soft-snag multipliers for the CA-FFE. These parameters result in the values shown in Table 4.13.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft	Notes
Port-Orford-cedar	1.24	1.0	–	All species: soft snags do not normally occur; height loss stops at 50% of original height
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	–	
canyon live oak	1.55	1.0	–	

Species	Snag Fall	Height loss	Hard-to-Soft	Notes
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 chinkapin	1.55	1.0	–	
Pacific dogwood	1.55	1.0	–	
Oregon ash	1.55	1.0	–	
walnut species	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 species	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	–	

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.13.4 are used to convert volume to biomass.

4.13.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt and others 2001) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in Section 4 of the FFE Model Description.

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 transferred to the FFE after being computed 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 4.13.4 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 chinkapin and California laurel are based on tanoak; and Pacific dogwood is based on bigleaf maple. The value for juniper is from Chojnacky and Moisen (1993).

Table 4.13.4. Woody density (ovendry lbs/green ft^3) used in the CA-FFE variant.

Species	Density (lbs/ft^3)
Port-Orford-cedar	24.3
incense-cedar	21.8
western redcedar	19.3
white fir	23.1
California red fir	22.5
Shasta red fir	22.5
Douglas-fir	28.7
western hemlock	26.2
mountain hemlock	26.2
whitebark pine	22.5
knobcone pine	23.7
lodgepole pine	23.7
Coulter pine	23.7
limber pine	22.5
Jeffrey pine	21.2
sugar pine	21.2
western white pine	22.5
ponderosa pine	23.7
Monterey pine	23.7
gray pine	23.7
western juniper	34.9
Brewer spruce	20.6
giant sequoia	21.2
Pacific yew	26.2
coast live oak	49.9
canyon live oak	49.9
blue oak	37.4
Engelmann oak	37.4
Oregon white oak	37.4
California black oak	34.9
valley white oak	37.4
interior live oak	49.9
bigleaf maple	27.4
California buckeye	37.4
red alder	23.1
Pacific madrone	36.2
giant chinkapin	36.2
Pacific dogwood	27.4
Oregon ash	31.2
walnut species	31.8
tanoak	36.2
California sycamore	28.7
quaking aspen	21.8
black cottonwood	19.3
willow species	22.5
California nutmeg	34.9
California-laurel	36.2
other softwoods	23.7
other hardwoods	34.9

Tree Crown

As described in the Section 2 of the FFE Model Description, 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 4.13.5.

Table 4.13.5. The crown biomass equations used in the CA-FFE. 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 (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	Rocky Mountain Juniper; Grier (1992)
Brewer spruce	Engelmann spruce; Brown and Johnston (1976)
giant sequoia	western redcedar, western hemlock; Brown and Johnston (1976)
Pacific yew	western redcedar; Brown and Johnston (1976)
coast live oak	tanoak; Snell and Little (1983), Snell (1979)
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)

Species	Species Mapping and Equation Source
Pacific madrone	Snell and Little (1983)
giant chinkapin	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 species	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	bigtooth aspen; Smith (1985), Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
black cottonwood	Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
willow species	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 4.13.6. 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 4.13.6. Life span of live and dead foliage (yr) and dead branches for species modeled in the CA-FFE variant.

	Live	Dead			
Species	Foliage	Foliage	<0.25”	0.25–1”	> 1”
Port-Orford-cedar	4	3	10	15	20
incense-cedar	5	1	10	15	20
western redcedar	5	3	10	15	20
white fir	7	3	10	15	15
California red fir	7	3	10	15	15
Shasta red fir	7	3	10	15	15
Douglas-fir	5	3	10	15	15
western hemlock	5	3	10	15	15
mountain hemlock	4	3	10	15	15
whitebark pine	3	3	10	15	15
knobcone pine	4	3	10	15	15
lodgepole pine	3	3	10	15	15
Coulter pine	3	3	10	15	15
limber pine	3	3	10	15	15
Jeffrey pine	3	3	10	15	15
sugar pine	3	3	10	15	15
western white pine	3	3	10	15	15

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
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
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 chinkapin	1	1	10	15	15
Pacific dogwood	1	1	10	15	15
Oregon ash	1	1	10	15	15
walnut species	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 species	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 by the FFE. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.13.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand (Model Description, Section 4.2). When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.13.7). 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 4.13.7) 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 Gambel oak stands reported by Chojnacky (1992). 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.

Table 4.13.7. Values (dry weight, tons/acre) for live fuels used in the CA-FFE. Biomass is linearly interpolated between the "initiating" (I) and "established"(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
Port-Orford-cedar	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
incense-cedar	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
western redcedar	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
white fir	E	0.15	0.10	grand fir, NI-FFE
	I	0.30	2.00	
California red fir	E	0.15	0.10	grand fir, NI-FFE
	I	0.30	2.00	
Shasta red fir	E	0.15	0.10	grand fir, NI-FFE
	I	0.30	2.00	
Douglas-fir	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
western hemlock	E	0.20	0.20	NI-FFE
	I	0.40	2.00	
mountain hemlock	E	0.15	0.20	subalpine fir, NI-FFE
	I	0.30	2.00	
whitebark pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	0.10	
knobcone pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	0.10	
lodgepole pine	E	0.20	0.10	NI-FFE
	I	0.40	0.10	
Coulter pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	0.10	
limber pine	E	0.20	0.10	lodgepole pine, NI-FFE
	I	0.40	0.10	
Jeffrey pine	E	0.20	0.25	ponderosa pine, NI-FFE
	I	0.25	1.00	
sugar pine	E	0.20	0.25	ponderosa pine, NI-FFE
	I	0.25	1.00	
western white pine	E	0.15	0.10	NI-FFE
	I	0.30	0.20	
ponderosa pine	E	0.20	0.25	NI-FFE
	I	0.25	1.00	
Monterey pine	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
gray pine	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
western juniper	E	0.14	0.35	Ottmar photo series, Volume I

Species		Herbs	Shrubs	Notes
	I	0.10	2.06	
Brewer spruce	E	0.15	0.20	Engelmann spruce, NI-FFE
	I	0.30	2.00	
giant sequoia	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
Pacific yew	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
coast live oak	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
canyon live oak	E	0.25	0.25	aspen, CR-FFE
	I	0.18	2.00	
blue oak	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
Engelmann oak	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
Oregon white oak	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
California black oak	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
valley white oak	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
interior live oak	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	
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 chinkapin	E	0.25	0.25	aspen, CR-FFE
	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 species	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
tanoak	E	0.25	0.25	aspen, CR-FFE
	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	CR-FFE
	I	0.18	2.00	
black cottonwood	E	0.25	0.25	aspen, CR-FFE
	I	0.18	2.00	
willow species	E	0.25	0.25	aspen, CR-FFE
	I	0.18	2.00	
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	

Species		Herbs	Shrubs	Notes
other softwoods	E	0.20	0.20	Douglas-fir, NI-FFE
	I	0.40	2.00	
other hardwoods	E	0.23	0.22	Gambel oak, CR-FFE
	I	0.55	0.35	

Dead Fuels

Initial default CWD 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 (Model Description, Section 4.2). Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.13.8). If tree canopy cover is <10 percent, the CWD 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 4.13.8) representing the two dominant species. Those two estimates are themselves weighted by the relative amount of the two dominant species. Initial fuel loads can be modified using the FUELINIT keyword.

Table 4.13.8. Canopy cover and cover type are used to assign default coarse woody debris (tons/acre) by size class for established (E) and initiating (I) stands.

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
Port-Orford-cedar	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
incense-cedar	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
western redcedar	E	1.6	1.6	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
California red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Shasta red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Douglas-fir	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
western hemlock	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
whitebark pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
knobcone pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
lodgepole pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Coulter pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
limber pine	E	0.7	0.7	1.6	2.5	2.5	0.0	1.4	5.0
	I	0.1	0.1	0.2	0.5	0.5	0.0	0.5	0.8
Jeffrey pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0

Species		**Size Class (in)**							
		< 0.25	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
sugar pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
western white pine	E	1.0	1.0	1.6	10.0	10.0	10.0	0.8	30.0
	I	0.6	0.6	0.8	6.0	6.0	6.0	0.4	12.0
ponderosa pine	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
Monterey pine	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
gray pine	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
western juniper	E	0.1	0.2	0.4	0.5	0.8	1.0	0.1	0.0
	I	0.2	0.4	0.2	0.0	0.0	0.0	0.2	0.0
Brewer spruce	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
giant sequoia	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Pacific yew	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
coast live oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
canyon live oak	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
blue oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
Engelmann oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
Oregon white oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
California black oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
valley white oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
interior live oak	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0
bigleaf maple	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California buckeye	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
red alder	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Pacific madrone	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
giant chinkapin	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
Pacific dogwood	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
Oregon ash	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
walnut species	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
tanoak	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
California sycamore	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
quaking aspen	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
willow 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
California nutmeg	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
California-laurel	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
other softwoods	E	0.9	0.9	1.2	7.0	8.0	0.0	0.6	10.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	5.0
other hardwoods	E	0.3	0.7	1.4	0.2	0.1	0.0	3.9	0.0
	I	0.1	0.1	0.0	0.0	0.0	0.0	2.9	0.0

4.13.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires. The bark thickness multipliers in Table 4.13.9 are used to calculate single bark thickness (RMRS-GTR-116, 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 and others 2001).

Table 4.13.9. 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
lodgepole pine	0.028	giant chinkapin	0.045
Coulter pine	0.063	Pacific dogwood	0.062
limber pine	0.030	Oregon ash	0.042
Jeffrey pine	0.068	walnut species	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 species	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		

4.13.5 Decay Rate

Decay of down material is simulated by applying the loss rates shown in Table 4.13.10, as described in section 2.4.5 of the FFE documentation. Default decay rates are based on the decay rates used in the Sierra Nevada Framework.

Table 4.13.10. 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 4.13.11 modify the default decay rates of Table 4.13.10 to by incorporating a measure of site quality and moisture availability.

Table 4.13.11. The CA-FFE modifies default decay rate (Table 4.13.10) 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, the FFE decays all wood species at the rates shown in Table 4.13.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.13.12 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword.

Table 4.13.12. Default wood decay classes used in the CA-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
Port-Orford-cedar	2
Incense-cedar	2
western redcedar	2
white fir	4
California red fir	4
Shasta red fir	4
Douglas-fir	3
western hemlock	4
mountain hemlock	4
whitebark pine	4
knobcone pine	4
lodgepole pine	4
Coulter pine	4
limber pine	4
Jeffrey pine	4
sugar pine	4
western white pine	4
ponderosa pine	4
Monterey pine	4
gray pine	4
western juniper	2
Brewer spruce	4
giant sequoia	2
Pacific yew	1
coast live oak	2
canyon live oak	2
blue oak	2
Engelmann oak	2
Oregon white oak	2
California black oak	2
valley white oak	2
interior live oak	2
bigleaf maple	4
California buckeye	4
red alder	4
Pacific madrone	3
giant chinkapin	4
Pacific dogwood	4
Oregon ash	4
walnut species	2
tanoak	4
California sycamore	4
quaking aspen	4
black cottonwood	4
willow species	4
California nutmeg	4
California-laurel	2
other softwoods	4
other hardwoods	2

4.13.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups shown in Table 4.13.13, or they can specify moisture conditions for each class using the MOISTURE keyword.

Table 4.13.13. Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1 hr.)	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

4.13.7 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 4.13.14. Following the approach used in the WS-FFE, the table classifies stands by their canopy cover and the size of the larger trees in the stand, predicting CWHR size class and CWHR density class[2] (the third and fourth columns). Mayer and Laudenslayer's class definitions were modified to reflect the tree 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.

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[2] A BASIC-language function named 'CWHRSizeDensity' was provided at the WS-FFE workshop. This function is incorporated into the CA-FFE with some minor housekeeping modifications.

Table 4.13.14. California Wildlife Habitat Relationships, as defined by Mayer and Laudenslayer (1988), with modifications to the tree size and canopy cover class breakpoints for the 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 4.13.1 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.

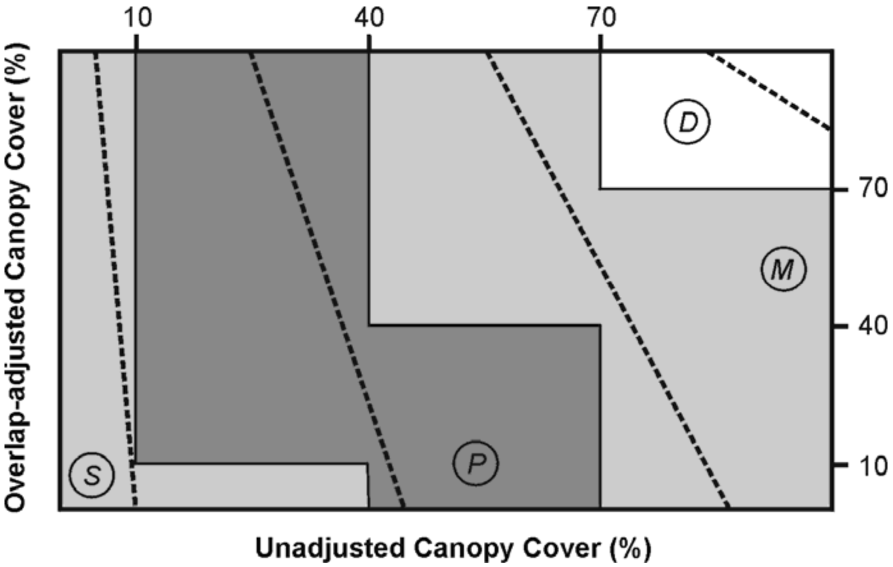


Figure 4.13.1. Two measures of canopy cover, unadjusted and overlap-adjusted percent canopy cover, are used to derive weighted estimates of the four CWHR density classes. (S = sparse, P = open, M = moderate and D = dense)

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 4.13.15. If no species is dominant, then other softwoods is the default cover type.

The rules governing Table 4.13.15 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 4.8 and Figure 4.5 of the FFE Model Description) 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 (Figure 4.13.2). Finally, in order to give Table 4.13.15 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 4.13.15. Fire behavior fuels models for the CA-FFE are determined using forest type and CWHR class, as described in the text. The modeling logic allows one or more fuel models to be selected.

Size Class	**1**	**2**				**3**				**4**				**5**				**6**
Density Class		**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	**S**	**P**	**M**	**D**	
Forest Type																		
Ponderosa pine	5	6	6	6	6	2	2	9	9	2	2	2	9	2	2	9	9	10
Red fir	5	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
White fir – east side	5	5	5	8	8	11	11	11	8	8	8	8	8	8	8	8	8	10
White fir – west side	5	5	5	8	8	11	11	8	8	8	8	8	8	8	8	8	8	10
Douglas-fir	5	5	5	6	6	6	6	8	8	11	11	9	8	11	11	9	8	10
Jeffrey pine	5	2	2	6	6	2	2	2	9	2	2	2	9	2	2	2	9	10
Hardwoods	5	5	5	6	6	11	11	11	9	9	9	9	9	9	9	9	9	10
Lodgepole pine	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	10
Pine mixed – conifer	5	5	5	6	6	6	6	6	9	9	9	8	8	8	8	8	8	10
Fir mixed – conifer	5	5	5	6	6	6	6	6	8	6	6	8	8	6	6	8	8	10
Other softwoods	5	5	5	6	6	6	6	6	8	6	6	8	8	6	6	8	8	10

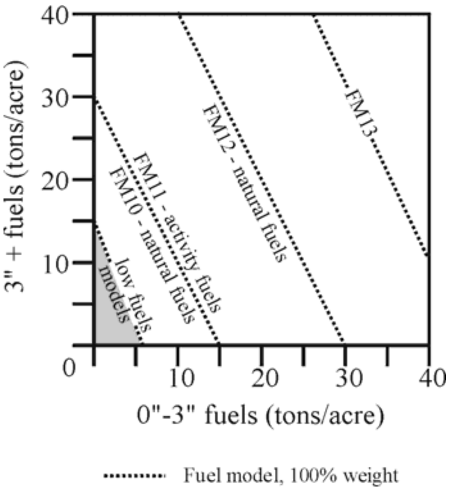


Figure 4.13.2. If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.13.15. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description Section 4.8 for further details).

4.14 Inland Empire (IE)

4.14.1 Tree Species

The Inland Empire variant models the 21 tree species shown in Table 4.14.1. Two additional categories, ‘other hardwoods’ and ‘other softwoods’, are modeled using red alder and mountain hemlock.

Table 4.14.1. Tree species simulated by the Inland Empire variant.

Common Name	Scientific Name	Notes
western white pine	*Pinus monticola*	
western larch	*Larix occidentalis*	
Douglas-fir	*Pseudotsuga menziesii*	
grand fir	*Abies grandis*	
western hemlock	*Tsuga heterophylla*	
western redcedar	*Thuja plicata*	
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
subalpine fir	*Abies lasiocarpa*	
ponderosa pine	*Pinus ponderosa*	
mountain hemlock	*Tsuga mertensiana*	
whitebark pine	*Pinus albicaulis*	
limber pine	*Pinus flexilis*	
subalpine larch	*Larix lyallii*	
pinyon pine	*Pinus edulis*	
Rocky Mountain juniper	*Juniperus scopulorum*	
pacific yew	*Taxus brevifolia*	
quaking aspen	*Populus tremuloides*	
cottonwood species	*Populus spp.*	
Rocky Mountain maple	*Acer glabrum*	
paper birch	*Betula papyrifera*	
other hardwoods		= red alder
other softwoods		= mountain hemlock

4.14.2 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 3 of the FFE Model Description.

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 Tables 4.14.2 and 4.14.3.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.14.4 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 described in the FFE Model Description.

Table 4.14.2. 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 4.14.3.

Species	95% Fallen (yr)	All Down (yr)	50% Height (yr)	Hard-to-Soft (yr)
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
Rocky Mountain juniper	31	100	30	39
Pacific yew	31	100	30	39
quaking aspen	31	100	30	39
cottonwood species	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 4.14.3. Default snag fall, snag height loss and soft-snag multipliers for the IE-FFE. These parameters result in the values shown in Table 4.14.2. (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
Rocky Mountain juniper	1.0	1.0	1.0
Pacific yew	1.0	1.0	1.0
quaking aspen	1.0	1.0	1.0
cottonwood species	1.0	1.0	1.0
Rocky Mountain maple	1.0	1.0	1.0
paper birch	1.0	1.0	1.0
other hardwoods	1.0	1.0	1.0
other softwoods	1.0	1.0	1.0

4.14.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt and others 2001) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in Section 4 of the FFE Model Description.

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 transferred to the FFE after being computed 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 4.14.4 for Douglas-fir is based on 'Douglas-fir Interior north'. The values for pinyon pine and juniper are from Chojnacky and Moisen (1993).

Table 4.14.4. Woody density (ovendry lbs/green ft^3) used in the IE-FFE variant.

Species	Density (lbs/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
Rocky Mountain juniper	34.9
Pacific yew (used baldcypress)	26.2
quaking aspen	21.8
cottonwood species (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 of the FFE Model Description, 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 (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 4.14.5. The crown biomass equations used in the IE-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)
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)
mountain hemlock	Gholz (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	Chojnacky (1992), Grier and others (1992)
Rocky Mountain juniper	Chojnacky (1992), Grier and others (1992)
Pacific yew	western redcedar: Brown and Johnston (1976)
quaking aspen	Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
cottonwood species	Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Rocky Mountain maple	big-leaf maple: Snell and Little (1983)
paper birch	aspen: Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other hardwoods	red alder: Snell and Little (1983)
other softwoods	mountain hemlock: Gholz (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 4.14.6. 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 4.14.6. Life span of live and dead foliage (yr) and dead branches for species modeled in the IE-FFE variant.

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
western white pine	4	2	5	5	15
western larch	1	1	5	5	15
Douglas-fir	5	2	5	5	15
grand fir	7	2	5	5	15
western hemlock	5	2	5	5	15
western redcedar	5	2	5	5	20
lodgepole pine	3	2	5	5	15
Engelmann spruce	6	2	5	5	10
subalpine fir	7	2	5	5	15
ponderosa pine	4	2	5	5	10
mountain hemlock	4	2	5	5	15
whitebark pine	3	2	5	5	15
limber pine	3	2	5	5	15
subalpine larch	1	1	5	5	15
pinyon pine	3	2	5	5	15
Rocky Mountain juniper	4	2	5	5	15
Pacific yew	7	2	5	5	15
quaking aspen	1	1	5	5	15
cottonwood species	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 by the FFE. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.14.7). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand (Model Description, Section 4.2). When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.14.7). 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).

Table 4.14.7. Values (dry weight, tons/acre) for live fuels used in the IE-FFE. Biomass is linearly interpolated between the "initiating" (I) and "established"(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
western white pine	E	0.15	0.10	
	I	0.30	2.00	
western larch	E	0.20	0.20	
	I	0.40	2.00	
Douglas-fir	E	0.20	0.20	
	I	0.40	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
western hemlock	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
western redcedar	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
lodgepole pine	E	0.20	0.10	
	I	0.40	1.00	
Engelmann spruce	E	0.15	0.20	
	I	0.30	2.00	
subalpine fir	E	0.15	0.20	
	I	0.30	2.00	
ponderosa pine	E	0.20	0.25	
	I	0.25	0.10	
mountain hemlock	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	
whitebark pine	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	
limber pine	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
subalpine larch	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	
pinyon pine	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
Rocky Mountain juniper	E	0.20	0.25	Use ponderosa pine
	I	0.25	0.10	
Pacific yew	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
quaking aspen	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
cottonwood species	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
Rocky Mountain maple	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	
other hardwoods	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
other softwoods	E	0.15	0.20	Use spruce-subalpine fir
	I	0.30	2.00	

Dead Fuels

Initial default CWD 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 (Model Description, Section 4.2). Default fuel loadings were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) (Table 4.14.8). If tree canopy cover is <10 percent, the CWD 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. Initial fuel loads can be modified using the FUELINIT keyword. Mappings are the same as with the live herb and shrub estimates.

Table 4.14.8. Canopy cover and cover type are used to assign default coarse woody debris (tons/acre) by size class for established (E) and initiating (I) stands.

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

Species		Size Class (in)							
		< 0.25	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
Rocky Mountain maple	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
paper birch	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
other hardwoods	E	0.9	0.9	1.6	3.5	3.5	0.0	0.6	10.0
	I	0.5	0.5	1.0	1.4	1.4	0.0	0.3	5.0
other softwoods	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0

4.14.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.14.9 are used to calculate single bark thickness (RMRS-GTR-116, 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 and others 2001).

Table 4.14.9. 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 *pinus* spp.)	0.030
Rocky Mountain juniper	0.025
Pacific yew	0.025
quaking aspen	0.044
cottonwood species	0.038
Rocky Mountain maple	0.040
paper birch	0.027
other hardwoods	0.026
other softwoods	0.040

4.14.5 Decay Rate

Decay of down material is simulated by applying loss rates to pieces by size class (Table 4.14.10), as described in section 2.4.5 of the FFE documentation. 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 4.14.10. Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.12	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.015	
6 – 12		
> 12		
Litter	0.50	
Duff	0.002	0.0

By default, the FFE decays all wood species at the rates shown in Table 4.14.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.14.11 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword.

Table 4.14.11. 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
Rocky Mountain juniper	2
Pacific yew	1
quaking aspen	4
cottonwood species	4
Rocky Mountain maple	4
paper birch	4
other hardwoods	4
other softwoods	4

4.14.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups (Table 4.14.12) or they can specify moisture conditions for each class using the MOISTURE keyword.

Table 4.14.12. Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

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

4.14.7 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 (Model Description, Section 4.8) 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 the FFE variant to determine a weighted set of fuel models, or
4. allowing the FFE variant 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 4.14.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The habitat types shown in Table 4.14.13 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 4.14.1 or Table 4.14.13. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

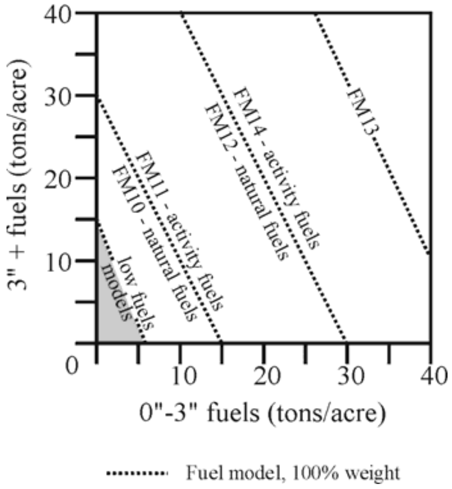


Figure 4.14.1. If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Table 4.14.13. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description Section 4.8 for further details).

Table 4.14.13. When low fuel loads are present in the IE-FFE, fire behavior fuel models are determined using one of three habitat groups: dry grassy, dry shrubby and other. Fuel model is linearly interpolated between the two low fuel models when canopy cover falls between 30 and 50 percent.

Habitat Type Number	Habitat Type Name	FFE Habitat Category	Canopy Cover < 30%	Canopy Cover > 50%
			Fuel Model	
130	PIPO/AGSP	Dry Grassy	1	9
140	PIPO/FEID			
210	PSME/AGSP			
220	PSME/FEID			
230	PSME/FESC			
161	PIPO/PUTR	Dry Shrubby	2	9
170	PIPO/SYAL			
171	PIPO/SYAL-SYAL			
172	PIPO/SYAL-BERE			
180	PIPO/PRVI			
181	PIPO/PRVI-PRVI			
182	PIPO/PRVI-SHCA			
310	PSME/SYAL			
311	PSME/SYAL-AGSP			
312	PSME/SYAL-CARU			
313	PSME/SYAL-SYAL			
All others		Other	8	8

4.15 Southern (SN)

4.15.1 Tree Species

The Southern variant models the 90 tree species categories shown in Table 4.15.1.

Table 4.15.1. Tree species simulated by the Southern variant.

Common name	Scientific name
fir species	*Abies spp.*
redcedar species	*Juniperus spp.*
spruce species	*Picea spp.*
sand pine	*Pinus clausa*
shortleaf pine	*Pinus echinata*
slash pine	*Pinus elliottii*
spruce pine	*Pinus glabra*
longleaf pine	*Pinus palustris*
table mountain pine	*Pinus pungens*
pitch pine	*Pinus rigida*
pond pine	*Pinus serotina*
eastern white pine	*Pinus strobus*
loblolly pine	*Pinus taeda*
Virginia pine	*Pinus virginiana*
baldcypress	*Taxodium distichum*
pondcypress	*Taxodium distichum var. nutans*
hemlock species	*Tsuga spp.*
Florida maple	*Acer barbatum*
boxelder	*Acer negundo*
red maple	*Acer rubrum*
silver maple	*Acer saccharinum*
sugar maple	*Acer saccharum*
buckeye/horsechestnut species	*Aesculus spp.*
birch species	*Betula spp.*
sweet birch	*Betula lenta*
American hornbeam	*Carpinus caroliniana*
hickory species	*Carya spp.*
catalpa	*Catalpa spp.*
hackberry species	*Celtis spp.*
eastern redbud	*Cercis canadensis*
flowering dogwood	*Cornus florida*
common persimmon	*Diospyros virginiana*
American beech	*Fagus grandifolia*
ash species	*Fraxinus spp.*
white ash	*Fraxinus americana*
magnolia species	*Magnolia spp.*
cucumbertree	*Magnolia acuminata*
southern magnolia	*Magnolia grandiflora*
sweetbay	*Magnolia virginiana*
bigleaf magnolia	*Magnolia macrophylla*
apple species	*Malus spp.*
mulberry species	*Morus spp.*
water tupelo	*Nyssa aquatica*
blackgum/black tupelo	*Nyssa sylvatica*
swamp tupelo	*Nyssa sylvatica var. biflora*
eastern hophornbeam	*Ostrya virginiana*
sourwood	*Oxydendrum arboreum*
redbay	*Persea borbonia*
sycamore	*Platanus occidentalis*
cottonwood species	*Populus spp.*
bigtooth aspen	*Populus grandidentata*
black cherry	*Prunus serotina*
white oak	*Quercus alba*
scarlet oak	*Quercus coccinea*
southern red oak	*Quercus falcata var. falcata*
cherrybark oak	*Quercus falcata*
turkey oak	*Quercus laevis*
laurel oak	*Quercus laurifolia*
overcup oak	*Quercus lyrata*
blackjack oak	*Quercus marilandica*
swamp chestnut oak	*Quercus michauxii*
chinkapin oak	*Quercus muehlenbergii*
water oak	*Quercus nigra*
chestnut oak	*Quercus prinus*
northern red oak	*Quercus rubra*
Shumard oak	*Quercus shumardii*
post oak	*Quercus stellata*
black oak	*Quercus velutina*
live oak	*Quercus virginiana*
black locust	*Robinia pseudoacacia*

Common name	Scientific name	Common name	Scientific name
black ash	*Fraxinus nigra*	willow species	*Salix spp.*
green ash	*Fraxinus pennsylvanica*	sassafras	*Sassafras albidum*
honeylocust	*Gleditsia triacanthos*	basswood species	*Tilia spp.*
loblolly-bay	*Gordonia lasianthus*	elm species	*Ulmus spp.*
silverbell	*Halesia spp.*	winged elm	*Ulmus alata*
American holly	*Ilex opaca*	American elm	*Ulmus americana*
butternut	*Juglans cinerea*	slippery elm	*Ulmus rubra*
black walnut	*Juglans nigra*	other softwoods	
sweetgum	*Liquidambar styraciflua*	other hardwoods	
yellow-poplar	*Liriodendron tulipifera*	other species	

4.15.2 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 3 of the FFE Model Description.

Three 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; 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 4.15.2. 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 Tables 4.15.3 and 4.15.4.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.15.5 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 described in the FFE Model Description.

Table 4.15.2. Snag class for each species in SN-FFE.

Species	Snag class
fir species	2
redcedar species	3
spruce species	2
sand pine	1
shortleaf pine	1
slash pine	1
spruce pine	1
longleaf pine	1
table mountain pine	1
pitch pine	1
pond pine	1
eastern white pine	1
loblolly pine	1
Virginia pine	1
baldcypress	3
pondcypress	3
hemlock species	2
Florida maple	2
boxelder	2
red maple	2
silver maple	2
sugar maple	2
buckeye/horsechestnut species	2
birch species	1
sweet birch	1
American hornbeam	2
hickory species	3
catalpa	2
hackberry species	2
eastern redbud	2
flowering dogwood	2
common persimmon	3
American beech	2
ash species	2
white ash	2
black ash	2
green ash	2
honeylocust	3
loblolly-bay	2
silverbell	2
American holly	2
butternut	2
black walnut	2
sweetgum	2
yellow-poplar	2
magnolia species	2
cucumbertree	2
southern magnolia	2
sweetbay	2
bigleaf magnolia	2
apple species	2
mulberry species	2
water tupelo	3
blackgum/black tupelo	3
swamp tupelo	3
eastern hophornbeam	2
sourwood	2
redbay	2
sycamore	2
cottonwood species	1
bigtooth aspen	1
black cherry	2
white oak	3
scarlet oak	2
southern red oak	2
cherrybark oak	2
turkey oak	2
laurel oak	2
overcup oak	2
blackjack oak	3
swamp chestnut oak	2
chinkapin oak	3
water oak	3
chestnut oak	2
northern red oak	2
Shumard oak	2
post oak	3
black oak	2
live oak	2
black locust	3
willow	1
sassafras	2
basswood species	1
elm species	1
winged elm	1
American elm	1
slippery elm	1
other softwoods	1
other hardwoods	2
other species	2

Table 4.15.3. 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 4.15.4.

Snag Class	95% Fallen (yr)	All Down (yr)	50% Height (yr)	Hard-to-Soft (yr)	Notes
1	3	6 (pines are 50)	--	2	Snag height loss is not modeled in SN-FFE
2	7	15	--	6	
3	11	25 (RC is 100)	--	10	

Table 4.15.4. Default snag fall, snag height loss and soft-snag multipliers for the SN-FFE. These parameters result in the values shown in Table 4.15.3. (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.

Figures 4.15.1, 4.15.2, and 4.15.3 show how these values translate for 10 and 20 inch snags of varying species.

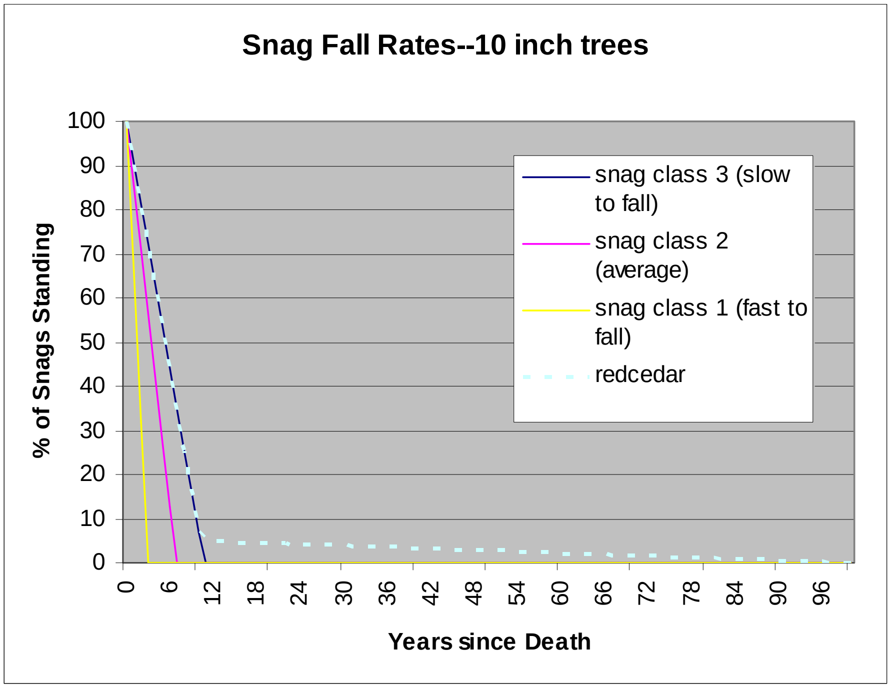


Figure 4.15.1. Snag fall rates for 10 inch trees.

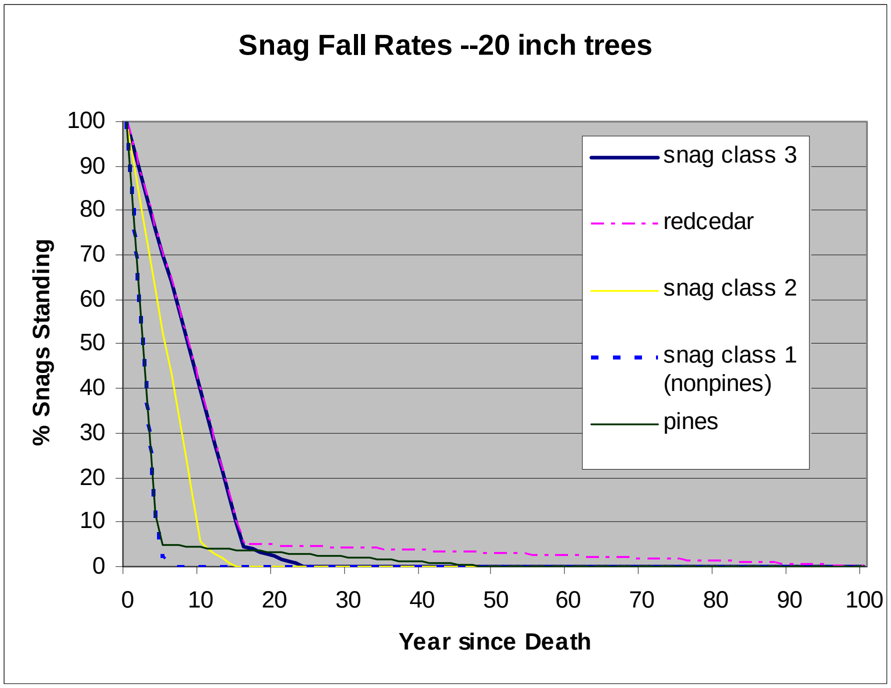


Figure 4.15.2. Snag fall rates for 20 inch trees.

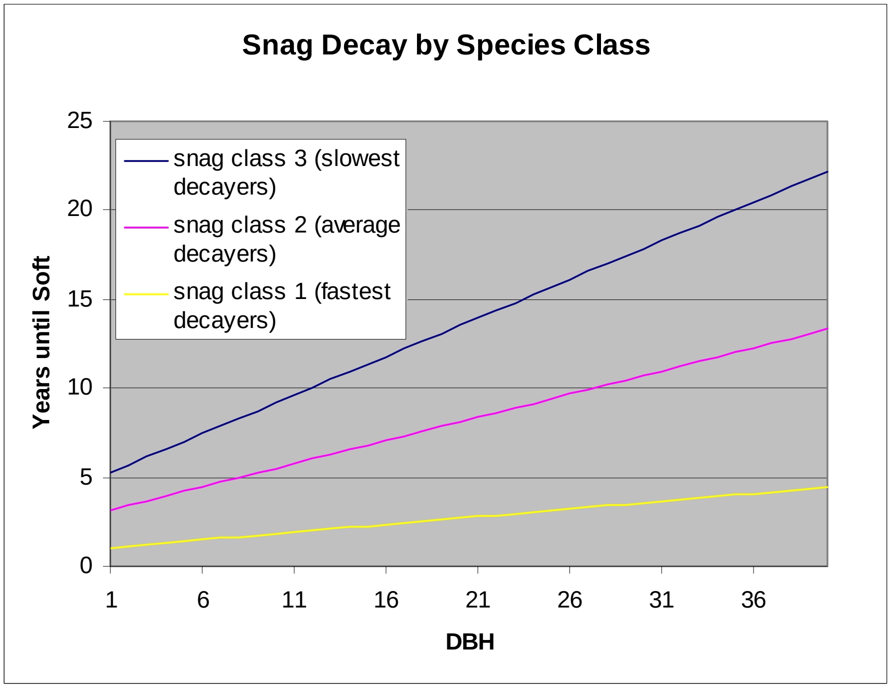


Figure 4.15.3. The number of years until soft for various diameter snags.

4.15.3 Fuels

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 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 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 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.
3. Because the total biomass of a tree is calculated by adding the biomass of the merchantable and unmerchantable portions, the minimum merchantable DBH value SHOULD NOT be changed using the Volume keyword.
4. 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 transferred to the FFE after being computed 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, for species not listed, softwoods were mapped to redcedar species and hardwoods were mapped to black oak.

Table 4.15.5. Woody density (ovendry lbs/green ft^3) used in the SN-FFE variant.

Species	lbs/cuft	Species used
fir species	20.6	balsam fir
redcedar species	27.4	
spruce species	23.1	red spruce
sand pine	28.7	
shortleaf pine	29.3	
slash pine	33.7	
spruce pine	25.6	
longleaf pine	33.7	
table mountain pine	28.1	Virginia pine
pitch pine	29.3	
pond pine	31.8	
eastern white pine	21.2	
loblolly pine	29.3	
Virginia pine	28.1	
baldcypress	26.2	
pondcypress	26.2	baldcypress
hemlock species	23.7	
Florida maple	34.9	sugar maple
boxelder	30.6	red maple
red maple	30.6	
silver maple	27.4	
sugar maple	34.9	
buckeye/horsechestnut species	34.9	blackoak
birch species	34.3	yellow birch
sweet birch	37.4	
American hornbeam	34.9	blackoak
hickory species	39.9	shagbark/ mockernut
catalpa	34.9	blackoak
hackberry species	30.6	
eastern redbud	34.9	blackoak
flowering dogwood	34.9	blackoak
common persimmon	34.9	blackoak
American beech	34.9	
ash species	33.1	green ash
white ash	34.3	
black ash	28.1	
green ash	33.1	
honeylocust	37.4	
loblolly-bay	34.9	blackoak
silverbell	34.9	blackoak
American holly	34.9	blackoak
butternut	22.5	
black walnut	31.8	
sweetgum	28.7	
yellow-poplar	24.9	

Species	lbs/cuft	Species used
magnolia species	27.4	cucumbertree
cucumbertree	27.4	
southern magnolia	28.7	
sweetbay	27.4	cucumbertree
bigleaf magnolia	27.4	cucumbertree
apple species	34.9	blackoak
mulberry species	34.9	blackoak
water tupelo	28.7	
blackgum/black tupelo	28.7	
swamp tupelo	28.7	
eastern hophornbeam	34.9	blackoak
sourwood	34.9	blackoak
redbay	34.9	blackoak
sycamore	28.7	
cottonwood species	23.1	
bigtooth aspen	22.5	
black cherry	29.3	
white oak	37.4	
scarlet oak	37.4	
southern red oak	32.4	
cherrybark oak	38.0	
turkey oak	34.9	blackoak
laurel oak	34.9	
overcup oak	35.6	
blackjack oak	34.9	blackoak
swamp chestnut oak	37.4	
chinkapin oak	37.4	whiteoak
water oak	34.9	
chestnut oak	35.6	
northern red oak	34.9	
Shumard oak	34.9	blackoak
post oak	37.4	
black oak	34.9	
live oak	49.9	
black locust	41.2	
willow species	22.5	
sassafras	26.2	
basswood species	20.0	
elm species	28.7	American elm
winged elm	28.7	American elm
American elm	28.7	
slippery elm	29.9	
other softwoods	27.4	redcedar species
other hardwoods	34.9	blackoak
other species	34.9	blackoak

Tree Crown

For trees greater than 4 inches dbh, estimates of crown material, including branchwood and bolewood above a 4 inch top (DOB), are from Smith (1985). Due to the nature of these equations, for trees between 4 and 5 inches in diameter, the estimate for a 5-inch tree is scaled back based on height. These equations do not provide foliage estimates, which are taken from Jenkins et. al. (2003). Also, the Smith 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 (1987), 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. Smith’s equations include branchwood and stem material above a 4 inch DOB top, while the southern 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 trees less than 4 inches dbh, total above ground biomass is predicted using equations in Jenkins et. al. (2003). 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 4.15.6. 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
fir species	8	5
redcedar species	5	1
spruce species	8	5
sand pine	2	6
shortleaf pine	4	6
slash pine	2	6
spruce pine	2	6
longleaf pine	2	6
table mountain pine	3	6
pitch pine	2	6
pond pine	2	6
eastern white pine	2	6
loblolly pine	3	6
Virginia pine	3	6
baldcypress	1	1
pondcypress	1	1
hemlock species	4	5
Florida maple	1	5
boxelder	1	5
red maple	1	5
silver maple	1	5
sugar maple	1	5
buckeye/horsechestnut species	1	5
birch species	1	5
sweet birch	1	5
American hornbeam	1	4
hickory species	1	2
catalpa	1	4
hackberry species	1	4
eastern redbud	1	5
flowering dogwood	1	5
common persimmon	1	4
American beech	1	4
ash species	1	5
white ash	1	5
black ash	1	5
green ash	1	5
honeylocust	1	2
loblolly-bay	1	5
silverbell	1	5
American holly	3	4
butternut	1	4
black walnut	1	4
sweetgum	1	5
yellow-poplar	1	4
magnolia species	1	4
cucumbertree	1	4
southern magnolia	2	4
sweetbay	1	4
bigleaf magnolia	1	4
apple species	1	4
mulberry species	1	5
water tupelo	1	3
blackgum/black tupelo	1	3
swamp tupelo	1	3
eastern hophornbeam	1	4
sourwood	1	5
redbay	1	5
sycamore	1	5
cottonwood species	1	5
bigtooth aspen	1	5
black cherry	1	4
white oak	1	3
scarlet oak	1	4
southern red oak	1	4
cherrybark oak	1	4
turkey oak	1	4
laurel oak	1	4
overcup oak	1	3
blackjack oak	1	2
swamp chestnut oak	1	3
chinkapin oak	1	3
water oak	1	3
chestnut oak	1	3
northern red oak	1	4
Shumard oak	1	4
post oak	1	3
black oak	1	4
live oak	1	5
black locust	1	2
willow species	1	6
sassafras	1	4
basswood species	1	5
elm species	1	5
winged elm	1	5
American elm	1	5
slippery elm	1	5
other softwoods	2	5
other hardwoods	1	5
other species	1	5

Table 4.15.7. Years until all snag crown material of certain sizes has fallen by crown fall class

Crown fall class	Snag Crown Material Time to 100% Fallen (years)					
	Foliage	**<0.25”**	**0.25–1”**	**1-3”**	**3-6”**	**6-12”**
1	1 (RC is 3)	5	5	10	25	25
2	1	3	3	6	12	12
3	1	2	2	5	10	10
4	1	1	1	4	8	8
5	1	1	1	3	6	6
6	1	1	1	2	4	4

Live Herbs and Shrubs

Live herb and shrub fuels are modeled very simply by the FFE. 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).

Table 4.15.8. Values (dry weight, tons/acre) for live fuels used in the SN-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 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.

Table 4.15.9. Forest type is used to assign default coarse woody debris (tons/acre) by size class.

Forest Type	**FIA Forest Type Codes**	Size Class (in)							
		< 0.25	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
White Pine	101-105	0.10	0.50	1.68	0.55	0.64	0.07	4.02	12.52
Longleaf – slash pine	141, 142	0.10	0.66	0.98	0.12	0.29	0.26	6.38	8.66
Loblolly – shortleaf pine	160s	0.14	0.72	1.54	0.25	0.44	0.33	4.90	6.03
Eastern redcedar	181, 402	0.24	1.24	2.72	0.36	0.97	0.33	3.82	3.80
Pine-hardwood	400s (not 402)	0.18	0.77	2.17	0.31	0.86	0.78	4.07	6.15
Oak-hickory	500s	0.13	0.68	1.93	0.43	1.01	1.01	4.28	5.91
Oak-gum-cypress	600s	0.13	0.67	1.83	0.18	0.57	0.77	2.49	5.68

Elm-ash-cottonwood	700s	0.22	1.09	2.68	0.26	0.76	0.43	2.33	1.60
Maple-beech-birch	800s	0.09	0.64	2.03	0.43	1.18	3.38	3.75	4.10

4.15.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.15.10 are used to calculate single bark thickness, which in turn, for most species, is used to calculate fire-related mortality (RMRS-GTR-116, 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 and others 2001). For shortleaf pine, the bark thickness is based on an equation in Harmon (1984). For some species, (northern red oak, black oak, scarlet oak, white oak, chestnut oak, black gum, red maple, and hickory), 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 4.15.10. Species specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species used	Species	Multiplier (V_{sp})	Species used
fir species	0.052		magnolia species	0.039	
redcedar species	0.038		cucumbertree	0.036	
spruce species	0.034		southern magnolia	0.033	
sand pine	0.035		sweetbay	0.04	
shortleaf pine	***		bigleaf magnolia	0.033	
slash pine	0.055		apple species	0.043	
spruce pine	0.035		mulberry species	0.038	red mulberry
longleaf pine	0.049		water tupelo	0.03	
table mountain pine	0.04		blackgum/black tupelo	0.039	
pitch pine	0.045		swamp tupelo	0.037	
pond pine	0.062		eastern hophornbeam	0.037	
eastern white pine	0.045		sourwood	0.036	
loblolly pine	0.052		redbay	0.038	
Virginia pine	0.033		sycamore	0.033	
baldcypress	0.025		cottonwood species	0.04	
pondcypress	0.042		bigtooth aspen	0.039	
hemlock species	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 species	0.036	Ohio buckeye	laurel oak	0.036	
birch species	0.033		overcup oak	0.039	
sweet birch	0.03		blackjack oak	0.037	
American hornbeam	0.03		swamp chestnut oak	0.046	
hickory species	0.04	shagbark hickory	chinkapin oak	0.042	

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

4.15.5 Decay Rate

Decay of down material is simulated by applying loss rates to pieces by size class (Table 4.15.11), as described in section 2.4.5 of the FFE documentation. 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 4.15.11. Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.11	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.07	
6 – 12		
> 12		
Litter	0.65	
Duff	0.002	0.0

By default, the FFE decays all wood species at the rates shown in Table 4.15.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.15.12 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword. The decay rate classes were generally determined from the Wood Handbook

(1999). When species were classified differently for young or old growth, young growth was assumed. 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 4.15.12. Default wood decay classes used in the SN-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
fir species	4
redcedar species	2
spruce species	4
sand pine	4
shortleaf pine	4
slash pine	4
spruce pine	4
longleaf pine	4
table mountain pine	4
pitch pine	4
pond pine	4
eastern white pine	4
loblolly pine	4
Virginia pine	4
baldcypress	3
pondcypress	3
hemlock species	4
Florida maple	4
boxelder	4
red maple	4
silver maple	4
sugar maple	4
buckeye/horsechestnut species	4
birch species	4
sweet birch	4
American hornbeam	3
hickory species	4
catalpa	2
hackberry species	4
eastern redbud	3
flowering dogwood	3
common persimmon	2
American beech	4
ash species	4
white ash	4
black ash	4
green ash	4
honeylocust	2
loblolly-bay	4
silverbell	4
American holly	3
magnolia species	4
cucumbertree	4
southern magnolia	4
sweetbay	4
bigleaf magnolia	4
apple species	3
mulberry species	1
water tupelo	2
blackgum/black tupelo	2
swamp tupelo	2
eastern hophornbeam	3
sourwood	4
redbay	4
sycamore	4
cottonwood species	4
bigtooth aspen	4
black cherry	2
white oak	2
scarlet oak	3
southern red oak	3
cherrybark oak	3
turkey oak	3
laurel oak	3
overcup oak	3
blackjack oak	2
swamp chestnut oak	3
chinkapin oak	2
water oak	2
chestnut oak	3
northern red oak	3
Shumard oak	3
post oak	2
black oak	3
live oak	2
black locust	1
willow species	4
sassafras	2
basswood species	4
elm species	4
winged elm	4
American elm	4

Species	Decay Rate Class
butternut	4
black walnut	2
sweetgum	4
yellow-poplar	4

Species	Decay Rate Class
slippery elm	4
other softwoods	4
other hardwoods	4
other species	4

4.15.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups (Table 4.15.13) 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 4.15.13. Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	Extremely Dry	Very Dry	Dry	Wet
0 – 0.25 in. (1-hr)	5	6	7	16
0.25 – 1.0 in. (10-hr)	7	8	9	16
1.0 – 3.0 in. (100-hr)	12	13	14	18
> 3.0 in. (1000+ -hr)	17	18	20	50
Duff	40	75	100	175
Live	55	80	100	150

4.15.7 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 (Model Description, Section 4.8) 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 the FFE variant to determine a weighted set of fuel models, or
4. allowing the FFE variant 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 4.15.4, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. Tables 4.15.14 and 4.15.15 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 4.15.4 or Table 4.15.15. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

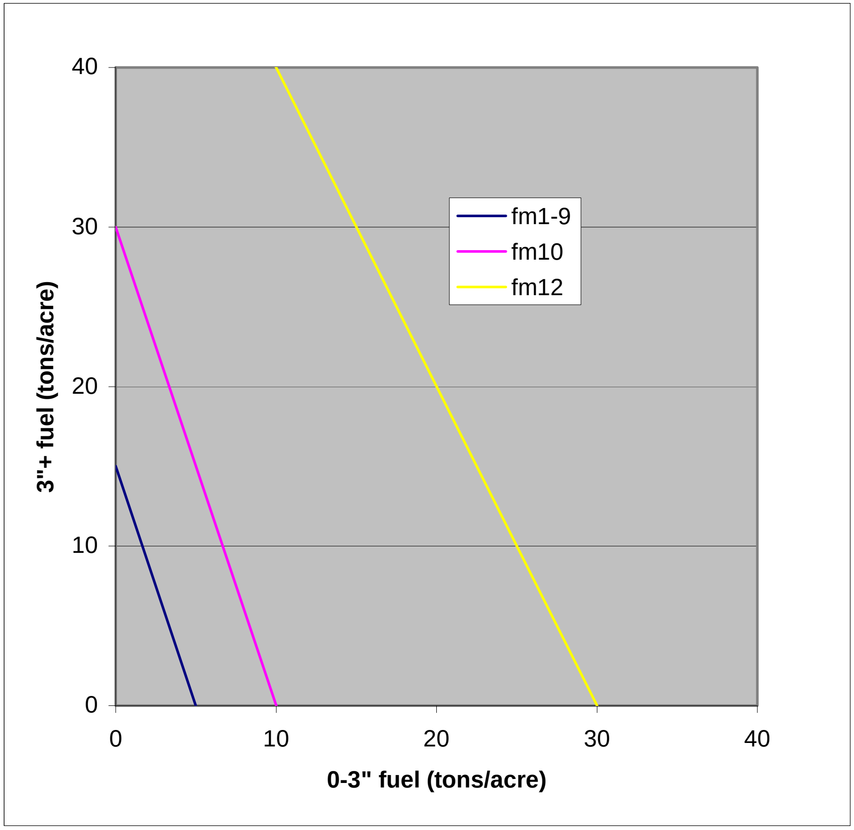


Figure 4.15.4. If large and small fuels map to fuel models 1 - 9, candidate fuel models are determined using the logic shown in Tables 4.15.14 and 4.15.15. Otherwise, fire behavior is based on the distance to the closest fuel models, identified by the dashed lines.

Table 4.15.14. 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 401, 403, 404, 405, 406, 407, or 409
Pine-Hardwood	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, or 996, 70% or less BA in pine, and not Pine-Bluestem
Pine	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, 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 4.15.15. Relationship between forest type and fuel model selected.

Forest type		Fuel model
Hardwood, Hardwood-Pine, and Pine-Hardwood	0-3” fuel > 5 tons	5
	0-3” fuel <=5 tons and 3”+ moisture >20%	8
	0-3” fuel <= 5 tons and 3”+ moisture <= 20%	9
Pine and Bottomland Hardwoods	3”+ moisture >20%	8
	3”+ moisture <= 20%	9
Pine-Bluestem		2
Oak Savannah		2
Eastern Redcedar	Avg. ht. of redcedar > 6 ft.	4
	Avg. ht. of redcedar <= 6 ft.	6
Non-stocked		6

4.15.8 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. 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.

4.16 Pacific Northwest Coast (PN)

4.16.1 Tree Species

The Pacific Northwest coast variant models the 37 tree species shown in Table 4.16.1. One additional category, 'other species', is modeled using quaking aspen.

Table 4.16.1. Tree species simulated by the Pacific Northwest Coast variant.

Common Name	Scientific Name	Notes
Pacific silver fir	*Abies amabilis*	
white fir	*Abies concolor*	
grand fir	*Abies grandis*	
subalpine fir	*Abies lasiocarpa*	
California red fir / Shasta red fir	*Abies magnifica*	
Sitka spruce	*Picea sitchensis*	
noble fir	*Abies procera*	
Alaska-cedar / western larch	*Chamaecyparis nootkatensis / Larix occidentalis*	*= Xanthocyparis nootkatensis*
incense-cedar	*Calocedrus decurrens*	*= Libocedrus decurrens*
Engelmann spruce	*Picea engelmannii*	
lodgepole pine	*Pinus contorta*	
Jeffrey pine	*Pinus jeffreyi*	
sugar pine	*Pinus lambertiana*	
western white pine	*Pinus monticola*	
ponderosa pine	*Pinus ponderosa*	
Douglas-fir	*Pseudotsuga menziesii*	
coast redwood	*Sequoia sempervirens*	
western redcedar	*Thuja plicata*	
western hemlock	*Tsuga heterophylla*	
mountain hemlock	*Tsuga mertensiana*	
bigleaf maple	*Acer macrophyllum*	
red alder	*Alnus rubra*	
white alder / Pacific madrone	*Alnus rhombifolia / Arbutus menziesii*	
paper birch	*Betula papyrifera*	
giant chinkapin / tanoak	*Castanopsis chrysophylla / Lithocarpus densiflorus*	
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus trichocarpa*	
Oregon white oak / California black oak	*Quercus garryana / Quercus kelloggii*	
western juniper	*Juniperus occidentalis*	

Common Name	Scientific Name	Notes
subalpine larch	*Larix lyallii*	
whitebark pine	*Pinus albicaulis*	
knobcone pine	*Pinus attenuata*	
Pacific yew	*Taxus brevifolia*	
Pacific dogwood	*Cornus nuttallii*	
hawthorn species	*Crataegus spp.*	
bitter cherry	*Prunus emarginata*	
willow species	*Salix spp.*	
other		= quaking aspen

4.16.2 Snags

The snag fall rate, snag decay, and snag height loss predictions were updated in the Region 6 variants of FFE, based on work by Kim Mellen, regional wildlife ecologist. Contact Stephanie Rebain (sarebain@fs.fed.us) for more information.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.16.2 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 described in the FFE Model Description.

4.16.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt and others 2001) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in Section 4 of the FFE Model Description.

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 suface 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 transferred to the FFE after being computed 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 4.16.2 for Douglas-fir is based on 'Douglas-fir coast'. The value for juniper is from Chojnacky and Moisen (1993).

Table 4.16.2. Woody density (ovendry lbs/green ft^3) used in the PN-FFE variant.

Species	Density (lbs/ft^3)	Species	Density (lbs/ft^3)
Pacific silver fir	24.9	mountain hemlock	26.2
white fir	23.1	bigleaf maple	27.4
grand fir	21.8	red alder	23.1
subalpine fir	19.3	white alder / Pacific madrone	36.2
California red fir / Shasta red fir	22.5	paper birch	29.9
Sitka spruce	20.6	giant chinkapin / 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
western redcedar	19.3	willow	22.5
western hemlock	26.2	other species	21.8

Tree Crown

As described in the Section 2 of the FFE Model Description, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for many species in the PN-FFE (Table 4.16.3).

Table 4.16.3. 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)

Species	Species Mapping and Equation Source
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 (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	aspen: Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
giant chinkapin / tanoak	tanoak; Snell and Little (1983), Snell (1979)
quaking aspen	bigtooth aspen; Smith (1985), Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
black cottonwood	Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Oregon white oak / California black oak	tanoak; Snell and Little (1983), Snell (1979)
western juniper	Chojnacky (1992), 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	flowering dogwood; Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
hawthorn species	apple; Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
bitter cherry	black cherry; Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
willow	Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other species	quaking aspen; Smith (1985); 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 4.16.4. 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 4.16.4. Life span of live and dead foliage (yr) and dead branches for species modeled in the PN-FFE variant.

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
Pacific silver fir	7	2	5	5	15
white fir	7	2	5	5	15
grand fir	7	2	5	5	15
subalpine fir	7	2	5	5	15
California red fir / 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 chinkapin / 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 by the FFE. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.16.5). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand (Model Description, Section 4.2). When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.16.5). 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).

Table 4.16.5. 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	

Species		Herbs	Shrubs	Notes
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 chinkapin / tanoak	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	
quaking aspen	E	0.25	0.25	
	I	0.18	2.00	
black cottonwood	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	
Oregon white oak / California black oak	E	0.23	0.22	
	I	0.55	0.35	
western juniper	E	0.14	0.35	Ottmar photo series, Volume I
	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
	I	0.18	2.00	
bitter cherry	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	
willow	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	
other species	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	

Dead Fuels

Initial default CWD 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 (Model Description, Section 4.2). 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 4.16.6). If tree canopy cover is <10 percent, the CWD 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. Initial fuel loads can be modified using the FUELINIT keyword.

Table 4.16.6. Canopy cover and cover type are used to assign default coarse woody debris (tons/acre) by size class for established (E) and initiating (I) stands.

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
Pacific silver fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
California red fir / Shasta red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Sitka spruce	E	0.7	0.7	3.0	7.0	7.0	10.0	1.0	35.0
	I	0.5	0.5	2.0	2.8	2.8	6.0	0.5	12.0
noble fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Alaska-cedar / western larch	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
incense-cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
Engelmann spruce	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	12.0	0.6	15.0
	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

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
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 chinkapin / 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
other 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

4.16.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.16.7 are used to calculate single bark thickness (RMRS-GTR-116, 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 and others 2001).

Table 4.16.7. Species specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})
Pacific silver fir	0.047
white fir	0.048
grand fir	0.046
subalpine fir	0.041
California red fir / Shasta red fir	0.039
Sitka spruce	0.027
noble fir	0.045
Alaska-cedar / western larch	0.022
incense-cedar	0.081
Engelmann spruce	0.036
lodgepole pine	0.028
Jeffrey pine	0.068
sugar pine	0.072
western white pine	0.035
ponderosa pine	0.063
Douglas-fir	0.063
coast redwood	0.081
western redcedar	0.035
western hemlock	0.040
mountain hemlock	0.040
bigleaf maple	0.024
red alder	0.026
white alder / Pacific madrone	0.060
paper birch	0.027
giant chinkapin / tanoak	0.045
quaking aspen	0.044
black cottonwood	0.044
Oregon white oak / California black oak	0.029
western juniper	0.025
subalpine larch	0.050
whitebark pine	0.030
knobcone pine	0.030
Pacific yew	0.025
Pacific dogwood	0.062
hawthorn species	0.038
bitter cherry	0.062
willow	0.041
other species	0.044

4.16.5 Decay Rate

Decay of down material is simulated by applying loss rates to pieces by size class, as described in section 2.4.5 of the FFE documentation. Default decay rates on mesic sites (Table 4.16.8) 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 4.16.8. Default annual loss rates on mesic sites are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.12	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.015	
6 – 12		
> 12		
Litter	0.50	
Duff	0.002	0.0

Decay rates on moist sites are one-third higher than the rates shown in Table 4.16.8; 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 4.16.9. These assignments were provided by Tom DeMeo and Kim Mellen, USFS, Portland, OR (pers. comm. 2003).

Table 4.16.9. Habitat type – moisture regime relationships for the PN-FFE variant. Moisture classes modify default decay rates, as described in the text.

Habitat Type Code	Regime	Habitat Type Code	Regime	Habitat Type Code	Regime	Habitat Type Code	Regime
CDS221	Dry	CFS217	Wet	CHS132	Dry	CHS422	Wet
CDS255	Dry	CFS218	Mesic	CHS133	Dry	CHS423	Mesic
CDS651	Dry	CFS219	Mesic	CHS134	Dry	CHS512	Wet
CEF321	Dry	CFS311	Wet	CHS136	Wet	CHS521	Wet
CES212	Dry	CFS611	Dry	CHS137	Mesic	CHS610	Mesic
CES321	Dry	CFS612	Mesic	CHS138	Mesic	CHS621	Mesic
CES621	Dry	CHF112	Wet	CHS139	Mesic	CHS622	Dry
CFF111	Wet	CHF121	Wet	CHS221	Mesic	CHS623	Wet
CFF211	Dry	CHF122	Mesic	CHS222	Wet	CHS624	Wet
CFF311	Dry	CHF131	Wet	CHS321	Dry	CMS242	Wet
CFF611	Mesic	CHF132	Wet	CHS322	Dry	CSF111	Wet
CFF612	Wet	CHF211	Wet	CHS323	Wet	CSF121	Wet
CFF911	Mesic	CHF511	Dry	CHS324	Dry	CSF321	Wet
CFS156	Mesic	CHF911	Mesic	CHS331	Mesic	CSS221	Wet
CFS211	Dry	CHM111	Wet	CHS332	Dry	CSS321	Wet
CFS212	Mesic	CHS121	Mesic	CHS333	Dry	CSS521	Wet
CFS213	Mesic	CHS122	Mesic	CHS334	Dry	CSS522	Wet
CFS214	Dry	CHS123	Dry	CHS335	Wet	CSS621	Wet
CFS215	Mesic	CHS131	Mesic	CHS421	Mesic		

The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.16.10 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword.

Table 4.16.10. Default wood decay classes used in the PN-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
Pacific silver fir	4	mountain hemlock	4
white fir	4	bigleaf maple	4
grand fir	4	red alder	4
subalpine fir	4	white alder / Pacific madrone	3
California red fir / Shasta red fir	4	paper birch	4
Sitka spruce	4	giant chinkapin / tanoak	4
noble fir	4	quaking aspen	4
Alaska-cedar / western larch	2	black cottonwood	4
incense-cedar	2	Oregon white oak / California black oak	2
Engelmann spruce	4	western juniper	2
lodgepole pine	4	subalpine larch	3
Jeffrey pine	4	whitebark pine	4
sugar pine	4	knobcone pine	4
western white pine	4	Pacific yew	1
ponderosa pine	4	Pacific dogwood	4
Douglas-fir	3	hawthorn species	4
coast redwood	2	bitter cherry	2
western redcedar	2	willow	4
western hemlock	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 (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups (Table 4.16.11) or they can specify moisture conditions for each class using the MOISTURE keyword.

Table 4.16.11. Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

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

4.16.7 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 (Model Description, Section 4.16) 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 the FFE variant to determine a weighted set of fuel models; or
4. allowing the FFE variant 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 closure (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 4.16.2);
- 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 4.16.1, 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 4.16.2, 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 4.16.2 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 4.16.9. Ground cover type is also based on habitat code, as shown in Table 4.16.12.

Table 4.16.12. Habitat type – ground cover mapping for the PN-FFE variant. Ground cover classes modify default fuel model selection, as described in the text. Unclassified habitat groups default to 'Grass'.

Habitat Type Code	Ground Cover	Habitat Type Code	Ground Cover	Habitat Type Code	Ground Cover	Habitat Type Code	Ground Cover
CDS221	Shrub	CFS217	Shrub	CHS132	Shrub	CHS422	Shrub
CDS255	Shrub	CFS218	Shrub	CHS133	Shrub	CHS423	Shrub
CDS651	Shrub	CFS219	Shrub	CHS134	Shrub	CHS512	Shrub
CEF321	Shrub	CFS311	Shrub	CHS136	Shrub	CHS521	Shrub
CES212	Shrub	CFS611	Shrub	CHS137	Shrub	CHS610	Shrub
CES321	Shrub	CFS612	Shrub	CHS138	Shrub	CHS621	Shrub
CES621	Shrub	CHF112	Forb	CHS139	Shrub	CHS622	Shrub
CFF111	Forb	CHF121	Forb	CHS221	Shrub	CHS623	Shrub
CFF211	Forb	CHF122	Forb	CHS222	Shrub	CHS624	Shrub
CFF311	Forb	CHF131	Forb	CHS321	Shrub	CMS242	Shrub
CFF611	Forb	CHF132	Forb	CHS322	Shrub	CSF111	Forb
CFF612	Forb	CHF211	Shrub	CHS323	Forb	CSF121	Forb
CFF911	–	CHF511	Forb	CHS324	Shrub	CSF321	Forb
CFS156	Shrub	CHF911	–	CHS331	Shrub	CSS221	Shrub
CFS211	Shrub	CHM111	Forb	CHS332	Shrub	CSS321	Shrub
CFS212	Shrub	CHS121	Shrub	CHS333	Shrub	CSS521	Shrub
CFS213	Shrub	CHS122	Shrub	CHS334	Shrub	CSS522	Shrub
CFS214	Shrub	CHS123	Shrub	CHS335	Shrub	CSS621	Shrub
CFS215	Shrub	CHS131	Shrub	CHS421	Shrub		

If the STATFUEL keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.16.1 or Figure 4.16.2. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

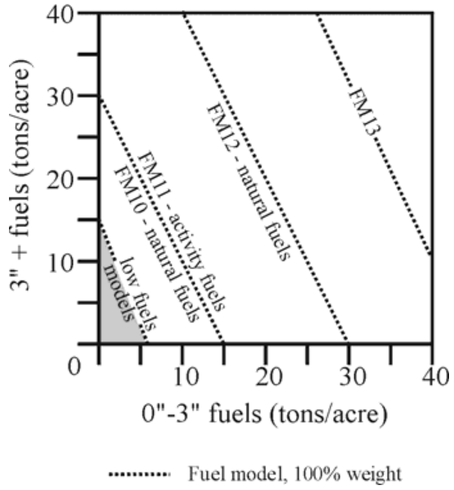
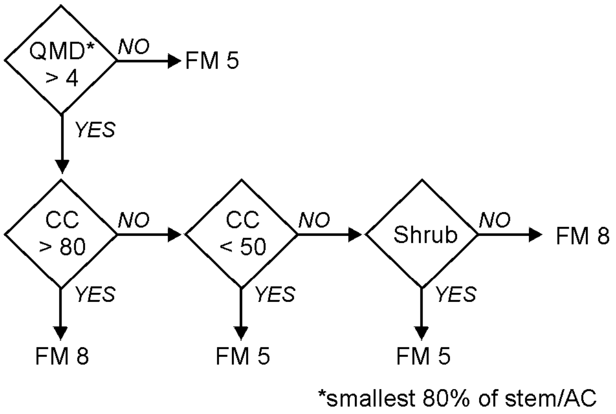
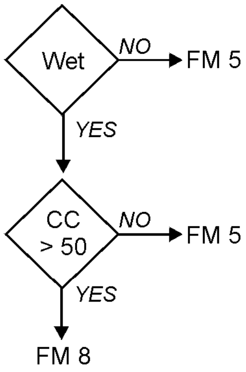


Figure 4.16.1. If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.16.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description Section 4.8 for further details).

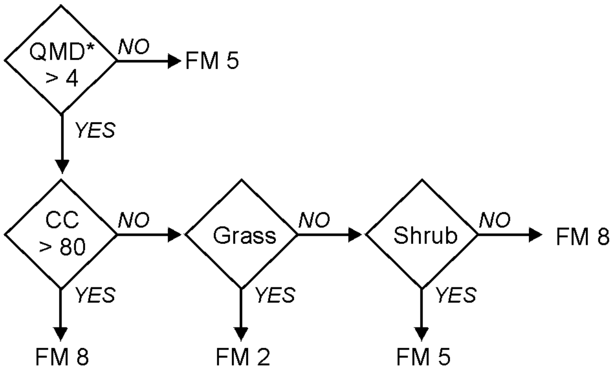
SF or WH or SS or RC



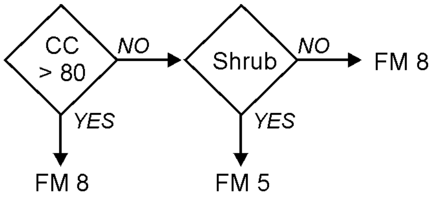
LP



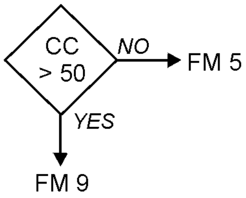
DF or GF or WP



MH or AF or WB



RA



WO or TA

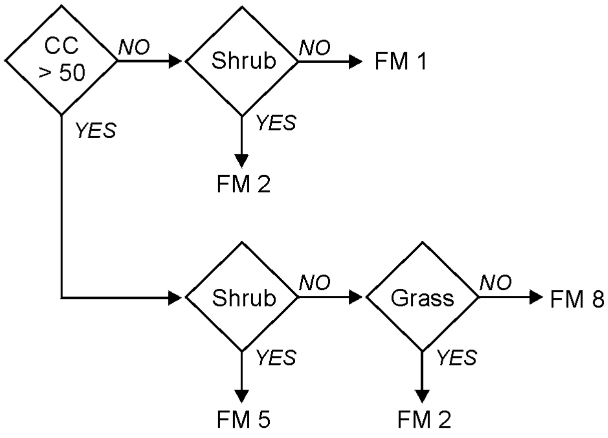


Figure 4.16.2. Fuel models for the PN-FFE variant.

4.17 Westside Cascades (WC)

4.17.1 Tree Species

The Westside Cascades variant models the 37 tree species shown in Table 4.17.1. One additional category, 'other species', is modeled using quaking aspen.

Table 4.17.1. Tree species simulated by the Westside Cascades variant.

Common Name	Scientific Name	Notes
Pacific silver fir	*Abies amabilis*	
white fir	*Abies concolor*	
grand fir	*Abies grandis*	
subalpine fir	*Abies lasiocarpa*	
California red fir / Shasta red fir	*Abies magnifica*	
noble fir	*Abies procera*	
Alaska-cedar / western larch	*Chamaecyparis nootkatensis / Larix occidentalis*	= *Xanthocyparis nootkatensis*
incense-cedar	*Calocedrus decurrens*	= *Libocedrus decurrens*
Engelmann spruce / Sitka spruce	*Picea engelmannii / Picea sitchensis*	
lodgepole pine	*Pinus contorta*	
Jeffrey pine	*Pinus jeffreyi*	
sugar pine	*Pinus lambertiana*	
western white pine	*Pinus monticola*	
ponderosa pine	*Pinus ponderosa*	
Douglas-fir	*Pseudotsuga menziesii*	
coast redwood	*Sequoia sempervirens*	
western redcedar	*Thuja plicata*	
western hemlock	*Tsuga heterophylla*	
mountain hemlock	*Tsuga mertensiana*	
bigleaf maple	*Acer macrophyllum*	
red alder	*Alnus rubra*	
white alder / Pacific madrone	*Alnus rhombifolia / Arbutus menziesii*	
paper birch	*Betula papyrifera*	
giant chinkapin / tanoak	*Castanopsis chrysophylla / Lithocarpus densiflorus*	
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus trichocarpa*	
Oregon white oak / California black oak	*Quercus garryana / Quercus kelloggii*	
western juniper	*Juniperus occidentalis*	

Common Name	Scientific Name	Notes
subalpine larch	*Larix lyallii*	
whitebark pine	*Pinus albicaulis*	
knobcone pine	*Pinus attenuata*	
Pacific yew	*Taxus brevifolia*	
Pacific dogwood	*Cornus nuttallii*	
hawthorn species	*Crataegus spp.*	
bitter cherry	*Prunus emarginata*	
willow species	*Salix spp.*	
other species		= quaking aspen

4.17.2 Snags

The snag fall rate, snag decay, and snag height loss predictions were modified in the Region 6 variants of FFE, based on work by Kim Mellen, regional wildlife ecologist. Contact Stephanie Rebain (sarebain@fs.fed.us) for more information.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.17.2 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 described in the FFE Model Description.

4.17.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt and others 2001) and in cooperation with Jim Brown, USFS, Missoula, MT (pers. comm. 1995). A complete description of the Fuel Submodel is provided in Section 4 of the FFE Model Description.

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 transferred to the FFE after being computed 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 4.17.2 for Douglas-fir is based on ‘Douglas-fir coast’. The value for juniper is from Chojnacky and Moisen (1993).

Table 4.17.2. Woody density (ovendry lbs/green ft^3) used in the WC-FFE variant.

Species	Density (lbs/ft^3)
Pacific silver fir	24.9
white fir	23.1
grand fir	21.8
subalpine fir	19.3
California red fir / Shasta red fir	22.5
noble fir	23.1
Alaska-cedar / western larch	26.2
incense-cedar	21.8
Engelmann spruce / Sitka spruce	20.6
lodgepole pine	23.7
Jeffrey pine	21.2
sugar pine	21.2
western white pine	22.5
ponderosa pine	23.7
Douglas-fir	28.1
coast redwood	21.2
western redcedar	19.3
western hemlock	26.2
mountain hemlock	26.2

Species	Density (lbs/ft^3)
bigleaf maple	27.4
red alder	23.1
white alder / Pacific madrone	36.2
paper birch	29.9
giant chinkapin / tanoak	36.2
quaking aspen	21.8
black cottonwood	19.3
Oregon white oak / California black oak	37.4
western juniper	34.9
subalpine larch	29.9
whitebark pine	22.5
knobcone pine	23.7
Pacific yew	26.2
Pacific dogwood	27.4
hawthorn species	27.4
bitter cherry	29.3
willow species	22.5
other species	21.8

Tree Crown

As described in the Section 2 of the FFE Model Description, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for many species in the WC-FFE (Table 4.17.3).

Table 4.17.3. 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 / Sitka 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)

Species	Species Mapping and Equation Source
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 (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	aspen: Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
giant chinkapin / tanoak	tanoak; Snell and Little (1983), Snell (1979)
quaking aspen	bigtooth aspen; Smith (1985), Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
black cottonwood	Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
Oregon white oak / California black oak	tanoak; Snell and Little (1983), Snell (1979)
western juniper	Chojnacky (1992), 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	flowering dogwood; Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
hawthorn species	apple; Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
bitter cherry	black cherry; Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
willow species	Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other species	quaking aspen; Smith (1985); 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 4.17.4. 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 4.17.4. Life span of live and dead foliage (yr) and dead branches for species modeled in the WC-FFE variant.

	Live	Dead			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
Pacific silver fir	7	2	5	5	15
white fir	7	2	5	5	15
grand fir	7	2	5	5	15
subalpine fir	7	2	5	5	15
California red fir / 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 chinkapin / 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 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 by the FFE. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.17.5). When there are no trees, habitat type is used to infer the most likely dominant species of the previous stand (Model Description, Section 4.2). When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.17.5). 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).

Table 4.17.5. Values (dry weight, tons/acre) for live fuels used in the WC-FFE. Biomass is linearly interpolated between the "initiating" (I) and "established"(E) values when canopy cover is between 10 and 60 percent.

Species		Herbs	Shrubs	Notes
Pacific silver fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
white fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
grand fir	E	0.15	0.10	
	I	0.30	2.00	
subalpine fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
California red fir / Shasta red fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
noble fir	E	0.15	0.10	Use grand fir
	I	0.30	2.00	
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 / 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	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	

Species		Herbs	Shrubs	Notes
paper birch	E	0.20	0.20	Use Douglas-fir
	I	0.40	2.00	
giant chinkapin / tanoak	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	
quaking aspen	E	0.25	0.25	
	I	0.18	2.00	
black cottonwood	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	
Oregon white oak / California black oak	E	0.23	0.22	
	I	0.55	0.35	
western juniper	E	0.14	0.35	Ottmar photo series, Volume I
	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
	I	0.18	2.00	
bitter cherry	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	
willow species	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	
other species	E	0.25	0.25	Use quaking aspen
	I	0.18	2.00	

Dead Fuels

Initial default CWD 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 (Model Description, Section 4.2). 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 4.17.6). If tree canopy cover is <10 percent, the CWD 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. Initial fuel loads can be modified using the FUELINIT keyword.

Table 4.17.6. Canopy cover and cover type are used to assign default coarse woody debris (tons/acre) by size class for established (E) and initiating (I) stands.

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	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
white fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
grand fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
California red fir / Shasta red fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
noble fir	E	0.7	0.7	3.0	7.0	7.0	0.0	0.6	25.0
	I	0.5	0.5	2.0	2.8	2.8	0.0	0.3	12.0
Alaska-cedar / western larch	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
incense-cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
Engelmann spruce / Sitka 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	15.0
	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

		Size Class (in)							
Species		**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
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 chinkapin / 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 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 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

4.17.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.17.7 are used to calculate single bark thickness (RMRS-GTR-116, 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 and others 2001).

Table 4.17.7. 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 chinkapin / 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		

4.17.5 Decay Rate

Decay of down material is simulated by applying loss rates to pieces by size class, as described in section 2.4.5 of the FFE documentation. Default decay rates on mesic sites (Table 4.17.8) 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 4.17.8. Default annual loss rates on mesic sites are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.12	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.015	
6 – 12		
> 12		
Litter	0.50	
Duff	0.002	0.0

Decay rates on moist sites are one-third higher than the rates shown in Table 4.17.8; 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 4.17.9. These assignments were provided by Tom DeMeo and Kim Mellen, USFS, Portland, OR (pers. comm. 2003).

Table 4.17.9. Habitat type – moisture regime relationships for the WC-FFE variant. Moisture classes modify default decay rates, as described in the text.

Habitat Type Code	Regime	Habitat Type Code	Regime	Habitat Type Code	Regime	Habitat Type Code	Regime
CAF211	Dry	CFS229	Dry	CHF222	Moist	CHS611	Moist
CAF311	Mesic	CFS230	Mesic	CHF250	Moist	CHS612	Dry
CAG211	Mesic	CFS231	Moist	CHF321	Mesic	CHS613	Moist
CAG311	Mesic	CFS251	Dry	CHF421	Moist	CHS614	Mesic
CAG312	Mesic	CFS252	Dry	CHM121	Moist	CHS615	Mesic
CAS211	Moist	CFS253	Moist	CHS111	Dry	CHS625	Mesic
CAS411	Dry	CFS254	Mesic	CHS113	Moist	CHS626	Mesic
CDC711	Dry	CFS255	Mesic	CHS114	Mesic	CMF250	Moist
CDC712	Mesic	CFS256	Mesic	CHS124	Mesic	CMF251	Moist
CDC713	Dry	CFS257	Mesic	CHS125	Mesic	CMS114	Dry
CDS211	Dry	CFS258	Mesic	CHS126	Mesic	CMS210	Mesic
CDS212	Dry	CFS259	Mesic	CHS127	Mesic	CMS216	Dry
CDS213	Dry	CFS260	Mesic	CHS128	Mesic	CMS218	Mesic
CDS641	Dry	CFS351	Moist	CHS129	Mesic	CMS221	Moist
CFC251	Dry	CFS352	Moist	CHS130	Mesic	CMS223	Moist
CFC311	Dry	CFS550	Moist	CHS135	Mesic	CMS241	Moist
CFF152	Moist	CFS551	Moist	CHS140	Dry	CMS244	Mesic
CFF153	Moist	CFS552	Moist	CHS141	Dry	CMS245	Dry
CFF154	Moist	CFS554	Dry	CHS223	Dry	CMS246	Dry
CFF250	Mesic	CFS555	Dry	CHS224	Dry	CMS250	Moist
CFF253	Mesic	CFS651	Moist	CHS251	Mesic	CMS251	Mesic
CFF312	Dry	CFS652	Mesic	CHS325	Dry	CMS252	Mesic
CFF450	Moist	CFS653	Dry	CHS326	Mesic	CMS253	Moist
CFM111	Moist	CFS654	Mesic	CHS327	Dry	CMS254	Dry
CFS110	Mesic	CHC212	Dry	CHS328	Dry	CMS255	Moist
CFS151	Mesic	CHC213	Dry	CHS351	Dry	CMS350	Moist
CFS152	Mesic	CHF111	Moist	CHS352	Dry	CMS351	Mesic
CFS154	Mesic	CHF123	Moist	CHS353	Dry	CMS352	Mesic
CFS216	Mesic	CHF124	Moist	CHS354	Moist	CMS353	Moist
CFS221	Dry	CHF125	Moist	CHS355	Mesic	CMS450	Moist
CFS222	Mesic	CHF133	Mesic	CHS511	Moist	CMS612	Mesic
CFS223	Dry	CHF134	Mesic	CHS513	Moist	CWF211	Dry
CFS224	Mesic	CHF135	Moist	CHS522	Moist	CWS521	Dry
CFS225	Moist	CHF151	Moist	CHS523	Moist	CWS522	Dry
CFS226	Moist	CHF221	Dry	CHS524	Moist		

The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.17.10 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword.

Table 4.17.10. Default wood decay classes used in the WC-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
Pacific silver fir	4
white fir	4
grand fir	4
subalpine fir	4
California red fir/Shasta red fir	4
noble fir	4
Alaska-cedar / western larch	2
incense-cedar	2
Engelmann spruce / Sitka spruce	4
lodgepole pine	4
Jeffrey pine	4
sugar pine	4
western white pine	4
ponderosa pine	4
Douglas-fir	3
coast redwood	2
western redcedar	2
western hemlock	4
mountain hemlock	4
bigleaf maple	4
red alder	4
white alder / Pacific madrone	3
paper birch	4
giant chinkapin / tanoak	4
quaking aspen	4
black cottonwood	4
Oregon white oak / California black oak	2
western juniper	2
subalpine larch	3
whitebark pine	4
knobcone pine	4
Pacific yew	1
Pacific dogwood	4
hawthorn species	4
bitter cherry	2
willow species	4
other species	4

4.17.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups (Table 4.17.11) or they can specify moisture conditions for each class using the MOISTURE keyword.

Table 4.17.11. Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

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

4.17.7 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 (Model Description, Section 4.17) 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 the FFE variant to determine a weighted set of fuel models; or
4. allowing the FFE variant 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 closure (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 4.17.2);
- 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 4.17.1, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. The two dominant cover types described above, along with the flow diagrams in Figure 4.17.2, 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 4.17.2 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 4.17.9. Ground cover type is also based on habitat code, as shown in Table 4.17.12.

Table 4.17.12. Habitat type – ground cover mapping for the WC-FFE variant. Ground cover classes modify default fuel model selection, as described in the text. Unclassified habitat groups default to ‘Grass’.

Habitat Type Code	Regime	Habitat Type Code	Regime	Habitat Type Code	Regime	Habitat Type Code	Regime
CAF211	–	CFS229	Shrub	CHF222	Forb	CHS611	Shrub
CAF311	–	CFS230	Shrub	CHF250	Forb	CHS612	Shrub
CAG211	–	CFS231	Shrub	CHF321	Forb	CHS613	Shrub
CAG311	–	CFS251	Shrub	CHF421	Forb	CHS614	Shrub
CAG312	–	CFS252	Shrub	CHM121	Forb	CHS615	Shrub
CAS211	–	CFS253	Shrub	CHS111	Shrub	CHS625	Shrub
CAS411	–	CFS254	Shrub	CHS113	Shrub	CHS626	Shrub
CDC711	Shrub	CFS255	Shrub	CHS114	Shrub	CMF250	Forb
CDC712	Shrub	CFS256	Shrub	CHS124	Shrub	CMF251	–
CDC713	Shrub	CFS257	Shrub	CHS125	Shrub	CMS114	Shrub
CDS211	Grass	CFS258	Shrub	CHS126	Shrub	CMS210	Shrub
CDS212	Grass	CFS259	Shrub	CHS127	Shrub	CMS216	Shrub
CDS213	Shrub	CFS260	Shrub	CHS128	Shrub	CMS218	Shrub
CDS641	Shrub	CFS351	Shrub	CHS129	Shrub	CMS221	Shrub
CFC251	Shrub	CFS352	Shrub	CHS130	Shrub	CMS223	Shrub
CFC311	Forb	CFS550	Shrub	CHS135	Shrub	CMS241	Shrub
CFF152	Forb	CFS551	Shrub	CHS140	Shrub	CMS244	Shrub
CFF153	Forb	CFS552	Shrub	CHS141	Shrub	CMS245	Shrub
CFF154	Forb	CFS554	Shrub	CHS223	Shrub	CMS246	Shrub
CFF250	Forb	CFS555	Shrub	CHS224	Forb	CMS250	Shrub
CFF253	Forb	CFS651	Shrub	CHS251	Shrub	CMS251	Shrub
CFF312	Forb	CFS652	Shrub	CHS325	Shrub	CMS252	Shrub
CFF450	Forb	CFS653	Shrub	CHS326	Shrub	CMS253	Shrub
CFM111	Forb	CFS654	Shrub	CHS327	Shrub	CMS254	Shrub
CFS110	Shrub	CHC212	Shrub	CHS328	Shrub	CMS255	Shrub
CFS151	Shrub	CHC213	Shrub	CHS351	Shrub	CMS350	Shrub
CFS152	Shrub	CHF111	Forb	CHS352	Shrub	CMS351	Shrub
CFS154	Shrub	CHF123	Forb	CHS353	Shrub	CMS352	Shrub
CFS216	Shrub	CHF124	Forb	CHS354	Shrub	CMS353	–
CFS221	Shrub	CHF125	Forb	CHS355	Shrub	CMS450	Shrub
CFS222	Shrub	CHF133	Forb	CHS511	Shrub	CMS612	Shrub
CFS223	Shrub	CHF134	Forb	CHS513	Shrub	CWF211	Shrub
CFS224	Shrub	CHF135	Forb	CHS522	Shrub	CWS521	Shrub
CFS225	Shrub	CHF151	Forb	CHS523	Shrub	CWS522	Shrub
CFS226	Shrub	CHF221	Forb	CHS524	Shrub		

If the STATFUEL keyword is selected, fuel model is determined by using only the closest-match fuel model identified by either Figure 4.17.1 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.

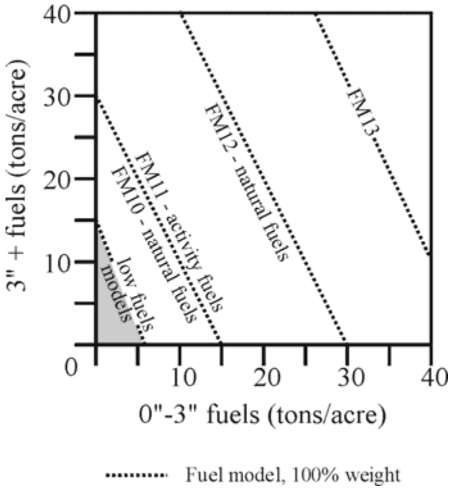


Figure 4.17.1. If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.17.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description Section 4.8 for further details).

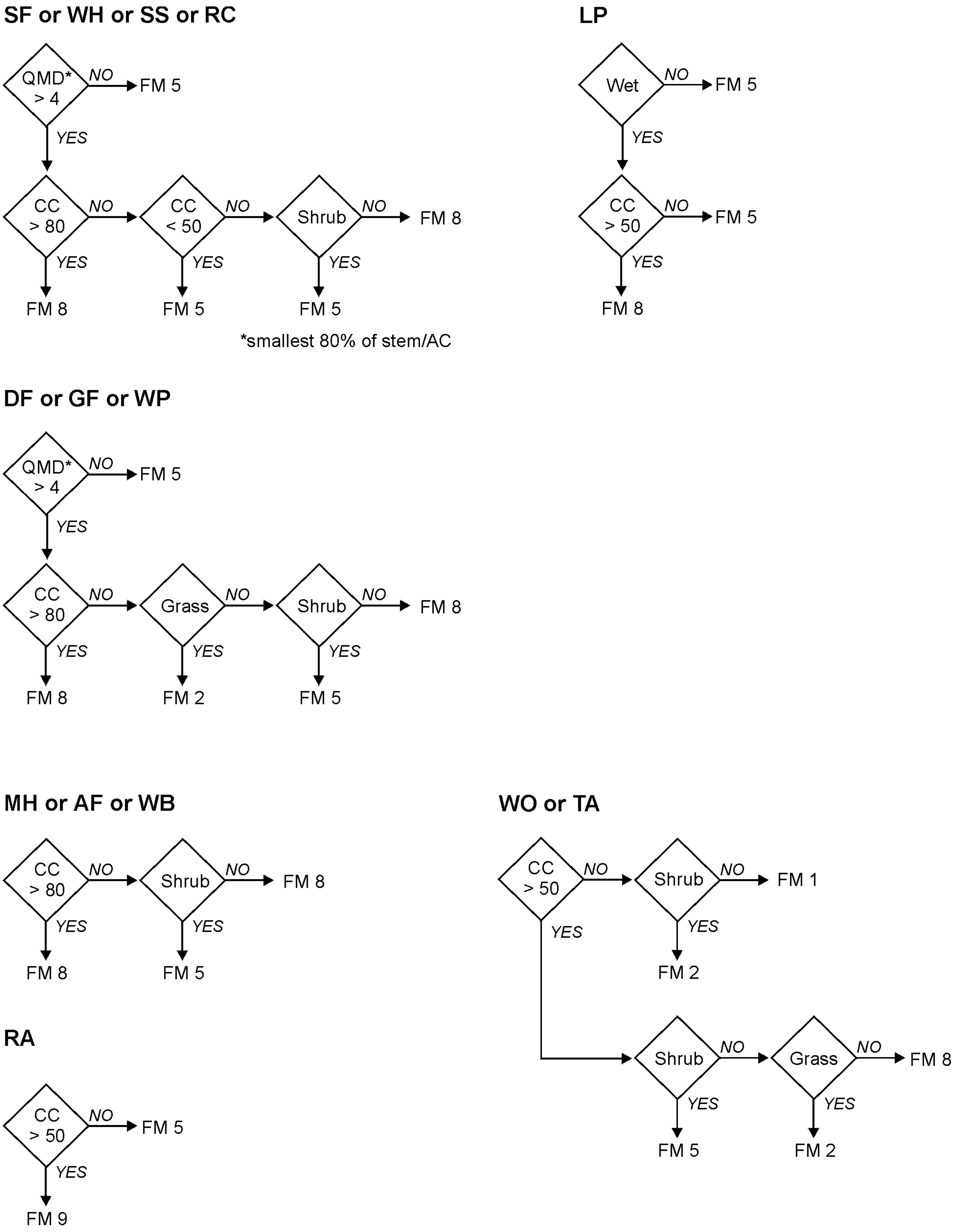


Figure 4.17.2. Fuel models for the WC-FFE variant.

4.18 Southern Oregon/Northern California (SO)

4.18.1 Tree Species

The expanded Southern Oregon/Northern California (SORNEC) variant models the 31 tree species shown in Table 4.18.1. Two additional categories, ‘other softwoods’ and ‘other hardwoods’, are modeled using Douglas-fir and quaking aspen.

Table 4.18.1. Tree species simulated by the Southern Oregon/Northern California variant.

Common Name	Scientific Name	Notes
western white pine	*Pinus monticola*	
sugar pine	*Pinus lambertiana*	
Douglas-fir	*Pseudotsuga menziesii*	
white fir	*Abies concolor*	
mountain hemlock	*Tsuga mertensiana*	
incense-cedar	*Calocedrus decurrens*	= *Libocedrus decurrens*
lodgepole pine	*Pinus contorta*	
Engelmann spruce	*Picea engelmannii*	
Shasta red fir	*Abies magnifica*	
ponderosa pine / Jeffrey pine	*Pinus ponderosa / Pinus jeffreyi*	
western juniper	*Juniperus occidentalis*	
grand fir	*Abies grandis*	
subalpine fir	*Abies lasiocarpa*	
pacific silver fir	*Abies amabilis*	
noble fir	*Abies procera*	
whitebark pine	*Pinus albicaulis*	
western larch	*Larix occidentalis*	
western redcedar	*Thuja plicata*	
western hemlock	*Tsuga heterophylla*	
pacific yew	*Taxus brevifolia*	
white alder	*Alnus rhombifolia*	
red alder	*Alnus rubra*	
bigleaf maple	*Acer macrophyllum*	
quaking aspen	*Populus tremuloides*	
black cottonwood	*Populus trichocarpa*	
bitter cherry	*Prunus emarginata*	
Oregon white oak	*Quercus garryana*	
willow species	*Salix spp.*	
giant chinkapin	*Chrysolepis chrysophylla*	=*Castanopsis chrysophylla*
curl-leaf mt. mahogany	*Cercocarpus ledifolius*	

birch-leaf mt. mahogany	*Cercocarpus betuloides*	= *C. montanus var. glaber?*
other softwoods		= Douglas-fir
other hardwoods		= quaking aspen

4.18.2 Snags

Oregon –
The snag fall rate, snag decay, and snag height loss predictions were modified in the Region 6 (Oregon) portion of the SO variant of FFE, based on work by Kim Mellen, regional wildlife ecologist. Contact Stephanie Rebain (sarebain@fs.fed.us) for more information.

Snag bole volume is determined 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 described in the FFE Model Description.

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 of the FFE documentation.

Four variables are used to modify the Snag Submodel for the different species in the SO-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
- a multiplier to modify the species' height loss rate

These variables are summarized in Tables 4.18.2 and 4.18.3.

Snag bole volume is determined 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.

Table 4.18.2. 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 4.18.3. 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 (yr)	All Down (yr)	50% Height (yr)	Hard-to-Soft (yr)
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	–
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 chinkapin	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 4.18.3. 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 4.18.2. (These three columns are the default values used by the SNAGFALL, SNAGBRK and SNAGDCAY keywords, respectively.)

Species	Snag Fall	Height loss	Hard-to-Soft
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 chinkapin	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	–

4.18.3 Fuels

Information on live fuels was developed using FOFEM 4.0 (Reinhardt and others 1997) and FOFEM 5.0 (Reinhardt and others 2001) 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 of the FFE Documentation.

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 transferred to the FFE after being computed 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 4.18.4 for Douglas-fir is based on ‘Douglas-fir Interior west.’ The value for juniper is from Chojnacky and Moisen (1993).

Table 4.18.4. Woody density (ovendry lbs/green ft^3) used in the SO-FFE variant.

Species	Density (lbs/ft^3)
western white pine	22.5
sugar pine	21.2
Douglas-fir	28.7
white fir	23.1
mountain hemlock	26.2
incense-cedar	21.8
lodgepole pine	23.7
Engelmann spruce	20.6
Shasta red fir, 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 chinkapin	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 2.2 of the FFE documentation, 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 4.18.5. Mountain hemlock biomass is based on Gholz (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 4.18.5. 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 (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	Chojnacky (1992), 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	bigtooth aspen; Smith (1985), Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
black cottonwood	Smith (1985), Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
bitter cherry	black cherry; Smith (1985), Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
Oregon white oak	tanoak; Snell and Little (1983), Snell (1979)
willow species	Smith (1985), Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
giant chinkapin	tanoak; Snell and Little (1983), Snell (1979)
curl-leaf mt. mahogany	bigtooth aspen; Smith (1985), Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
birch-leaf mt. mahogany	bigtooth aspen; Smith (1985), Jenkins et. al. (2003), Loomis and Roussopoulos (1978)
other softwoods	Douglas-fir; Brown and Johnston (1976)
other hardwoods	bigtooth aspen; Smith (1985), 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 4.18.6. 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 4.18.6. Life span of live and dead foliage (yr) and dead branches for species modeled in the SO-FFE variant.

	Live	**Dead**			
Species	**Foliage**	**Foliage**	**<0.25”**	**0.25–1”**	**> 1”**
Oregon					
western white pine	4	2	5	5	15
sugar pine	3	2	5	5	15
Douglas-fir	5	2	5	5	15
white fir	7	2	5	5	15
mountain hemlock	4	2	5	5	15
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 chinkapin	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
bitter cherry	1	1	10	15	15
Oregon white oak	1	1	10	15	15

willow species	1	1	10	15	15
giant chinkapin	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 by the FFE. 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 4.18.7. 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 4.18.8. Finally, shrub and herb loads are assigned using Table 4.18.9, 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 4.18.7. 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 4.18.8. 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 coarse woody debris load. FCCs for sugar pine are mapped using western white pine. When a ponderosa pine stand is classed as regenerating from bare ground, it is assumed that it has been recently logged and is assigned FCC-1 instead of FCC-4. Species 12 –33 are assumed the same as Douglas-fir.

	Structural Stage §					
Species	**1**	**2**	**3**	**4, 5**	**6**	**7**
western white pine	52	53	56	58	57	61
sugar pine	52	53	56	58	57	61
Douglas-fir	52	53	56	58	62	62
white fir	52	53	56	58	62	62
mountain hemlock	52	53	56	58	62	62
incense-cedar	52	53	56	58	62	62
lodgepole pine	103	106	107	110	112	113
Engelmann spruce	52	53	56	59	61	62
Shasta red fir	52	53	56	59	62	62
ponderosa pine / 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
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 chinkapin	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 4.18.9. Default live fuel loads (tons/acre) are determined for each FCC. The appropriate FCC is assigned using Table 4.18.8.

FCC	Herb	Shrub
1	0.3	0.4
4	0.5	0.5
8	0.0	0.0
10	0.5	2.5
11	0.5	0.5
52	0.5	0.5
53	0.5	0.5
56	0.5	0.5
57	0.3	0.4
58	0.3	0.4
59	0.7	0.7
61	0.3	0.4
62	0.8	0.5
103	0.3	0.4
106	0.5	0.5
107	0.5	0.5
110	0.5	0.5
112	0.3	0.4
113	0.5	0.5
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 Tables 4.18.7 and 4.18.8 and following the process just described in the section on live herbs and shrubs. The FCC diameter breakpoints shown in Table 4.18.10 are different from those used by the FFE. Linear interpolation is used to partition the FCC fuel loads into the FFE size classes. 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 keyword.

Table 4.18.10. 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 Tables 4.18.7 and 4.18.8. Litter estimates are absent in the FCC, and set to zero.

	Size Class (in)							
FCC	< 0.25	0.25 – 1	1 – 3	3 – 9	9 – 20	> 20	Litter	Duff
1	0.5	0.8	1.7	1.9	3.0	0.0	–	2.3
4	0.1	1.5	2.2	1.1	1.8	3.3	–	6.0
8	0.1	1.6	4.2	2.1	2.9	4.7	–	9.8
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

4.18.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.18.11 are used to calculate single bark as described in 2.5.5 of the FFE documentation. 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 and others 2001).

Table 4.18.11. 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
quaking aspen	0.044
black cottonwood	0.044
bitter cherry	0.062
Oregon white oak	0.029
willow species	0.041
giant chinkapin	0.045
curl-leaf mt. mahogany	0.044
birch-leaf mt. mahogany	0.044
other softwoods	0.063
other hardwoods	0.044

4.18.5 Decay Rate

Decay of down material is simulated by applying the loss rates shown in table 4.18.12, as described in section 2.4.5 of the FFE documentation. Default decay rates are based on Abbott and Crossley (1982). Decay 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), based on the decay rates used in the Sierra Nevada Framework.

Table 4.18.12. Default annual loss rates are applied based on size class.

Size Class	Annual Loss Rate	Proportion of Loss Becoming Duff
Oregon		
0 – 0.25 in.	0.12	0.02
0.25 – 1.0 in.		
1.0 – 3.0 in.	0.09	
3.0 – 6.0 in.	0.015	
6.0 – 12.0 in.		
> 12.0 in.		
Litter	0.5	
Duff	0.002	0.0
California		
0 – 0.25 in.	0.025	0.02
0.25 – 1.0 in.		
1.0 – 3.0 in.		
3.0 – 6.0 in.	0.0125	
6.0 – 12.0 in.		
> 12.0 in.		
Litter	0.5	
Duff	0.002	0.0

By default, the FFE decays all wood species at the rates shown in Table 4.18.12. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.18.13 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword.

Table 4.18.13. Default wood decay classes used in the SO-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
sugar pine	4
Douglas-fir	3
white fir	4

mountain hemlock	4
incense-cedar	2
lodgepole pine	4
Engelmann spruce	4
Shasta red fir	4
ponderosa pine / Jeffrey pine	4
western juniper	2
grand fir	4
subalpine fir	4
pacific silver fir	4
noble fir	4
whitebark pine	4
western larch	3
western redcedar	2
western hemlock	4
pacific yew	1
white alder	4
red alder	4
bigleaf maple	4
quaking aspen	4
black cottonwood	4
bitter cherry	2
Oregon white oak	2
willow species	4
giant chinkapin	4
curl-leaf mt. mahogany	4
birch-leaf mt. mahogany	4
other softwoods	3
other hardwoods	4

4.18.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (section 2.52 of the FFE documentation). Users can choose from four predefined moisture groups shown in Table 4.18.14, 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 4.18.14. 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

4.18.7 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 (section 2.4.8) 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 the FFE variant to determine a weighted set of fuel models, or
4. allowing the FFE variant 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 4.18.1, 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.). 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 4.18.1 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.

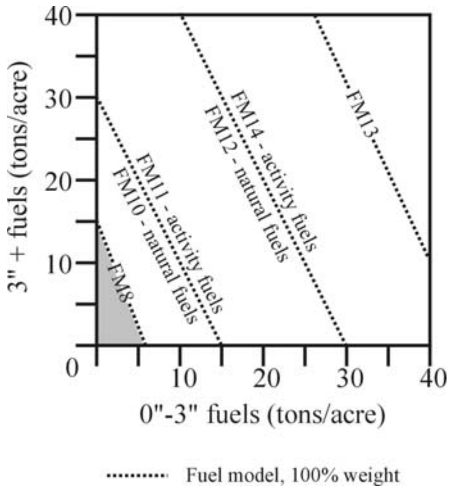


Figure 4.18.1. If large and small fuels map to the shaded area, candidate fuel models are determined using the logic shown in Figure 4.18.2. Otherwise, fire behavior is based on the closest fuel models, identified by the dashed lines, and on recent management (see Model Description section 2.4.8 for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

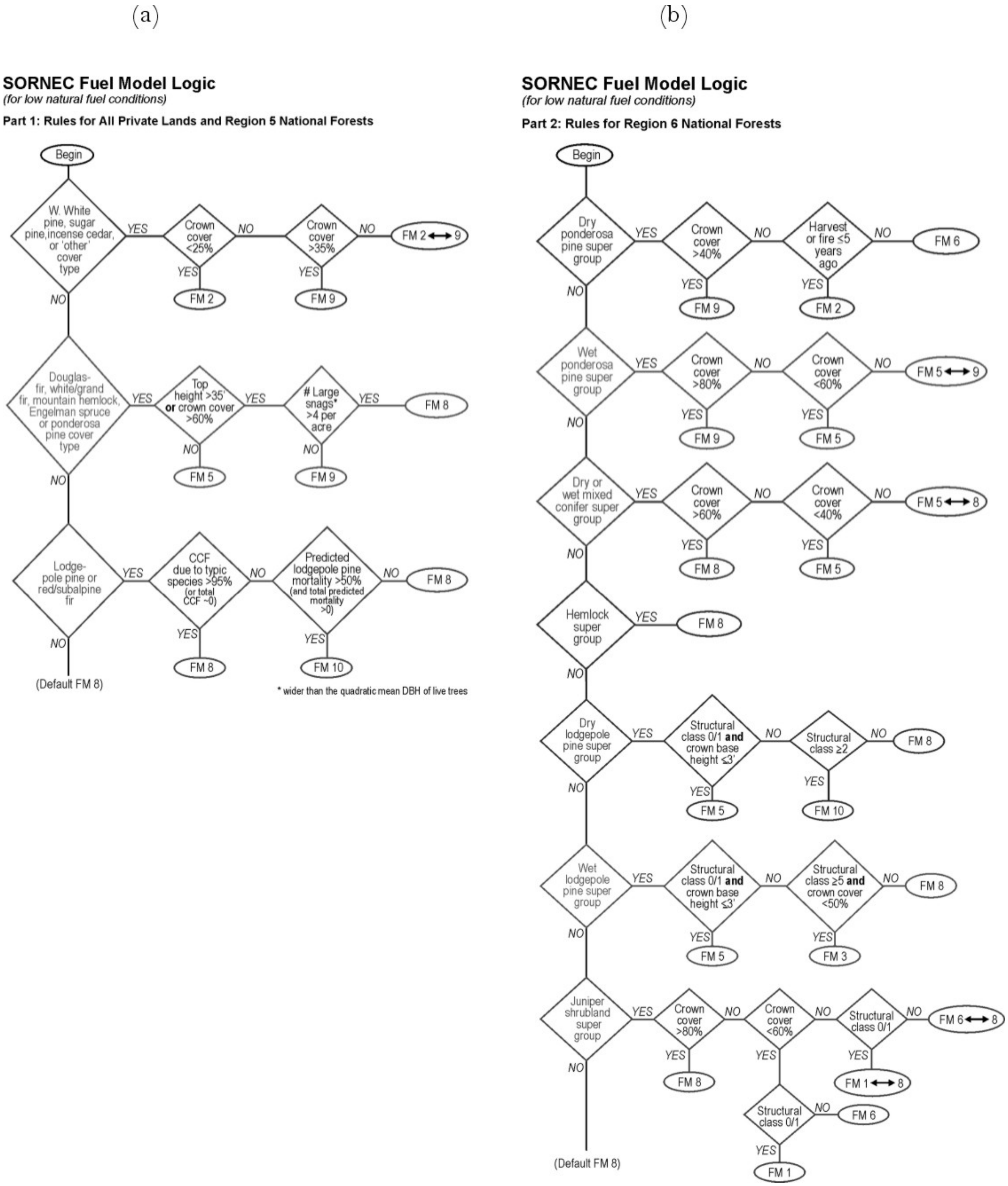


Figure 4.18.2. Fuel model logic for Region 5 (a) and Region 6 (b) forests modeled in the SO-FFE.

4.18.8 Consumption

Consumption of natural fuels is modeled in the same way as in the NI-FFE (Model Description, Section 5.5.2). Activity fuels, material created from a stand entry in the previous five years, are modeled using equations from Consume 1.0 (Ottmar and other 1993) with some modifications based on new information.

1-hr and 10-hr fuels

100 percent consumption.

100-hr fuels

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

where:

C	is the percent consumption
F	is the amount of 100-hr fuel present before the burn, in tons/acre
M_{10}	is the percent fuel moisture of the 10-hr fuels
$Slope$	is the site slope, in percent
$Wind$	is the wind speed at the time of the fire, in mph.

1000-hr+ fuels

The consumption of larger fuels depends on their moisture as well as the moisture level of the 10-hr fuels, 1000-hr fuels, and the amount of consumption of the 100-hr fuels.

First, a diameter reduction variable (DRED) is calculated based on fuel moisture (M):

Condition	**Equation**
M > 60%	1: *DRED* = –0.005 × M + 0.731
M > 44% and M ≤ 60%	2: *DRED* = –0.0178 × M + 1.489
M ≥ 44% and Consumption of 100hr ≤ 75%	3: *DRED* = –0.096 × M + 4.6495
M < 44% and Consumption of 100hr ≥ 85%	4: *DRED* = –0.125 × M + 6.27
M < 44% and Consumption of 100hr 75% – 85%	Interpolate between eq. 3 and 4

Then, if the 10-hr fuel moisture is less than 15 percent, the DRED value is further modified:

1000-hr Fuel Moisture	**Equation**
M ≤ 40%	*DRED* = *DRED* × (1 - 0.22)
M 40%-50%	*DRED* = *DRED* × (1 - 0.11)

Finally, the percent consumption can be calculated as:

$$C = 1 - \left(\frac{a - DRED}{5.2} \right)^2$$

where: C is the percent consumption
$DRED$ is the diameter reduction factor calculated above, and
a is 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%	$R = 0.537 + (C_{1000} + C_{10000})$
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 is the consumption value of the *i*-th hour fuels.
$DRED$ is the diameter reduction factor of the large fuels, as calculated above.
R is the 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 is the maximum tons/acre of duff consumed
R is calculated above, and
b is a multiplier which is:
0.50 – when duff depth is less than 1 inch;
0.75 – when duff depth is 2 or more inches, and
is interpolated when duff depth is 1–2 inches.

4.19 Lake States (LS)

4.19.1 Tree Species

The Lake States variant models the 68 tree species categories shown in Table 4.19.1.

Table 4.19.1. Tree species simulated by the Lake States variant.

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

4.19.2 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 3 of the FFE Model Description.

Initially, each species was put into a snag class (1 - 6), as listed in Table 4.19.2. 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 4.19.2. Snag class for each species in LS-FFE.

Species	Snag class
jack pine	2
scotch pine	4
red pine natural	4
red pine plantation	4
eastern white pine	3
white spruce	1
Norway spruce	1
balsam fir	1
black spruce	1
tamarack	6
northern white-cedar	6
eastern hemlock	6
other softwoods	6
eastern redcedar	6
black ash	5
green ash	5
eastern cottonwood	1
silver maple	5
red maple	5
black cherry	5
American elm	5
slippery elm	5
rock elm	5
yellow birch	1
American basswood	1
sugar maple	5
black maple	5
American beech	5
white ash	5
white oak	6

Species	Snag class
black oak	6
northern pin oak	6
bitternut hickory	6
pignut hickory	6
shagbark hickory	6
bigtooth aspen	1
quaking aspen	1
balsam poplar	1
paper birch	1
commercial hardwoods	5
butternut	5
black walnut	5
eastern hophornbeam	5
black locust	5
non-commercial hardwoods	5
boxelder	5
striped maple	5
mountain maple	5
American hornbeam	5
American chestnut	5
hackberry	5
flowering dogwood	5
hawthorn species	5
apple species	5
black gum	5
sycamore	5
pin cherry	5
chokecherry	5
plum, cherry species	5
willow species	5

Species	Snag class
swamp white oak	6
bur oak	6
chinkapin oak	6
northern red oak	6

Species	Snag class
black willow	5
diamond willow	5
sassafras	5
American mountain-ash	5

The snag class is used to modify the Snag Submodel for the different species in the LS-FFE variant thru:

- a multiplier to modify the species' fall rate;
- a multiplier to modify the time required for snags to decay from a "hard" to "soft" state;
- the maximum number of years that snags will remain standing; and
- a multiplier to modify the species' height loss rate.

Unlike most FFE variants, the LS-FFE base snag fall rate was modified from the one used in the NI-FFE model. The base snag fall rate is calculated as:

$R = 0.18 - 0.006*d$
$F = mRN_o$

where
R = rate of fall;
d = initial dbh of the snag (inches);
N_o = initial density (stems/acre) of snags in the record;
m = multiplier that changes the rate of fall; it is based on the snag class and listed in table 4.19.4
F = density of snags (stems/acre) that fall each year from that record;
and $mR \geq 0.01$.

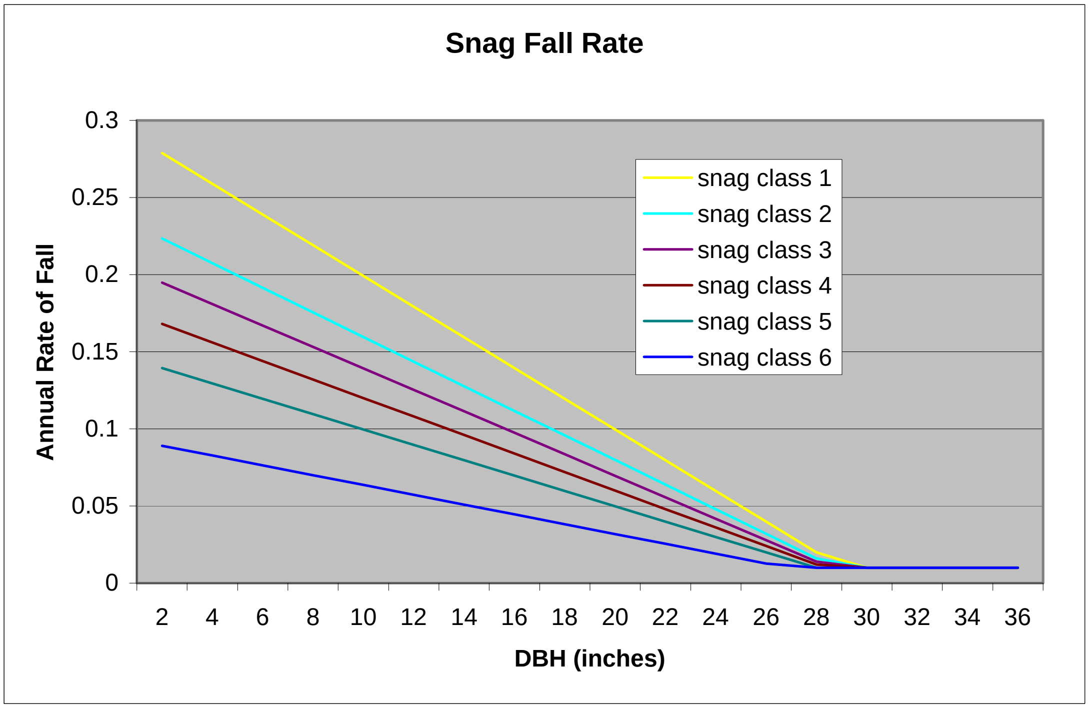


Figure 4.19.1. The rate of fall of small snags and the first 95% of large snags.

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

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

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; and
N_o = 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 4.19.4.

Figures 4.19.2 and 4.19.3 show the proportion of 12 and 20 inch trees still standing after various amounts of time. From Figure 4.19.3, 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.

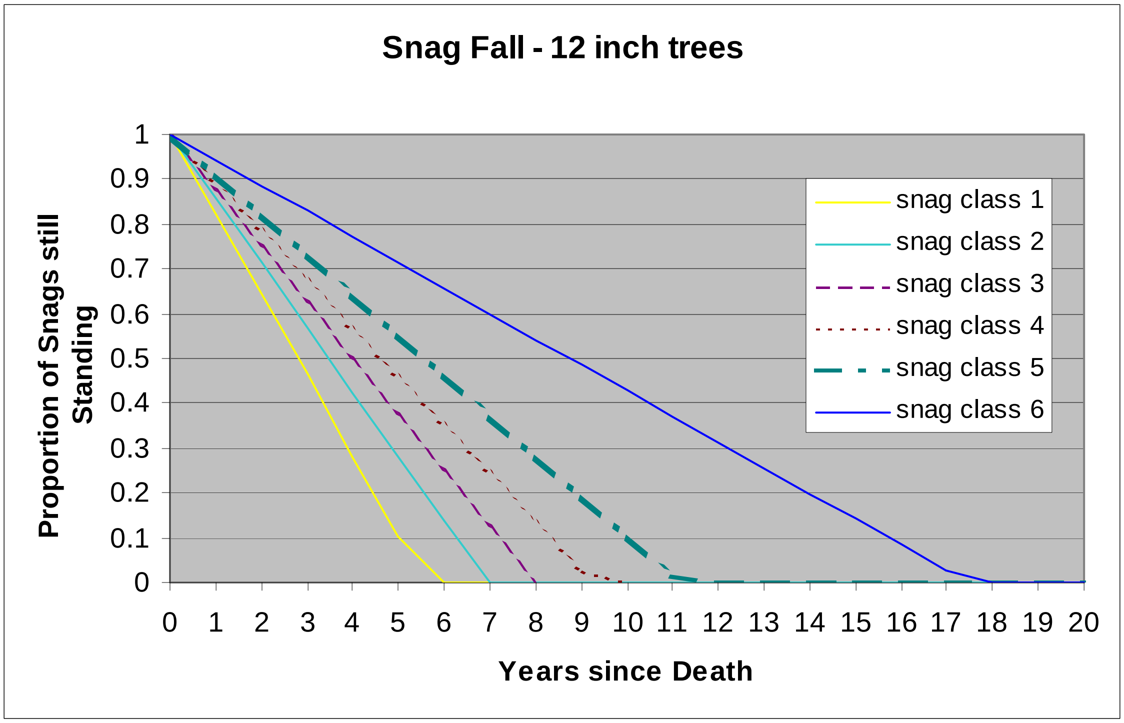


Figure 4.19.2 Snag fall rates for 12 inch trees.

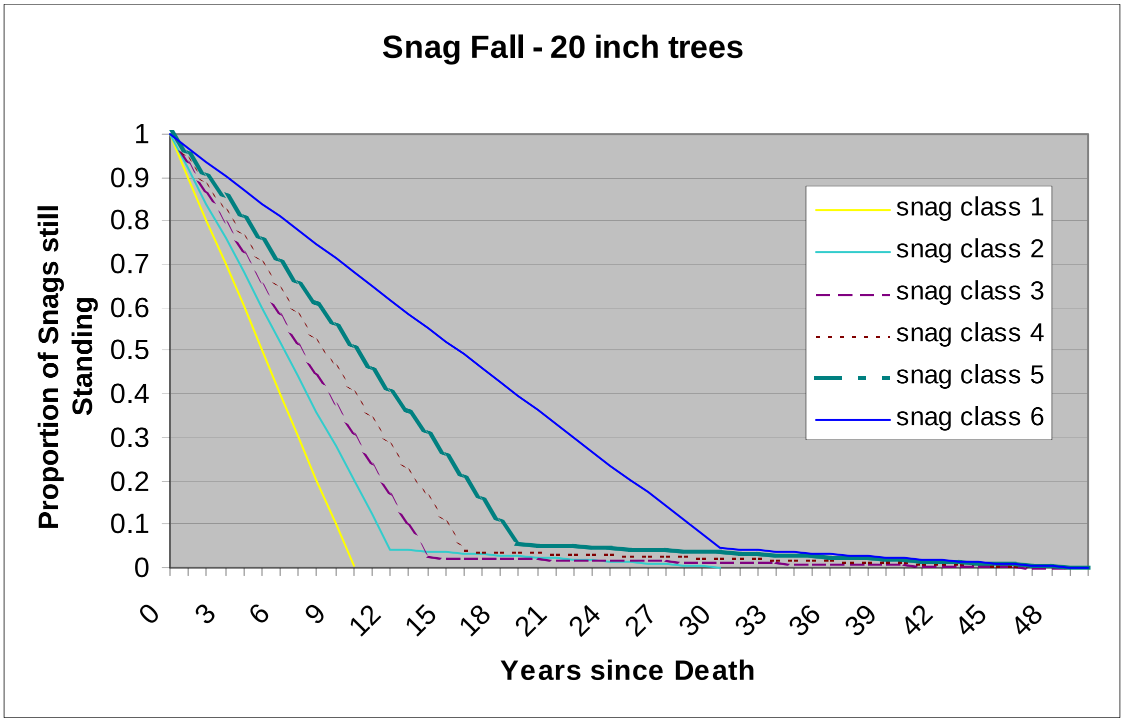


Figure 4.19.3 Snag fall rates for 20 inch trees.

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

4.19.4. The corresponding number of years until a snag reaches 50% of its original height are found in table 4.19.3. The base height loss rate after 50% of a snag's height is lost is 1%. Soft snags lose height twice as fast as hard snags.

LS-FFE also models the decay of snags from a hard to a soft state. The number of years this is predicted to take is:

DecayTime = m(0.65*d)

where
DecayTime = number of years it takes for a hard snag to become soft (the time from death to transition to soft);
d = initial dbh of the snag (inches); and
m = multiplier used to scale the equation to increase or decrease the decay rate for different species (see table 4.19.4)

Figure 4.19.4 shows the number of years it takes a hard snag to become soft for different diameter snags.

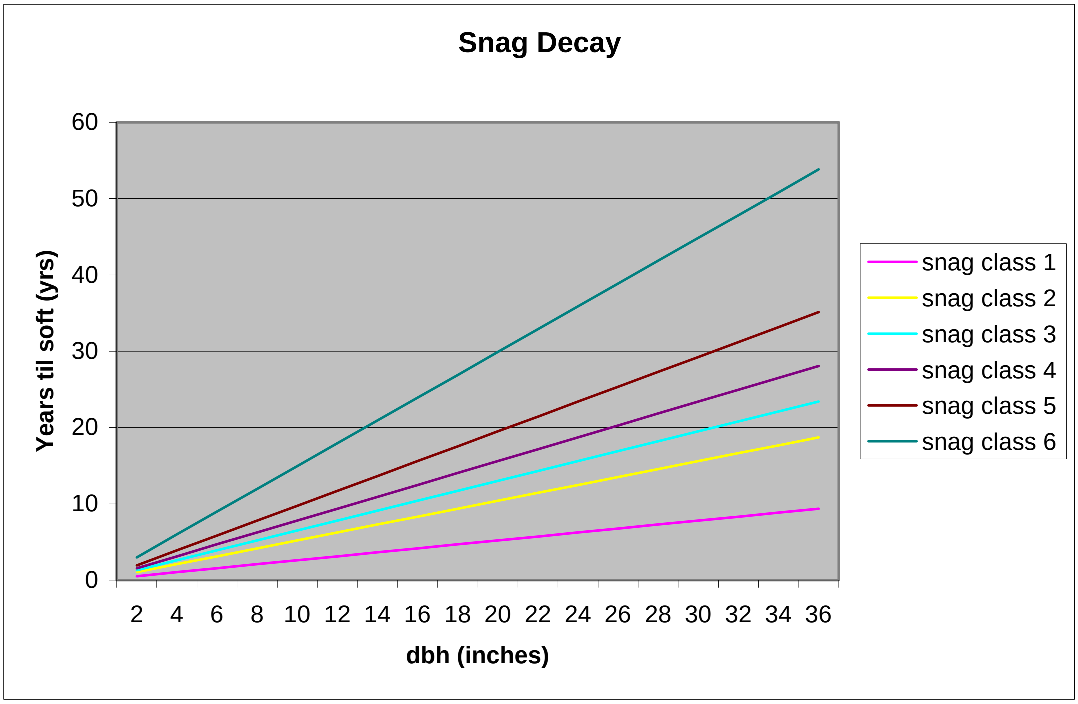


Figure 4.19.4. The number of years until soft for various diameter snags.

Table 4.19.3. 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 4.19.4.

Snag Class	95% Fallen (yr)	50% Height (yr)	Hard-to-Soft (yr)
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 4.19.4. 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 hemock, which is 0)	2.3	50

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.19.5 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 described in the FFE Model Description.

4.19.3 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 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 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 transferred to the FFE after being computed 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 4.19.5. Woody density (ovendry lbs/green ft^3) used in the LS-FFE variant.

Species	lbs/cuft	Species used
jack pine	24.9	
scotch pine	25.6	red pine
red pine natural	25.6	
red pine plantation	25.6	
eastern white pine	21.2	
white spruce	23.1	
Norway spruce	23.1	white spruce
balsam fir	20.6	
black spruce	23.7	
tamarack	30.6	
northern white-cedar	18.1	
eastern hemlock	23.7	
other softwoods	27.4	eastern redcedar
eastern redcedar	27.4	
black ash	28.1	
green ash	33.1	
eastern cottonwood	23.1	
silver maple	27.4	
red maple	30.6	
black cherry	29.3	
American elm	28.7	
slippery elm	29.9	
rock elm	35.6	
yellow birch	34.3	
American basswood	20.0	
sugar maple	34.9	
black maple	32.4	
American beech	34.9	
white ash	34.3	
white oak	37.4	
swamp white oak	39.9	
bur oak	36.2	
chinkapin oak	37.4	white oak
northern red oak	34.9	
black oak	34.9	
northern pin oak	36.2	
bitternut hickory	37.4	
pignut hickory	41.2	
shagbark hickory	39.9	
bigtooth aspen	22.5	
quaking aspen	21.8	
balsam poplar	19.3	
paper birch	29.9	
commercial hardwoods	31.8	black walnut
butternut	22.5	
black walnut	31.8	
eastern hophornbeam	31.8	black walnut
black locust	41.2	
non-commercial hardwoods	28.7	default
boxelder	30.6	red maple
striped maple	30.6	red maple
mountain maple	30.6	red maple
American hornbeam	28.7	default
American chestnut	28.7	default
hackberry	30.6	
flowering dogwood	28.7	default
hawthorn species	28.7	default
apple species	29.3	black cherry
black gum	28.7	
sycamore	28.7	
pin cherry	29.3	black cherry
chokecherry	29.3	black cherry
plum, cherry species	29.3	black cherry
willow species	22.5	black willow
black willow	22.5	
diamond willow	22.5	black willow
sassafras	26.2	
American mountain-ash	28.7	default

Tree Crown

For merchantable trees, estimates of crown material, including branchwood and bolewood above a 4 inch top (DOB), are from Jenkins et al. (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 (1987), 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 using equations in Jenkins et. al. (2003). Due to the nature of these equations, for trees less than 1 inch in diameter, the estimate for a 1-inch tree is scaled back based on diameter. 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 4.19.6. Life span of live foliage and crown fall class (1 to 4) for species modeled in the LS-FFE variant.

Species	Leaf Life (years)	Crown Fall Class
jack pine	2	4
scotch pine	3	4
red pine natural	4	4
red pine plantation	4	4
eastern white pine	2	4
white spruce	8	4
Norway spruce	8	4
balsam fir	8	4
black spruce	8	4
tamarack	1	1
northern white-cedar	2	1
eastern hemlock	3	1
other softwoods	5	1
eastern redcedar	5	1
black ash	1	3
green ash	1	3
eastern cottonwood	1	4
silver maple	1	3
red maple	1	3
black cherry	1	3
American elm	1	3
slippery elm	1	3
rock elm	1	3
yellow birch	1	4
black oak	1	2
northern pin oak	1	2
bitternut hickory	1	1
pignut hickory	1	1
shagbark hickory	1	1
bigtooth aspen	1	4
quaking aspen	1	4
balsam poplar	1	4
paper birch	1	4
commercial hardwoods	1	3
butternut	1	3
black walnut	1	3
eastern hophornbeam	1	3
black locust	1	3
non-commercial hardwoods	1	3
boxelder	1	3
striped maple	1	3
mountain maple	1	3
American hornbeam	1	3
American chestnut	1	3
hackberry	1	3
flowering dogwood	1	3
hawthorn species	1	3
apple species	1	3

American basswood	1	4	black gum	1	3
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 4.19.7. 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 by the FFE. 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 4.19.8. Values (dry weight, tons/acre) for live fuels used in the LS-FFE.

FIA Forest Type	FIA Size Class	**Herbs**	**Shrubs**
all conifers except jack pine	1 (sawtimber)	0.12	0.17
	2 (poletimber)	0.08	0.02
	3 (seedling-sapling)	0.06	0.00
jack pine	1 (sawtimber)	0.06	0.63
	2 (poletimber)	0.10	0.04
	3 (seedling-sapling)	0.14	0.35
hardwoods	1 (sawtimber)	0.00	0.00
	2 (poletimber)	0.00	0.00
	3 (seedling-sapling)	0.00	0.01

Dead Fuels

Initial default fuel pools are based on FIA forest type and size class. Default fuel loadings are based on FIA fuels data collected in the Lake States and were provided by Chris Woodall. Initial fuel loads can be modified using the FUELINIT keyword.

Table 4.19.9. FIA forest type and size class are used to assign default surface fuel values (tons/acre) by size class.

FIA Forest Type	FIA Size Class	Size Class (in)							
		< 0.25	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
white-red pine	1	0.09	0.51	1.76	0.78	1.89	1.95	1.83	3.87
	2	0.07	0.51	0.93	0.06	0.26	0.00	0.54	1.43
	3	0.07	0.25	0.18	0.00	0.00	0.00	2.05	9.96
jack pine	1	0.31	2.22	4.99	0.64	2.11	1.46	1.44	9.05
	2	0.12	0.44	1.05	0.66	1.26	0.00	0.81	2.97
	3	0.11	0.89	4.58	4.98	4.76	0.00	0.20	2.09
spruce-fir	1	0.40	0.95	1.79	1.28	4.47	1.46	0.90	64.29
	2	0.19	0.60	1.22	0.52	1.88	0.57	2.36	80.12
	3	0.07	0.49	2.04	0.98	2.61	0.35	1.20	36.70
eastern redcedar	any	0.00	0.00	0.00	0.79	0.00	0.00	0.07	8.28
oak-pine	1	0.12	0.57	1.14	0.62	3.71	0.37	0.81	2.14
	2	0.11	0.95	1.59	0.17	1.89	0.00	0.29	1.28
	3	0.12	0.49	0.60	0.67	0.77	0.00	0.20	4.77
oak-hickory	1	0.18	0.53	1.60	0.78	1.65	0.52	0.91	4.45
	2	0.24	0.59	1.41	0.74	1.61	1.30	0.44	3.02
	3	0.09	0.80	0.16	0.48	0.51	0.00	0.49	3.96
elm-ash-eastern cottonwood	1	0.17	0.87	2.10	0.97	2.17	4.52	1.61	40.33
	2	0.22	0.48	1.78	1.01	3.09	0.89	1.00	156.25
	3	0.13	0.26	0.74	0.49	1.88	0.12	1.17	21.42
maple-beech-birch	1	0.22	0.62	1.74	0.99	1.77	1.41	1.38	7.82
	2	0.29	0.74	2.11	0.96	1.92	3.33	0.90	7.65
	3	0.23	0.69	2.96	1.15	2.81	0.28	0.81	2.37
aspen-birch	1	0.13	0.86	2.10	0.82	2.76	1.10	0.71	14.75
	2	0.12	0.70	2.51	1.04	2.41	2.70	0.53	6.58
	3	0.13	0.52	1.69	0.77	1.80	0.66	1.04	9.55
nonstocked	any	0.07	0.32	0.34	0.19	0.63	0.00	0.00	0.36

4.19.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.19.10 are used to calculate single bark thickness, which in turn is used to calculate fire-related mortality (RMRS-GTR-116, 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 and others 2001).

Table 4.19.10. Species specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species used
jack pine	0.04	
scotch pine	0.03	
red pine natural	0.043	
red pine plantation	0.043	
eastern white pine	0.045	
white spruce	0.025	
Norway spruce	0.029	
balsam fir	0.031	
black spruce	0.032	
tamarack	0.031	
northern white-cedar	0.025	
eastern hemlock	0.039	
other softwoods	0.038	easterm redcedar
eastern redcedar	0.038	
black ash	0.035	
green ash	0.039	
eastern cottonwood	0.04	
silver maple	0.031	
red maple	0.028	
black cherry	0.03	
American elm	0.031	
slippery elm	0.032	
rock elm	0.033	
yellow birch	0.031	
American basswood	0.038	
sugar maple	0.033	
black maple	0.035	
American beech	0.025	
white ash	0.042	
white oak	0.04	
swamp white oak	0.045	
bur oak	0.042	
chinkapin oak	0.042	
northern red oak	0.042	
black oak	0.045	
northern pin oak	0.038	
bitternut hickory	0.037	
pignut hickory	0.037	
shagbark hickory	0.04	
bigtooth aspen	0.039	
quaking aspen	0.044	
balsam poplar	0.04	
paper birch	0.027	
commercial hardwoods	0.041	butternut
butternut	0.041	
black walnut	0.041	
eastern hophornbeam	0.037	
black locust	0.049	
non-commercial hardwoods	0.034	boxelder
boxelder	0.034	
striped maple	0.045	
mountain maple	0.04	
American hornbeam	0.03	
American chestnut	0.04	
hackberry	0.036	sugarberry
flowering dogwood	0.041	
hawthorn species	0.038	
apple species	0.043	
black gum	0.039	
sycamore	0.033	
pin cherry	0.045	
chokecherry	0.04	
plum, cherry species	0.04	
willow species	0.041	
black willow	0.04	
diamond willow	0.04	
sassafras	0.035	
American mountain-ash	0.04	

4.19.5 Decay Rate

Decay of down material is simulated by applying loss rates to pieces by size class (Table 4.19.11), as described in section 2.4.5 of the FFE documentation. 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 4.19.11. Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.11	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.06	
6 – 12		
> 12	0.02	
Litter	0.31	
Duff	0.002	0.0

By default, the FFE decays all wood species at the rates shown in Table 4.19.11. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.19.12 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword. The decay rate classes were generally determined from the Wood Handbook (1999). When species were classified differently for young or old growth, young growth was assumed. Species not listed in the wood handbook were classed as 4.

Table 4.19.12. 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
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

Species	Decay Rate Class
rock elm	4
yellow birch	4
American basswood	4
sugar maple	4
black maple	4
American beech	4
white ash	4
white oak	2
swamp white oak	2
bur oak	2
chinkapin oak	2
northern red oak	2

Species	Decay Rate Class
hawthorn species	4
apple species	2
black gum	4
sycamore	4
pin cherry	2
chokecherry	2
plum, cherry species	2
willow species	4
black willow	4
diamond willow	4
sassafras	2
American mountain-ash	4

4.19.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups (Table 4.19.13) 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 4.19.13. 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

4.19.7 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 the FFE variant to determine a weighted set of fuel models, or

4. allowing the FFE variant 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 4.19.5, one or more low fuel fuel models become candidate models. In other regions of the graph, other fuel models may also be candidates. Tables 4.19.14 and 4.19.15 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 4.19.16 (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 4.19.5 or Table 4.19.15. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

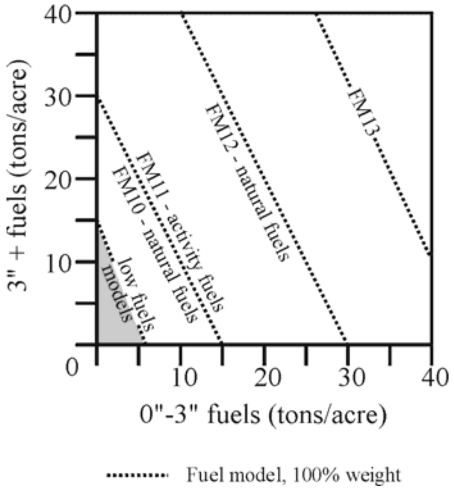


Figure 4.19.5. Candidate fuel models are determined using the logic shown in tables 4.19.14 and 4.19.15. At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. Not all fuel models are candidates under all forest types (see table 4.19.15).

Table 4.19.14. 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 4.19.15. Relationship between forest type and fuel model selected.

Forest Type		Fuel Model
Jack Pine	surface fuel load is high (see Figure 4.19.5)	10, 11, 12, or 13
	canopy cover ≤ 70% and stand height ≤ 25'	4
	canopy cover ≤ 70% and stand height > 25' and balsam fir understory (atleast 500 BF 1 – 3" per acre)	10 (before greenup) 162 (after greenup)
	canopy cover ≤ 70% and stand height > 25' and grass understory (native plant community is FDc12 or FDc23)	2
	canopy cover ≤ 70% and stand height > 25' and not a balsam fir or grass understory	10 (before greenup) 161 (after greenup)
	canopy cover > 70% and stand height ≤ 15'	4
	canopy cover > 70% and stand height > 15' and midflame windspeed ≤ 4mph	8
	canopy cover > 70% and stand height > 15' and midflame windspeed > 4mph	10
Northern Hardwoods	there is activity fuel and surface fuel load is high (see Figure 4.19.5)	11
	else if there is aspen or birch present or atleast 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 4.19.5)	10
	0 – 3” surface fuel is ≥ 5 tons/acre	10
	0 – 3” surface fuel is < 5 tons/acre and less than 500 1 – 3” conifer trees/acre and birch dominant	9
	0 – 3” surface fuel is < 5 tons/acre and less than 500 1 – 3” conifer trees/acre and aspen dominant	8
	0 – 3” surface fuel is < 5 tons/acre and 1 – 3” conifer trees/acre ≥ 500 and midflame windspeed > 4mph	164
	0 – 3” surface fuel is < 5 tons/acre and 1 – 3” conifer trees/acre ≥ 500 and midflame windspeed ≤ 4mph and birch dominant	9
	0 – 3” surface fuel is < 5 tons/acre and 1 – 3” conifer trees/acre ≥ 500 and midflame windspeed ≤ 4mph and aspen dominant	8
Oak	surface fuel load is high (see Figure 4.19.5)	10, 11
	overstory canopy cover (trees 5”+) ≥ 45% and it is an early spring burn and the fine fuel moisture is < 8%	186
	overstory canopy cover (trees 5”+) ≥ 45% and it is an early spring burn and the fine fuel moisture is ≥ 8%	8
	overstory canopy cover (trees 5”+) ≥ 45% and it is not an early spring burn and atleast 30% of the basal area is in white oak and black oak	189
	overstory canopy cover (trees 5”+) ≥ 45% and it is not an early spring burn and less than 30% of the basal area in white oak and black oak	9
	overstory canopy cover is between 15 and 45% and the number of 0-2” trees/acre < 500	2
	overstory canopy cover is between 15 and 45% and the number of 0-2” trees/acre ≥ 500	142
	overstory canopy cover is < 15% and the number of 0-2” trees/acre < 500	105
	overstory canopy cover is < 15% and the number of 0-2” trees/acre ≥ 500	142
Mixed Wood (aspen and birch with conifers in the overstory)	surface fuel load is high (see Figure 4.19.5)	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 4.19.5)	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 (atleast 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 (atleast 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 4.19.16. LS-FFE native plant community (NPV) codes and descriptions (Minnesota Department of Natural Resources 2003).

NPV Code	NPV description	NPV Code	NPV description
1	FDn12 Northern Dry-Sand Pine Woodland	33	FPn82 Northern Rich Tamarack Swamp (Western Basin)
2	FDn22 Northern Dry-Bedrock Pine (Oak) Woodland	34	FPs63 Southern Rich Conifer Swamp
3	FDn32 Northern Poor Dry-Mesic Mixed Woodland	35	FPw63 Northwestern Rich Conifer Swamp
4	FDn33 Northern Dry-Mesic Mixed Woodland	36	APn80 Northern Spruce Bog
5	FDn43 Northern Mesic Mixed Forest	37	APn81 Northern Poor Conifer Swamp
6	FDc12 Central Poor Dry Pine Woodland	38	APn90 Northern Open Bog
7	FDc23 Central Dry Pine Woodland	39	APn91 Northern Poor Fen
8	FDc24 Central Rich Dry Pine Woodland	40	CTn11 Northern Dry Cliff

9	FDc25 Central Dry Oak-Aspen (Pine) Woodland	41	CTn12 Northern Open Talus
10	FDc34 Central Dry-Mesic Pine-Hardwood Forest	42	CTn24 Northern Scrub Talus
11	MHn35 Northern Mesic Hardwood Forest	43	CTn32 Northern Mesic Cliff
12	MHn44 Northern Wet-Mesic Boreal Hardwood-Conifer Forest	44	CTn42 Northern Wet Cliff
13	MHn45 Northern Mesic Hardwood (Cedar) Forest	45	CTu22 Lake Superior Cliff
14	MHn46 Northern Wet-Mesic Hardwood Forest	46	ROn12 Northern Bedrock Outcrop
15	MHn47 Northern Rich Mesic Hardwood Forest	47	ROn23 Northern Bedrock Shrubland
16	MHc26 Central Dry-Mesic Oak-Aspen Forest	48	LKi32 Inland Lake Sand/Gravel/Cobble Shore
17	MHc36 Central Mesic Hardwood Forest (Eastern)	49	LKi43 Inland Lake Rocky Shore
18	MHc37 Central Mesic Hardwood Forest (Western)	50	LKi54 Inland Lake Clay/Mud Shore
19	MHc47 Central Wet-Mesic Hardwood Forest	51	LKu32 Lake Superior Sand/Gravel/Cobble Shore
20	FFn57 Northern Terrace Forest	52	LKu43 Lake Superior Rocky Shore
21	FFn67 Northern Floodplain Forest	53	RVx32 Sand/Gravel/Cobble River Shore
22	WFn53 Northern Wet Cedar Forest	54	RVx43 Rocky River Shore
23	WFn55 Northern Wet Ash Swamp	55	RVx54 Clay/Mud River Shore
24	WFn64 Northern Very Wet Ash Swamp	56	OPn81 Northern Shrub Shore Fen
25	WFs57 Southern Wet Ash Swamp	57	OPn91 Northern Rich Fen (Water Track)
26	WFw54 Northwestern Wet Aspen Forest	58	OPn92 Northern Rich Fen (Basin)
27	FPn62 Northern Rich Spruce Swamp (Basin)	59	OPn93 Northern Extremely Rich Fen
28	FPn63 Northern Cedar Swamp	60	WMn82 Northern Wet Meadow/Carr
29	FPn71 Northern Rich Spruce Swamp (Water Track)	61	MRn83 Northern Mixed Cattail Marsh
30	FPn72 Northern Rich Tamarack Swamp (Eastern Basin)	62	MRn93 Northern Bulrush-Spikerush Marsh
31	FPn73 Northern Alder Swamp	63	MRu94 Lake Superior Coastal Marsh
32	FPn81 Northern Rich Tamarack Swamp (Water Track)		

4.19.8 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.

4.20 Northeastern (NE)

4.20.1 Tree Species

The Northeastern variant models the 108 tree species categories shown in Table 4.20.1.

Table 4.20.1. Tree species simulated by the Northeastern variant.

Common name	Scientific name
balsam fir	*Abies balsamea*
tamarack	*Larix laricina*
white spruce	*Picea glauca*
red spruce	*Picea rubens*
Norway spruce	*Picea abies*
black spruce	*Picea mariana*
other spruce species	*Picea sp.*
red pine	*Pinus resinosa*
eastern white pine	*Pinus strobus*
loblolly pine	*Pinus taeda*
Virginia pine	*Pinus virginiana*
northern white-cedar	*Thuja occidentalis*
Atlantic white-cedar	*Chamaecyparis thoides*
eastern redcedar	*Juniperus virginiana*
other cedar species	*juniperus species*
eastern hemlock	*Tsuga canadensis*
other hemlock species	*Tsuga sp.*
other pine species	*Pinus sp.*
jack pine	*Pinus banksiana*
shortleaf pine	*Pinus echinata*
Table Mountain pine	*Pinus pungens*
pitch pine	*Pinus rigida*
pond pine	*Pinus serotina*
Scotch pine	*Pinus sylvestris*
other softwoods	
red maple	*Acer rubrum*
sugar maple	*Acer saccharum*
black maple	*Acer nigrum*
silver maple	*Acer saccharinum*
yellow birch	*Betula alleghaniensis*
sweet birch	*Betula lenta*
river birch	*Betula nigra*
paper birch	*Betula papyrifera*
gray birch	*Betula populifolia*
hickory species	*Carya sp.*
white oak	*Quercus alba*
bur oak	*Quercus macrocarpa*
chinkapin oak	*Quercus muehlenbergii*
post oak	*Quercus stellata*
other oak species	*Quercus sp.*
scarlet oak	*Quercus coccinea*
shingle oak	*Quercus imbricaria*
water oak	*Quercus nigra*
pin oak	*Quercus palustris*
chestnut oak	*Quercus prinus*
swamp white oak	*Quercus bicolor*
swamp chestnut oak	*Quercus michauxii*
northern red oak	*Quercus rubra*
southern red oak	*Quercus falcata var. falcata*
black oak	*Quercus velutina*
cherrybark oak	*Quercus falcata var. pagodaefolia*
other hardwoods	
buckeye species	*Aesculus sp.*
yellow buckeye	*Aesculus octandra*
water birch	*Betula occidentalis*
hackberry	*Celtis occidentalis*
common persimmon	*Diospyros virginiana*
American holly	*Ilex opaca*
butternut	*Juglans cinerea*
black walnut	*Juglans nigra*
Osage-orange	*Maclura pomifera*
magnolia species	*Magnolia sp.*
sweetbay	*Magnolia virginiana*
apple species	*Malus sp.*
water tupelo	*Nyssa aquatica*
blackgum	*Nyssa sylvatica*
sourwood	*Oxydendrum arboreum*
Paulownia	*Paulownia tomentosa*
sycamore	*Platanus occidentalis*
willow oak	*Quercus phellos*

Common name	Scientific name
pignut hickory	*Carya glabra*
shellbark hickory	*Carya laciniosa*
shagbark hickory	*Carya ovata*
mockernut hickory	*Carya tomentosa*
American beech	*Fagus grandifolia*
ash species	*Fraxinus sp.*
white ash	*Fraxinus americana*
black ash	*Fraxinus nigra*
green ash	*Fraxinus pennsylvanica*
pumpkin ash	*Fraxinus profunda*
yellow-poplar	*Liriodendron tulipifera*
sweetgum	*Liquidambar styraciflua*
cucumbertree	*Magnolia acuminata*
quaking aspen	*Populus tremuloides*
balsam poplar	*Populus balsamifera*
eastern cottonwood	*Populus deltoides*
bigtooth aspen	*Populus grandidentata*
swamp cottonwood	*Populus heterophylla*
black cherry	*Prunus serotina*
black locust	*Robinia psuedoacacia*
black willow	*Salix nigra*
sassafras	*Sassafras albidum*
American basswood	*Sorbus americana*
white basswood	*Tilia heterophylla*
other elm species	*Ulmus sp.*
American elm	*Ulmus americana*
slippery elm	*Ulmus rubra*
non-commercial hardwoods	
boxelder	*Acer negundo*
striped maple	*Acer pensylvanicum*
ailanthus	*Ailanthus altissima*
serviceberry	*Amelanchier sp.*
American hornbeam	*Carpinus caroliniana*
flowering dogwood	*Cornus florida*
hawthorn species	*Crataegus sp.*
eastern hophornbeam	*Ostrya virginiana*
plum, cherry species	*Prunus sp.*
pin cherry	*Prunus pensylvanica*

4.20.2 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 3 of the FFE Model Description.

Initially, each species was put into a snag class (1 - 3), as listed in Table 4.20.2. 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 4.20.2. Snag class for each species in NE-FFE.

Species	Snag class
balsam fir	1
tamarack	3
white spruce	1
red spruce	1
Norway spruce	1
black spruce	1
other spruce species	1
red pine	1
eastern white pine	2
loblolly pine	1
Virginia pine	1
northern white-cedar	3
white oak	3
bur oak	3
chinkapin oak	3
post oak	3
other oak species	3
scarlet oak	2
shingle oak	2
water oak	2
pin oak	2
chestnut oak	3
swamp white oak	3
swamp chestnut oak	3

Species	Snag class
Atlantic white-cedar	3
eastern redcedar	3
other cedar species	3
eastern hemlock	3
other hemlock species	3
other pine species	1
jack pine	1
shortleaf pine	1
Table Mountain pine	1
pitch pine	1
pond pine	1
Scotch pine	1
other softwoods	1
red maple	2
sugar maple	2
black maple	2
silver maple	2
yellow birch	1
sweet birch	1
river birch	1
paper birch	1
gray birch	1
hickory species	3
pignut hickory	3
shellbark hickory	3
shagbark hickory	3
mockernut hickory	3
American beech	2
ash species	2
white ash	2
black ash	2
green ash	2
pumpkin ash	2
yellow-poplar	2
sweetgum	2
cucumbertree	2
quaking aspen	1
balsam poplar	1
eastern cottonwood	1
bigtooth aspen	1
swamp cottonwood	1
black cherry	2

Species	Snag class
northern red oak	2
southern red oak	2
black oak	2
cherrybark oak	2
other hardwoods	2
buckeye species	2
yellow buckeye	2
water birch	1
hackberry	2
common persimmon	3
American holly	2
butternut	2
black walnut	2
Osage-orange	2
magnolia species	2
sweetbay	2
apple species	2
water tupelo	3
blackgum	3
sourwood	2
Paulownia	2
sycamore	2
willow oak	2
black locust	3
black willow	1
sassafras	2
American basswood	1
white basswood	1
other elm species	1
American elm	1
slippery elm	1
non-commercial hardwoods	2
boxelder	2
striped maple	2
ailanthus	2
serviceberry	2
American hornbeam	2
flowering dogwood	2
hawthorn species	2
eastern hophornbeam	2
plum, cherry species	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 the FFE documentation, section 2.3.5 (RMRS-GTR-116).

Table 4.20.3. 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 4.20.4. They were based on discussions with Coeli Hoover and Linda Heather (FS Northern Research Station) and Yamasaki and Leak (in review).

Table 4.20.4. Default snag fall rates for the NE-FFE.

DBH (inches)	Years until all snags have fallen (yrs)	Associated snag fall rate (proportion eachyear)
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.

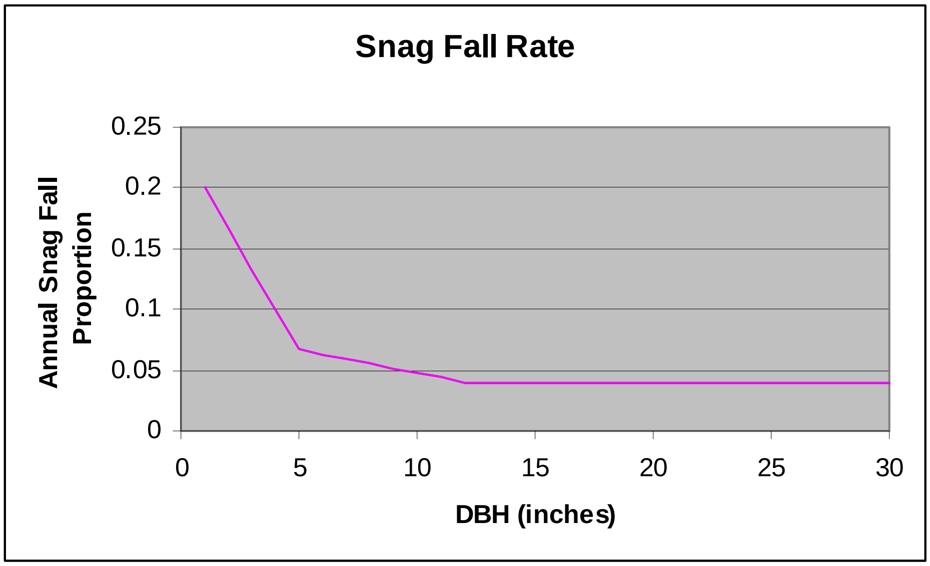


Figure 4.20.1. The rate of fall of small snags and the first 95% of large snags.

Figures 4.20.2 and 4.20.3 show the proportion of 5”, 12”, and larger trees still standing after various amounts of time. From Figure 4.20.3, 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.

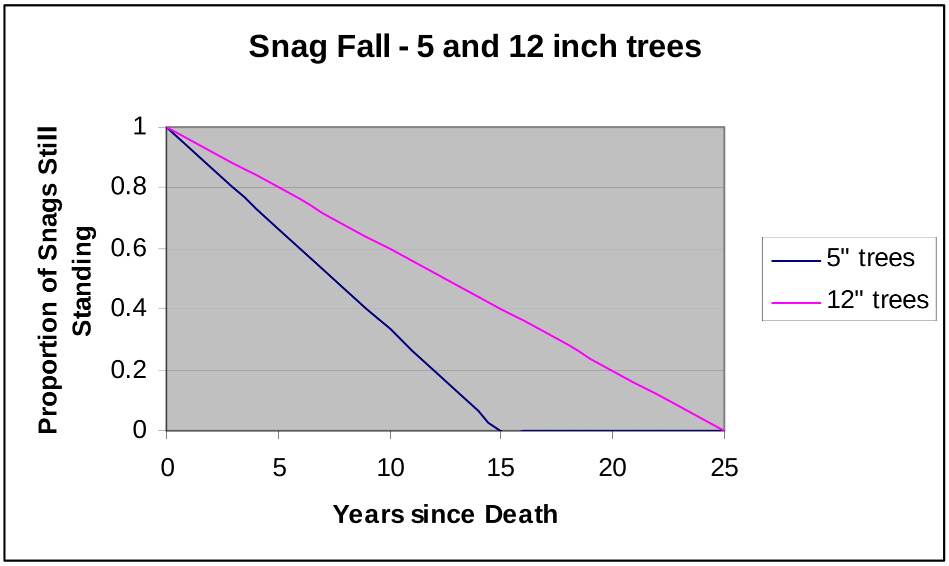


Figure 4.20.2 Snag fall rates for 5 and 12 inch trees.

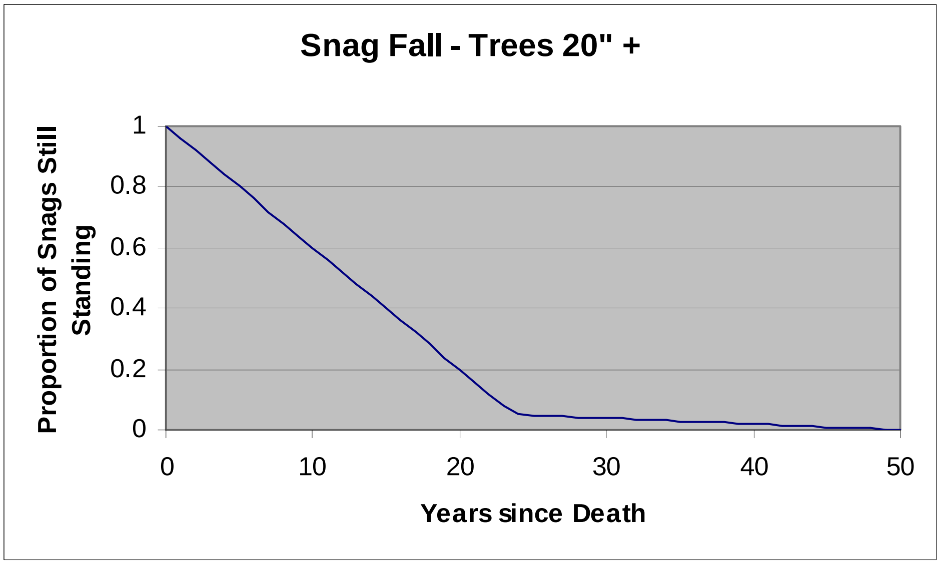


Figure 4.20.3 Snag fall rates for trees larger than 20 inches dbh.

Figure 4.20.4 shows the number of years it takes a hard snag to become soft for different diameter snags.

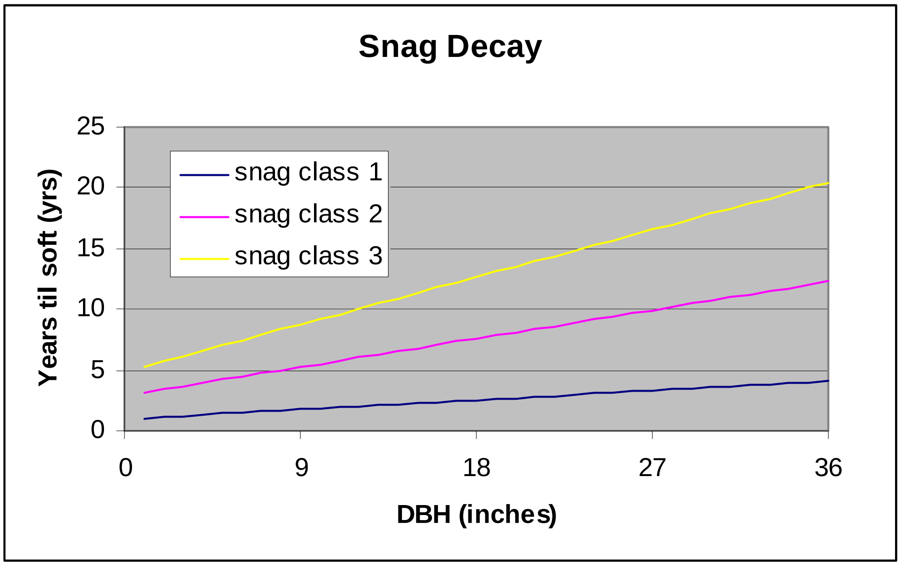


Figure 4.20.4. The number of years until soft for various diameter snags.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.20.5 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 described in the FFE Model Description.

4.20.3 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 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 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 transferred to the FFE after being computed 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 4.20.5. Woody density (ovendry lbs/green ft^3) used in the NE-FFE variant.

Species	lbs/cuft	Species used	Species	lbs/cuft	Species used
balsam fir	20.6		white oak	37.4	
tamarack	30.6		bur oak	36.2	
white spruce	23.1		chinkapin oak	37.4	White oak
red spruce	23.1		post oak	37.4	
Norway spruce	23.1	Red / white spruce	other oak species	37.4	White oak
black spruce	23.7		scarlet oak	37.4	
other spruce species	23.1	Red / white spruce	shingle oak	34.9	Northern red oak
red pine	25.6		water oak	34.9	
eastern white pine	21.2		pin oak	36.2	
loblolly pine	29.3		chestnut oak	35.6	
Virginia pine	28.1		swamp white oak	39.9	
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	
other hemlock species	26.2	Mountain / western hemlock	other hardwoods	28.7	Default
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	

Species	lbs/cuft	Species used
green ash	33.1	
pumpkin ash	33.1	Green ash
yellow-poplar	24.9	
sweetgum	28.7	
cucumbertree	27.4	
quaking aspen	21.8	
balsam poplar	19.3	
eastern cottonwood	23.1	
bigtooth aspen	22.5	
swamp cottonwood	23.1	Eastern cottonwood
black cherry	29.3	
non-commercial hardwoods	28.7	Default
boxelder	30.6	Red maple
striped maple	30.6	Red maple
ailanthus	28.7	Default
serviceberry	28.7	Default
American hornbeam	28.7	Default
flowering dogwood	28.7	Default
hawthorn species	28.7	Default
eastern hophornbeam	28.7	Default
plum, cherry species	29.3	Black cherry
pin cherry	29.3	Black cherry

Tree Crown

For merchantable trees, estimates of crown material, including branchwood and bolewood above a 4 inch top (DOB), are from Jenkins et al. (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 (1987), 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 using equations in Jenkins et. al. (2003). Due to the nature of these equations, for trees less than 1 inch in diameter, the estimate for a 1-inch tree is scaled back based on diameter. 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 4.20.6. 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
balsam fir	8	6
tamarack	1	1
white spruce	8	6
red spruce	8	6
Norway spruce	8	6
black spruce	8	6
other spruce species	8	6
red pine	4	6
eastern white pine	2	6
loblolly pine	3	6
Virginia pine	3	6
northern white-cedar	2	1
Atlantic white-cedar	3	1
eastern redcedar	5	1
other cedar species	5	1
eastern hemlock	3	3
other hemlock species	3	3
other pine species	2	6
jack pine	2	6
shortleaf pine	4	6
Table Mountain pine	3	6
pitch pine	2	6
pond pine	2	6
Scotch pine	3	6
other softwoods	2	6
red maple	1	5
sugar maple	1	5
black maple	1	5
silver maple	1	5
yellow birch	1	6
sweet birch	1	6
river birch	1	6
paper birch	1	6
gray birch	1	6
hickory species	1	2
pignut hickory	1	2
shellbark hickory	1	2
shagbark hickory	1	2
mockernut hickory	1	2
American beech	1	4
ash species	1	5
white ash	1	5
black ash	1	5
green ash	1	5
pumpkin ash	1	5
yellow-poplar	1	4
sweetgum	1	5
white oak	1	3
bur oak	1	3
chinkapin oak	1	3
post oak	1	3
other oak species	1	3
scarlet oak	1	4
shingle oak	1	4
water oak	1	4
pin oak	1	4
chestnut oak	1	3
swamp white oak	1	3
swamp chestnut oak	1	3
northern red oak	1	4
southern red oak	1	4
black oak	1	4
cherrybark oak	1	4
other hardwoods	1	5
buckeye species	1	5
yellow buckeye	1	5
water birch	1	6
hackberry	1	4
common persimmon	1	4
American holly	3	4
butternut	1	4
black walnut	1	4
Osage-orange	1	5
magnolia species	1	4
sweetbay	1	4
apple species	1	4
water tupelo	1	3
blackgum	1	3
sourwood	1	5
Paulownia	1	5
sycamore	1	5
willow oak	1	4
black locust	1	2
black willow	1	6
sassafras	1	4
American basswood	1	6
white basswood	1	6
other elm species	1	5
American elm	1	5
slippery elm	1	5
non-commercial hardwoods	1	5
boxelder	1	5
striped maple	1	5
ailanthus	1	5

cucumbertree	1	4	serviceberry	1	5
quaking aspen	1	6	American hornbeam	1	4
balsam poplar	1	6	flowering dogwood	1	5
eastern cottonwood	1	6	hawthorn species	1	5
bigtooth aspen	1	6	eastern hophornbeam	1	4
swamp cottonwood	1	6	plum, cherry species	1	4
black cherry	1	4	pin cherry	1	4

Table 4.20.7. 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 4.20.8. 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. Initial fuel loads can be modified using the FUELINIT keyword.

Table 4.20.9. FIA forest type and size class are used to assign default surface fuel values (tons/acre) by size class.

FIA Forest type	FIA size class	Size class (inches)							
		< 0.25	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
white / red / jack pine	all	0.81	1.19	1.66	0.73	2.24	2.01	3.06	11.20
spruce –fir	1	0.37	0.59	1.85	0.82	2.47	5.40	3.36	48.56
spruce –fir	2	0.50	0.68	1.77	1.52	3.17	1.64	1.91	22.14
spruce –fir	3	0.31	0.65	1.55	1.45	2.82	1.08	1.57	25.87

loblolly-shortleaf pine	all	0.21	1.08	7.32	0.53	0.57	0.00	4.21	13.94
exotic softwoods	all	0.34	0.50	0.56	0.08	0.00	0.00	0.60	8.11
oak-pine	1	0.23	0.82	2.55	0.83	2.11	1.20	4.06	22.63
oak-pine	2 or 3	0.26	0.84	1.15	0.49	0.50	4.64	3.12	17.56
oak-hickory	1	0.31	0.72	2.09	0.86	1.49	2.34	2.01	7.64
oak-hickory	2	0.32	1.13	2.51	0.53	0.98	0.52	1.75	7.31
oak-hickory	3	0.17	0.77	1.43	0.45	0.54	0.06	1.35	3.43
oak-gum-cypress	all	0.32	0.75	1.31	0.64	2.10	0.98	1.07	15.21
elm-ash-cottonwood	1 or 2	0.17	0.68	1.65	0.57	1.20	1.66	0.70	5.83
elm-ash-cottonwood	3	0.22	2.15	0.85	0.03	0.05	0.21	0.36	1.38
maple-beech-birch	1	0.39	0.90	2.88	0.95	2.25	1.96	2.39	13.75
maple-beech-birch	2	0.37	1.03	2.61	0.91	1.46	1.57	2.28	16.74
maple-beech-birch	3	0.33	0.73	1.25	0.54	0.92	1.99	1.71	8.27
aspen-birch	1 or 2	0.48	1.66	2.80	0.87	1.70	2.97	2.72	19.61
aspen-birch	3	0.52	0.76	2.57	1.15	0.94	0.34	1.34	10.36
nonstocked	5	0.33	1.08	1.47	0.24	0.49	0.53	1.01	1.07

4.20.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.20.10 are used to calculate single bark thickness, which in turn is used to calculate fire-related mortality (RMRS-GTR-116, 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 and others 2001).

Table 4.20.10. Species specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species used	Species	Multiplier (V_{sp})	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	
other hemlock species	0.04	Western / mountain hemlock	other hardwoods	0.04	Middle of this group
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	

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

4.20.5 Decay Rate

Decay of down material is simulated by applying loss rates to pieces by size class (Table 4.20.11), as described in section 2.4.5 of the FFE documentation. 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 4.20.11. Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.19	0.02
0.25 – 1		
1 – 3	0.11	
3 – 6	0.07	
6 – 12	0.03	
> 12		
Litter	0.40	
Duff	0.002	0.0

By default, the FFE decays all wood species at the rates shown in Table 4.20.11. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.20.12 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword. The decay rate classes were generally determined from the Wood Handbook (1999). When species were classified differently for young or old growth, young growth was assumed. Species not listed in the wood handbook were classed as 4.

Table 4.20.12. Default wood decay classes used in the NE-FFE variant. Classes are from the Wood Handbook (1999). (1 = exceptionally high; 2 = resistant or very resistant; 3 = moderately resistant, and 4 = slightly or nonresistant)

Species	Decay Rate Class
balsam fir	4
tamarack	3
white spruce	4
red spruce	4
Norway spruce	4
black spruce	4
other spruce species	4
red pine	4
eastern white pine	4
loblolly pine	4
Virginia pine	4
northern white-cedar	2
Atlantic white-cedar	2
eastern redcedar	2
other cedar species	2
eastern hemlock	4
other hemlock species	4
other pine species	4
jack pine	4
shortleaf pine	4
Table Mountain pine	4
pitch pine	4
white oak	2
bur oak	2
chinkapin oak	2
post oak	2
other oak species	2
scarlet oak	2
shingle oak	2
water oak	2
pin oak	2
chestnut oak	2
swamp white oak	2
swamp chestnut oak	2
northern red oak	2
southern red oak	2
black oak	2
cherrybark oak	2
other hardwoods	4
buckeye species	4
yellow buckeye	4
water birch	4
hackberry	4
common persimmon	4

Species	Decay Rate Class
pond pine	4
Scotch pine	4
other softwoods	4
red maple	4
sugar maple	4
black maple	4
silver maple	4
yellow birch	4
sweet birch	4
river birch	4
paper birch	4
gray birch	4
hickory species	4
pignut hickory	4
shellbark hickory	4
shagbark hickory	4
mockernut hickory	4
American beech	4
ash species	4
white ash	4
black ash	4
green ash	4
pumpkin ash	4
yellow-poplar	4
sweetgum	4
cucumbertree	4
quaking aspen	4
balsam poplar	4
eastern cottonwood	4
bigtooth aspen	4
swamp cottonwood	4
black cherry	2
American holly	4
butternut	4
black walnut	2
Osage-orange	1
magnolia species	4
sweetbay	4
apple species	2
water tupelo	4
blackgum	4
sourwood	4
Paulownia	4
sycamore	4
willow oak	2
black locust	1
black willow	4
sassafras	2
American basswood	4
white basswood	4
other elm species	4
American elm	4
slippery elm	4
non-commercial hardwoods	4
boxelder	4
striped maple	4
ailanthus	4
serviceberry	4
American hornbeam	4
flowering dogwood	4
hawthorn species	4
eastern hophornbeam	4
plum, cherry species	2
pin cherry	2

4.20.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups (Table 4.20.13) or they can specify moisture conditions using the MOISTURE keyword. These defaults were set based on the values used in LS-FFE.

Table 4.20.13. Moisture values (%), which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Very Dry**	**Dry**	**Moist**	**Wet**
0 – 0.25 in. (1-hr)	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

4.20.7 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 the FFE variant to determine a weighted set of fuel models, or
4. allowing the FFE variant 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 4.20.5). When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.20.5, 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.

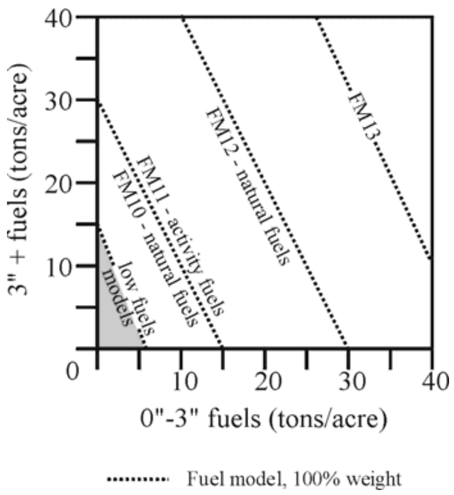


Figure 4.20.5. At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. At low fuel loads, fuel model 9 is selected.

4.20.8 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.

4.21 Central States (CS)

4.21.1 Tree Species

The Central States variant models the 96 tree species categories shown in Table 4.21.1. 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-commerical hardwoods" category is modeled as flowering dogwood.

Table 4.21.1. Tree species simulated by the Central States variant.

Common name	Scientific name
eastern redcedar	*Juniperus virginiana*
juniper species	*Juniperus sp.*
shortleaf pine	*Pinus echinata*
Virginia pine	*Pinus viginiana*
loblolly pine	*Pinus taeda*
other softwood species	
eastern white pine	*Pinus strobus*
black walnut	*Juglans nigra*
butternut	*Juglans cinerea*
tupelo species	*Nyssa sp.*
swamp tupelo	*Nyssa biflora*
water tupelo	*Nyssa aquatica*
blackgum, black tupelo	*Nyssa sylvatica*
select hickory	*Carya sp.*
shagbark hickory	*Carya ovata*
shellbark hickory	*Carya laciniosa*
mockernut hickory	*Carya alba*
pignut hickory	*Carya glabra*
hickory species	*Carya sp.*
water hickory	*Carya aquatica*
bitternut hickory	*Carya cordiformis*
pecan	*Carya illinoensis*
black hickory	*Carya texana*
American beech	*Fagus grandifolia*
black ash	*Fraxinus nigra*
pumpkin ash	*Fraxinus profunda*
blue ash	*Fraxinus quadrangulata*
eastern cottonwood	*Populus deltoides*
red maple	*Acer rubrum*
boxelder	*Acer negundo*
silver maple	*Acer saccharinum*
black cherry	*Prunus serotina*
American elm	*Ulmus americana*
sugarberry	*Celtis laevigata*
hackberry	*Celtis occidentalis*
southern red oak	*Quercus falcata*
black oak	*Quercus velutina*
scarlet oak	*Quercus coccinea*
blackjack oak	*Quercus marilandica*
chinkapin oak	*Quercus muehlenbergii*
swamp white oak	*Quercus bicolor*
bur oak	*Quercus macrocarpa*
swamp chestnut oak	*Quercus michauxii*
post oak	*Quercus stellata*
Delta post oak	*Quercus stellata var. mississippiensi*
chestnut oak	*Quercus prinus*
pin oak	*Quercus palustris*
cherrybark oak	*Quercus pagoda*
shingle oak	*Quercus imbricaria*
overcup oak	*Quercus lyrata*
water oak	*Quercus nigra*
Nuttall oak	*Quercus nutallii*
willow oak	*Quercus phellos*
Shumard oak	*Quercus shumardii*
other upland hardwoods	
sassafras	*Sassafras albidum*
Ohio buckeye	*Aesculus glabra*
catalpa	*Catalpa sp.*
common persimmon	*Diospyros virginiana*
honeylocust	*Gleditsia triacanthos*
balsam poplar	*Populus balsamifera*
bigtooth aspen	*Populus grandidentata*
quaking aspen	*Populus tremuloides*
black locust	*Robinia pseudoacacia*
other lowland species	
sycamore	*Platanus occidentalis*
baldcypress	*Taxodium distichum*
river birch	*Betula nigra*
sweetgum	*Liquidamber styraciflua*
willow species	*Salix sp.*

Common name	Scientific name	Common name	Scientific name
winged elm	*Ulmus alata*	black willow	*Salix nigra*
elm species	*Ulmus sp.*	non-commercial hardwoods	
Siberian elm	*Ulmus pumilia*	American hornbeam	*Carpinus caroliniana*
slippery (red) elm	*Ulmus rubra*	eastern redbud	*Cercis canadensis*
rock elm	*Ulmus thomasii*	flowering dogwood	*Cornus florida*
yellow-poplar	*Liriodendron tulipifera*	hawthorn species	*Crataegus sp.*
American basswood	*Tilia americana*	Kentucky coffeetree	*Gymnocladus dioicus*
sugar maple	*Acer saccharum*	osage-orange	*Malcura pomifera*
ash species	*Fraxinus sp.*	cucumbertree	*Magnolia acuminata*
white ash	*Fraxinus americana*	sweetbay	*Magnolia virginiana*
green ash	*Fraxinus pennsylvanica*	mulberry species	*Morus sp.*
white oak	*Quercus alba*	eastern hophornbeam	*Ostrya virginiana*
northern red oak	*Quercus rubra*	sourwood	*Oxydendrum arboreum*

4.21.2 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 3 of the FFE Model Description.

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 4.21.2. 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 Tables 4.21.3 and 4.21.4.

Snag bole volume is determined using the base FVS model equations. The coefficients shown in Table 4.21.5 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 described in the FFE Model Description.

Table 4.21.2. Snag class for each species in CS-FFE.

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

Species	Snag class
eastern white pine	1
black walnut	2
butternut	2
tupelo species	3
swamp tupelo	3
water tupelo	3
blackgum, black tupelo	3
select hickory	3
shagbark hickory	3
shellbark hickory	3
mockernut hickory	3
pignut hickory	3
hickory species	3
water hickory	3
bitternut hickory	3
pecan	3
black hickory	3
American beech	2
black ash	2
pumpkin ash	2
blue ash	2
eastern cottonwood	1
red maple	2
boxelder	2
silver maple	2
black cherry	2
American elm	1
sugarberry	2
hackberry	2
winged elm	1
elm species	1
Siberian elm	1
slippery (red) elm	1
rock elm	1
yellow-poplar	2
American basswood	1
sugar maple	2
ash species	2
white ash	2
green ash	2
white oak	3
northern red oak	2

Species	Snag class
bur oak	3
swamp chestnut oak	2
post oak	3
Delta post oak	3
chestnut oak	2
pin oak	2
cherrybark oak	2
shingle oak	2
overcup oak	2
water oak	3
Nuttall oak	2
willow oak	2
Shumard oak	2
other upland hardwoods	3
sassafras	2
Ohio buckeye	2
catalpa	2
common persimmon	3
honeylocust	3
balsam poplar	1
bigtooth aspen	1
quaking aspen	1
black locust	3
other lowland species	2
sycamore	2
baldcypress	3
river birch	1
sweetgum	2
willow species	1
black willow	1
non-commercial hardwoods	2
American hornbeam	2
eastern redbud	2
flowering dogwood	2
hawthorn species	2
Kentucky coffeetree	2
osage-orange	2
cucumbertree	2
sweetbay	2
mulberry species	2
eastern hophornbeam	2
sourwood	2

Table 4.21.3. 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 4.21.4.

Snag Class	95% Fallen (yr)	All Down (yr)	50% Height (yr)	Hard-to-Soft (yr)	Notes
1	3	6 (pines are 50)	--	2	Snag height loss is not modeled in CS-FFE
2	7	15	--	6	
3	11	25 (RC is 100)	--	10	

Table 4.21.4. Default snag fall, snag height loss and soft-snag multipliers for the CS-FFE. These parameters result in the values shown in Table 4.21.3. (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.

Figures 4.21.1, 4.21.2, and 4.21.3 show how these values translate for 10 and 20 inch snags of varying species.

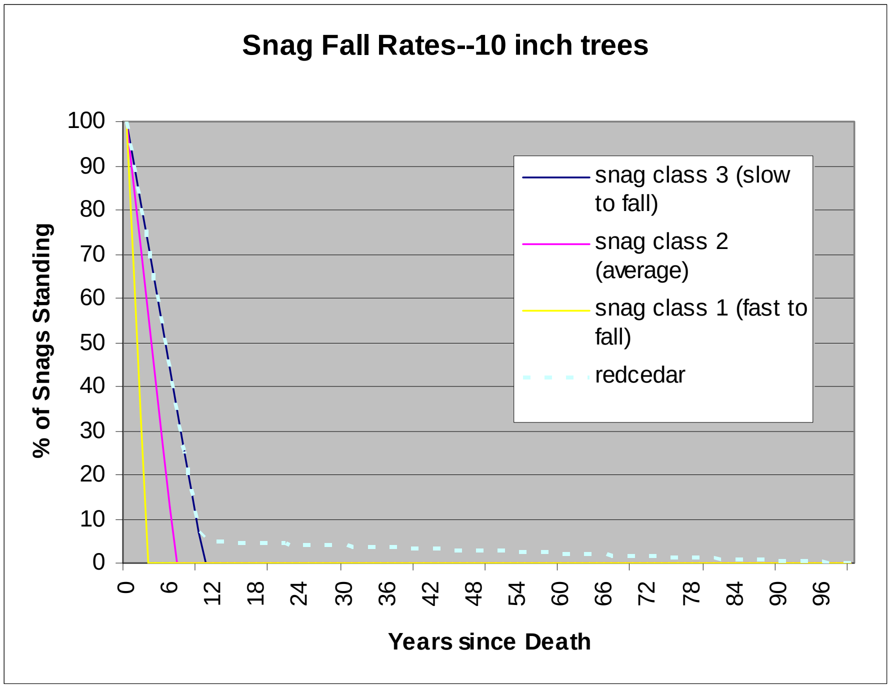


Figure 4.21.1. Snag fall rates for 10 inch trees.

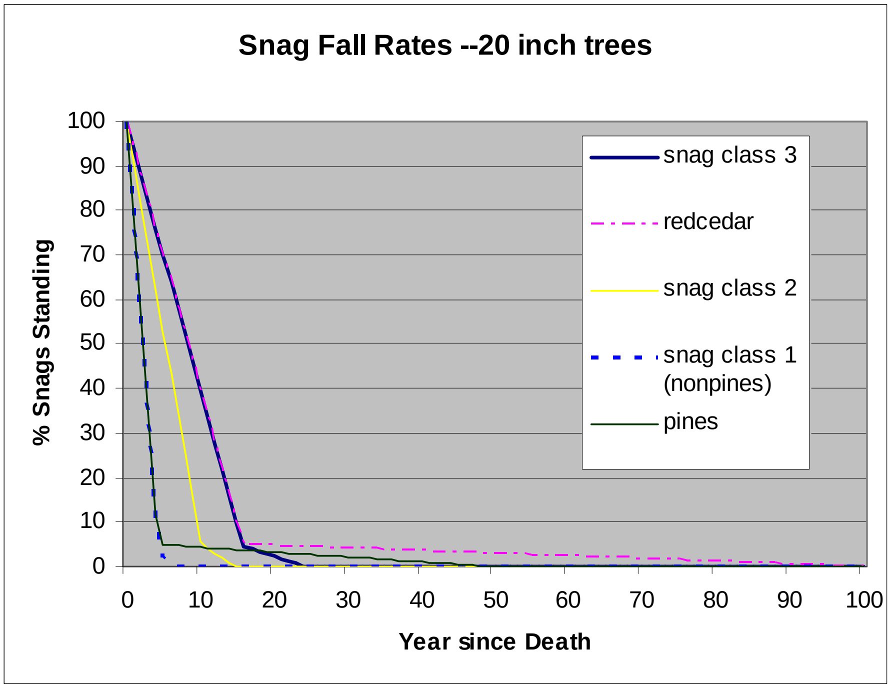


Figure 4.21.2. Snag fall rates for 20 inch trees.

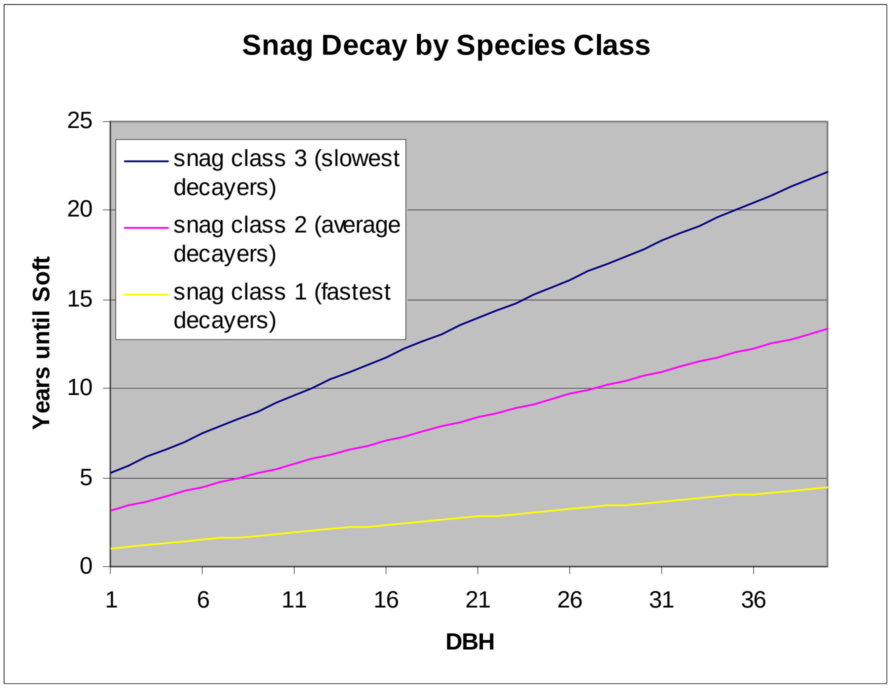


Figure 4.21.3. The number of years until soft for various diameter snags.

4.21.3 Fuels

Fuels are divided into to four categories: live tree bole, live tree crown, live herb and shrub, and dead surface fuels. Live herb and shrub fuel load and the initial dead surface fuel load are assigned based on the Forest Type code, as reported in the Summary Statistics Table.

One difference between the implementation of FFE in the Central States variant, relative to its implementation in all of the western variants, is the distinction between crown material and stemwood. In the western variants, stemwood biomass is calculated by converting total cubic foot volume to biomass for each tree. Crown biomass is calculated through equations that predict the biomass of branchwood 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 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 transferred to the FFE after being computed 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 (1995), or Jenkins et. al (2004).

Table 4.21.5. Woody density (ovendry lbs/green ft^3) used in the CS-FFE variant.

Species	lbs/cuft	Species used	Species	lbs/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 hardwoods	39.9	flowering dogwood
Siberian elm	28.7	American elm	American hornbeam	36.2	
slippery (red) elm	29.9		eastern redbud	36.2	
rock elm	35.6		flowering dogwood	39.9	
yellow-poplar	24.9		hawthorn species	38.7	
American basswood	20.0		Kentucky coffeetree	33.1	
sugar maple	34.9		osage-orange	47.4	
ash species	33.1	green ash	cucumbertree	27.4	
white ash	34.3		sweetbay	26.2	
green ash	33.1		mulberry species	36.8	
white oak	37.4		eastern hophornbeam	39.3	

Species	lbs/cuft	Species used	Species	lbs/cuft	Species used
northern red oak	34.9		sourwood	31.2	

Tree Crown

For merchantable trees, estimates of crown material, including branchwood and bolewood above a 4 inch top (DOB), are from Jenkins et al. (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 (1987), 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 using equations in Jenkins et. al. (2003). Due to the nature of these equations, for trees less than 1 inch in diameter, the estimate for a 1-inch tree is scaled back based on diameter. 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 4.21.6. 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
select hickory	1	2
shagbark hickory	1	2
shellbark hickory	1	2
mockernut hickory	1	2
pignut hickory	1	2
hickory species	1	2
water hickory	1	2
bitternut hickory	1	2
pecan	1	2
black hickory	1	2
American beech	1	4
black ash	1	5
pumpkin ash	1	5
blue ash	1	5
eastern cottonwood	1	5
red maple	1	5
boxelder	1	5
silver maple	1	5
black cherry	1	4
American elm	1	5
sugarberry	1	4
hackberry	1	4
winged elm	1	5
elm species	1	5
Siberian elm	1	5
slippery (red) elm	1	5
rock elm	1	5
yellow-poplar	1	5
American basswood	1	5
sugar maple	1	5
ash species	1	5
white ash	1	5
green ash	1	5
white oak	1	3
northern red oak	1	4
cherrybark oak	1	4
shingle oak	1	4
overcup oak	1	3
water oak	1	3
Nuttall oak	1	4
willow oak	1	4
Shumard oak	1	4
other upland hardwoods	1	2
sassafras	1	4
Ohio buckeye	1	5
catalpa	1	4
common persimmon	1	4
honeylocust	1	2
balsam poplar	1	5
bigtooth aspen	1	5
quaking aspen	1	5
black locust	1	2
other lowland species	1	5
sycamore	1	5
baldcypress	1	1
river birch	1	5
sweetgum	1	5
willow species	1	6
black willow	1	6
non-commercial hardwoods	1	5
American hornbeam	1	4
eastern redbud	1	5
flowering dogwood	1	5
hawthorn species	1	5
Kentucky coffeetree	1	5
osage-orange	1	4
cucumbertree	1	4
sweetbay	1	4
mulberry species	1	5
eastern hophornbeam	1	4
sourwood	1	5

Table 4.21.7. Years until all snag crown material of certain sizes has fallen by crown fall class

Crown fall class	Snag Crown Material Time to 100% Fallen (years)					
	Foliage	**<0.25”**	**0.25–1”**	**1-3”**	**3-6”**	**6-12”**
1	1 (RC is 3)	5	5	10	25	25
2	1	3	3	6	12	12
3	1	2	2	5	10	10
4	1	1	1	4	8	8
5	1	1	1	3	6	6
6	1	1	1	2	4	4

Live Herbs and Shrubs

Live herb and shrub fuels are modeled very simply by the FFE. 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 4.21.8. 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 CWD pools are based on forest type. Default woody fuel loadings were set based on FIA data collected in the Central States region (Table 4.21.9). Initial fuel loads can be modified using the FUELINIT keyword.

Table 4.21.9. Forest type is used to assign default coarse woody debris (tons/acre) by size class.

Forest Type Group	FIA Forest Type codes	Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
Pines	100s	0.18	0.93	1.77	0.27	0.75	8.38	4.10	3.82
Redcedar	181, 402	0.19	0.86	1.58	0.11	0.31	0.67	4.89	4.40
Pine-hardwood	400s	0.18	0.75	2.42	0.59	0.67	1.34	5.37	3.07
Oak-hickory	500s	0.15	0.74	1.70	0.38	0.97	2.68	5.17	4.52
Elm-ash-cottonwood	700s	0.20	0.92	2.19	0.41	1.46	3.80	2.49	2.80
Maple-beech-birch	800s	0.19	0.88	1.95	0.56	1.62	1.82	3.88	3.41
Nonstocked	999	0.02	0.21	0.40	0.02	0.33	0.42	3.12	2.05

4.21.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.21.10 are used to calculate single bark thickness, which in turn, for most species, is used to calculate fire-related mortality (RMRS-GTR-116, 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 and others 2001). 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 4.21.10. Species specific constants for determining single bark thickness.

Species	Multiplier (V_{sp})	Species used
eastern redcedar	0.038	
juniper species	0.033	
shortleaf pine	***	
Virginia pine	0.033	
loblolly pine	0.052	
other softwood species	0.045	
eastern white pine	0.045	
black walnut	0.041	
butternut	0.041	
tupelo species	0.025	
swamp tupelo	0.037	
water tupelo	0.03	
blackgum, black tupelo	0.039	
select hickory	0.044	hickory spp
shagbark hickory	0.04	
shellbark hickory	0.043	
mockernut hickory	0.043	
pignut hickory	0.037	
hickory species	0.044	
water hickory	0.044	hickory spp
bitternut hickory	0.037	
pecan	0.036	
black hickory	0.04	
American beech	0.025	
black ash	0.035	
pumpkin ash	0.037	
blue ash	0.03	
eastern cottonwood	0.04	
red maple	0.028	
boxelder	0.034	
silver maple	0.031	
black cherry	0.03	
American elm	0.031	
sugarberry	0.036	
hackberry	0.036	sugarberry
winged elm	0.031	
elm species	0.039	
Siberian elm	0.038	
slippery (red) elm	0.032	
rock elm	0.033	
yellow-poplar	0.041	
American basswood	0.038	
sugar maple	0.033	
ash species	0.042	
white ash	0.042	
green ash	0.039	
white oak	0.04	
northern red oak	0.042	
southern red oak	0.044	
black oak	0.045	
scarlet oak	0.04	
blackjack oak	0.037	
chinkapin oak	0.042	
swamp white oak	0.045	
bur oak	0.042	
swamp chestnut oak	0.046	
post oak	0.044	
Delta post oak	0.044	post oak
chestnut oak	0.049	
pin oak	0.041	
cherrybark oak	0.044	s. red oak
shingle oak	0.041	
overcup oak	0.039	
water oak	0.036	
Nuttall oak	0.03	
willow oak	0.041	
Shumard oak	0.037	
other upland hardwoods	0.038	honeylocust
sassafras	0.035	
Ohio buckeye	0.036	
catalpa	0.037	
common persimmon	0.041	
honeylocust	0.038	
balsam poplar	0.04	
bigtooth aspen	0.039	
quaking aspen	0.044	
black locust	0.049	
other lowland species	0.033	sycamore
sycamore	0.033	
baldcypress	0.025	
river birch	0.029	
sweetgum	0.036	
willow species	0.041	
black willow	0.04	
non-commercial hardwoods	0.041	dogwood
American hornbeam	0.03	
eastern redbud	0.035	
flowering dogwood	0.041	
hawthorn species	0.038	
Kentucky coffeetree	0.031	
osage-orange	0.037	
cucumbertree	0.036	
sweetbay	0.04	
mulberry species	0.033	
eastern hophornbeam	0.037	
sourwood	0.036	

4.21.5 Decay Rate

Decay of down material is simulated by applying loss rates to pieces by size class (Table 4.21.11), as described in section 2.4.5 of the FFE documentation. 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 4.21.11. Default annual loss rates are applied based on size class. A portion of the loss is added to the duff pool each year. Loss rates are for hard material. If present, soft material in all size classes except litter and duff decays 10% faster.

Size Class (inches)	Annual Loss Rate	Proportion of Loss Becoming Duff
< 0.25	0.11	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.07	
6 – 12		
> 12		
Litter	0.65	
Duff	0.002	0.0

By default, the FFE decays all wood species at the rates shown in Table 4.21.10. The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.21.12 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword. The decay rate classes were generally determined from the Wood Handbook (1999) and from input given at the SN-FFE development workshop.

Table 4.21.12. 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
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

Species	Decay Rate Class
select hickory	4
shagbark hickory	4
shellbark hickory	4
mockernut hickory	4
pignut hickory	4
hickory species	4
water hickory	4
bitternut hickory	4
pecan	4
black hickory	4
American beech	4
black ash	4
pumpkin ash	4
blue ash	4
eastern cottonwood	4
red maple	4
boxelder	4
silver maple	4
black cherry	2
American elm	4
sugarberry	4
hackberry	4
winged elm	4
elm species	4
Siberian elm	4
slippery (red) elm	4
rock elm	4
yellow-poplar	4
American basswood	4
sugar maple	4
ash species	4
white ash	4
green ash	4
white oak	2
northern red oak	3

Species	Decay Rate Class
shingle oak	2
overcup oak	3
water oak	2
Nuttall oak	3
willow oak	2
Shumard oak	3
other upland hardwoods	2
sassafras	2
Ohio buckeye	4
catalpa	2
common persimmon	2
honeylocust	2
balsam poplar	4
bigtooth aspen	4
quaking aspen	4
black locust	1
other lowland species	4
sycamore	4
baldcypress	3
river birch	4
sweetgum	4
willow species	4
black willow	4
non-commercial hardwoods	3
American hornbeam	3
eastern redbud	3
flowering dogwood	3
hawthorn species	4
Kentucky coffeetree	4
osage-orange	1
cucumbertree	4
sweetbay	4
mulberry species	1
eastern hophornbeam	3
sourwood	4

4.21.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups (Table 4.21.13) 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 4.21.13. Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

	Moisture Group			
Size Class	**Extremely Dry**	**Very Dry**	**Dry**	**Wet**
0 – 0.25 in. (1-hr)	5	6	7	16
0.25 – 1.0 in. (10-hr)	7	8	9	16
1.0 – 3.0 in. (100-hr)	12	13	14	18
> 3.0 in. (1000+ -hr)	17	18	20	50
Duff	40	75	100	175
Live	55	80	100	150

4.21.7 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 (Model Description, Section 4.8) 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 the FFE variant to determine a weighted set of fuel models, or
4. allowing the FFE variant 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 4.21.4, one or more low fuel fire models become candidate models. In other regions of the graph, other fire models may also be candidates. Tables 4.21.14 and 4.21.15 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 4.21.4 or Table 4.21.15. The FLAMEADJ keyword allows the user to scale the calculated flame length or override the calculated flame length with a value they choose.

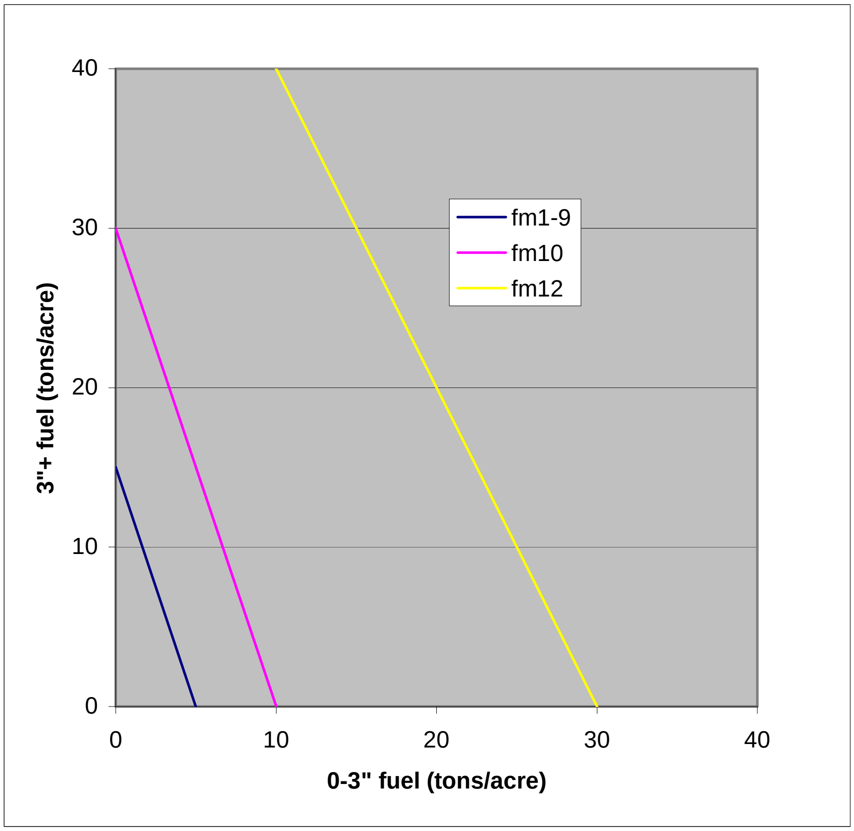


Figure 4.21.4. If large and small fuels map to fuel models 1 - 9, candidate fuel models are determined using the logic shown in Tables 4.21.14 and 4.21.15. Otherwise, fire behavior is based on the distance to the closest fuel models, identified by the dashed lines.

Table 4.21.14. 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 401, 403, 404, 405, 406, 407, or 409
Pine-Hardwood	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, or 996, 70% or less BA in pine, and not Pine-Bluestem
Pine	Forest type code of 103, 104, 141, 142, 161, 162, 163, 164, 165, 166, 167, 168, 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 4.21.15. Relationship between forest type and fuel model selected.

Forest type		**Fuel model**
Hardwood, Hardwood-Pine, and Pine-Hardwood	0-3” fuel > 5 tons	5
	0-3” fuel <=5 tons and 3”+ moisture >20%	8
	0-3” fuel <= 5 tons and 3”+ moisture <= 20%	9
Pine and Bottomland Hardwoods	3”+ moisture >20%	8
	3”+ moisture <= 20%	9
Pine-Bluestem		2
Oak Savannah		2
Eastern Redcedar	Avg. ht. of redcedar > 6 ft.	4
	Avg. ht. of redcedar <= 6 ft.	6
Non-stocked		6

4.21.8 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.

4.22 Southeast Alaska (AK)

4.22.1 Tree Species

The Southeast Alaska variant models the 11 tree species shown in Table 4.22.1. Two additional categories, ‘other hardwoods’and ‘other softwoods’, are modeled using black cottonwood and Pacific silver fir, respectively.

Table 4.22.1. Tree species simulated by the Southeast Alaska variant.

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

4.22.2 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, regional wildlife ecologist. Contact Stephanie Rebain (sarebain@fs.fed.us) for documentation. 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 4.22.2 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 described in the FFE Model Description.

4.22.3 Fuels

A complete description of the Fuel Submodel is provided in Section 4 of the FFE Model Description.

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 suface 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 transferred to the FFE after being computed 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 4.22.2. Woody density (ovendry lbs/green ft^3) 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 of the FFE Model Description, equations in Brown and Johnston (1976) provide estimates of live and dead crown material for many species in the AK-FFE (Table 4.22.3).

Table 4.22.3. 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)

Species	Species Mapping and Equation Source
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	Smith (1985); Jenkins et. al. (2003); Loomis and Roussopoulos (1978)
other hardwoods	Smith (1985); 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 4.22.4. 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 4.22.4. Life span of live and dead foliage (yr) and dead branches for species modeled in the AK-FFE variant.

	Live	Dead				
Species	Foliage	Foliage	<0.25”	0.25–1”	1 – 3”	3”+
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 by the FFE. Shrubs and herbs are assigned a biomass value based on total tree canopy cover and dominant overstory species (Table 4.22.5). When total tree canopy cover is <10 percent, herb and shrub biomass is assigned an “initiating” value (the ‘I’ rows from Table 4.22.5). 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 4.22.5. 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	
	I	0.18	2.00	
other hardwoods	E	0.25	0.25	use black cottonwood
	I	0.18	2.00	
other softwoods	E	0.15	0.10	use Pacific silver fir
	I	0.30	2.00	

Dead Fuels

Initial default CWD pools are based on overstory species. Default fuel loadings are based on those used in the PN-FFE (see Table 4.22.6). (They were provided by Jim Brown, USFS, Missoula, MT (pers. comm., 1995) and were reviewed and in some cases modified at the PN model workshop.) If tree canopy cover is <10 percent, the CWD 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. Initial fuel loads can be modified using the FUELINIT keyword.

Table 4.22.6. Canopy cover and cover type are used to assign default coarse woody debris (tons/acre) by size class for established (E) and initiating (I) stands.

Species		Size Class (in)							
		< 0.25	0.25 – 1	1 – 3	3 – 6	6 – 12	> 12	Litter	Duff
white 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
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
Pacific silver fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
mountain hemlock	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
western 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
Alaska-cedar	E	2.2	2.2	5.2	15.0	20.0	15.0	1.0	35.0
	I	1.6	1.6	3.6	6.0	8.0	6.0	0.5	12.0
lodgepole pine	E	0.9	0.9	1.2	7.0	8.0	0.2	0.6	30.0
	I	0.6	0.7	0.8	2.8	3.2	0.0	0.3	12.0
sitka spruce	E	0.7	0.7	3.0	7.0	7.0	10.0	1.0	35.0
	I	0.5	0.5	2.0	2.8	2.8	6.0	0.5	12.0
subalpine fir	E	1.1	1.1	2.2	10.0	10.0	0.0	0.6	30.0
	I	0.7	0.7	1.6	4.0	4.0	0.0	0.3	12.0
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
black cottonwood	E	0.2	0.6	2.4	3.6	5.6	0.0	1.4	16.8
	I	0.1	0.4	5.0	2.2	2.3	0.0	0.8	5.6
other 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
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

4.22.4 Bark Thickness

Bark thickness contributes to predicted tree mortality from simulated fires The bark thickness multipliers in Table 4.22.7 are used to calculate single bark thickness (RMRS-GTR-116, 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 and others 2001).

Table 4.22.7. 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

4.22.5 Decay Rate

Decay of down material is simulated by applying loss rates to pieces by size class, as described in section 2.4.5 of the FFE documentation. Default decay rates (Table 4.22.8) are based on values provided by Kim Mellen, 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 4.22.9).

Table 4.22.8. 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 Lose Rate				Proportion of Loss Becoming Duff
	decay class 1	decay class 2	decay class 3	decay class 4	
< 0.25	0.052	0.061	0.073	0.098	0.02
0.25 – 1					
1 – 3					
3 – 6	0.012	0.025	0.041	0.077	
6 – 12					
> 12	0.009	0.018	0.031	0.058	
Litter	0.35	0.40	0.45	0.50	
Duff	0.002	0.002	0.003	0.003	0.0

The decay rates of species groups may be modified by users, who can provide rates to the four decay classes shown in Table 4.22.9 using the FUELDCAY keyword. Users can also reassign species to different classes using the FUELPOOL keyword.

Table 4.22.9. Default wood decay classes used in the AK-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
white spruce	4
western redcedar	2
Pacific silver fir	4
mountain hemlock	4
western hemlock	4
Alaska-cedar	2
lodgepole pine	4
sitka spruce	4
subalpine fir	4
red alder	4
black cottonwood	4
other hardwoods	4
other softwoods	4

4.22.6 Moisture Content

Moisture content of the live and dead fuels is used to calculate fire intensity and fuel consumption (Model Description, Section 5.2.1). Users can choose from four predefined moisture groups (Table 4.22.10) or they can specify moisture conditions for each class using the MOISTURE keyword.

Table 4.22.10. Moisture values, which alter fire intensity and consumption, have been predefined for four groups.

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

4.22.7 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 the FFE variant to determine a weighted set of fuel models, or
4. allowing the FFE variant 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 4.22.1). When the combination of large and small fuel lies in the lower left corner of the graph shown in Figure 4.22.1, 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.

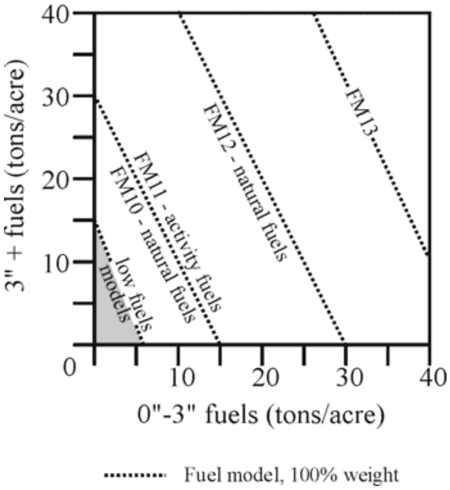


Figure 4.22.1. At high fuel loads, multiple fuel models may be candidates. In this case, fire behavior is based on the closest fuel models, identified by the dashed lines. At low fuel loads, fuel model 8 is selected.

Appendix A: P-Torch

P-Torch: A New Torching Index

Nicholas L. Crookston, RMRS-Moscow
Elizabeth Reinhardt, RMRS-Missoula

Contact: ncrookston@fs.fed.us, (208) 883-2317

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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.

1.0 Introduction

Will a surface fire stay on the surface? If it ignites the crowns of one or a group of trees, it is called a torching, passive, or candling fire. Torching fires have more extreme fire intensity and more radical effects than surface fires—assessing the likelihood of torching is an important part of assessing potential fire behavior (Scott and Reinhardt 2001). Torching fires are distinguished from more serious active crown fires that burn continuously through the forest canopy. They are ignited by surface fires and can be responsible for creating an active crown fire.

Scott and Reinhardt (2001) proposed a way to assess the hazard of both these kinds of fires by introducing Torching Index (TI) and Crowning Index (CI). Both these indices are outputs of the Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS, Reinhardt and Crookston 2003). Scott and Reinhardt (2001, p17) say that TI is the windspeed at which crown fires are expected to initiate, computed as “a function of surface fuel characteristics (fuel model), surface fuel moisture contents, foliar moisture content, canopy base height, slope steepness, and wind reduction by the canopy.” High values of TI imply a low risk of torching.

TI is quite sensitive to canopy base height (CBH). When it is computed in the context of FFE-FVS, CBH is a stand average value. CBH is difficult to assess at a stand level, however. As computed in FFE-FVS, canopy base height is the lowest height at which a threshold amount of canopy biomass occurs. The threshold value is arbitrarily set at 30 lbs/acre/ft. When stand development is simulated over time, predicted CBH often fluctuates dramatically, causing unrealistic erratic behavior in predicted TI. To understand what can happen, imagine a well-stocked, single-storied stand with medium sized trees and a CBH of about 20 feet. In this case, TI is often predicted to be a relatively large number indicating a low hazard of torching. Now, further imagine that there is one full-crown 20-foot tall tree below the larger trees. If this tree causes the 30 lbs/acre/ft threshold to be exceeded, the CBH drops to ground level. At that point, any surface fire will cause torching and the predicted TI drops radically. Sometimes, the number of small trees, and therefore the amount of biomass near ground level, will hover near the threshold. Then, if a single tree dies, TI will radically increase, only to be followed by another tree growing large enough to cause TI to radically decrease. Several threshold values have been tried, and a number of modifications to the algorithm for computing CBH have been made. These adjustments have only transferred the problem from one stand to another. Experience has shown that many stands have conditions that exhibit radically changing CBH and uninformative radical changes in predicted TI.

2.0 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.

2.1 Details

A small place where torching can happen is defined as a randomly located 0.025-acre (about 33 feet by 33 feet, or 10 m by 10 m) virtual plot that satisfies following conditions:

- A surface fire must be intense enough to ignite tree crowns of smaller trees that in turn ignite the crowns of larger trees, or where large trees have long crowns that are directly ignited by the surface fire.
- The height of the largest tree ignited must be greater than 50 percent of the stand top height (top height is the average height of the largest 40 trees per acre), or 50 feet, which ever is smaller. Furthermore, the size of the largest tree ignited must be greater than five feet.

Thirty virtual plots are generated and populated with sample trees using the following logic. Let 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 (Fig. 1). This relationship is based on the discussion in Scott and Reinhardt (2001, p13).

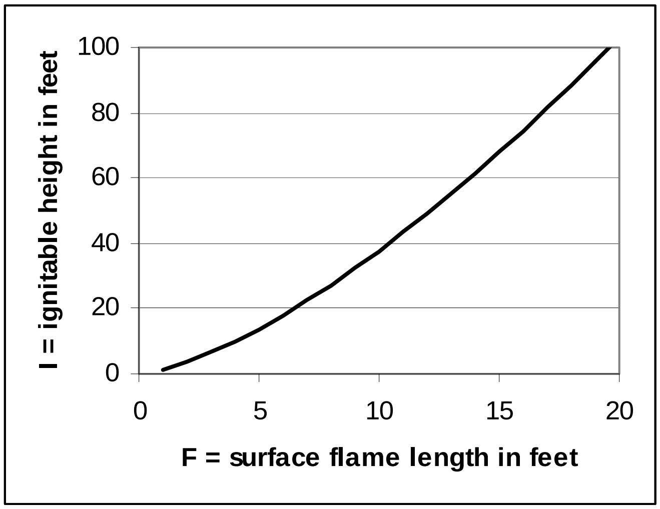

Figure 1—The relationship between surface flame length (*F*) and the height off the ground that flame can ignite (*I*).

The second assumption is that the distribution of *I* within a stand is lognormal with a constant standard deviation of 0.25. Figure 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.

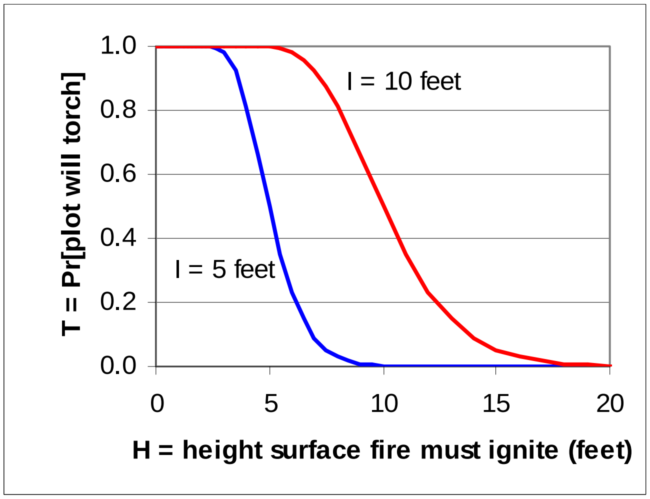

Figure 2—The probability that plot *j* will torch (T_j) is illustrated for two values of average ignition height (*I*). H_j is the height the surface fire must be able to ignite (feet) and is a function of the vertical crown structure on virtual plot *j*.

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 (Pr[*Torch*]) is computed as the sum of the products of a plot torching and the virtual plot sampling probability (1/*N* where *N* is the number of virtual plots), as follows: $\Pr[Torch] = \sum_{i=1}^{N} T_i \times \frac{1}{N}$.

2.3 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.

3.0 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.

3.1 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 3 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.

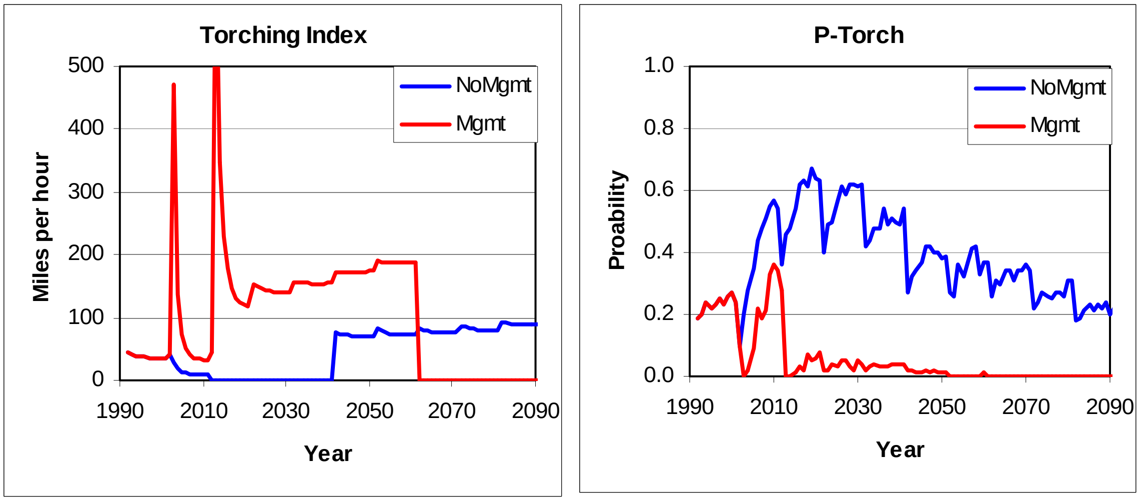

Figure 3—TI and P-Torch for stand 3024006. Both indices indicate that prescribed fire reduced the hazard of torching, but TI showed that the hazard greatly increased in 2062 when a few understory trees caused the CBH to drop to zero. P-Torch more realistically indicates that those trees do not adversely increase the torching hazard.

Figures 4 and 5 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.

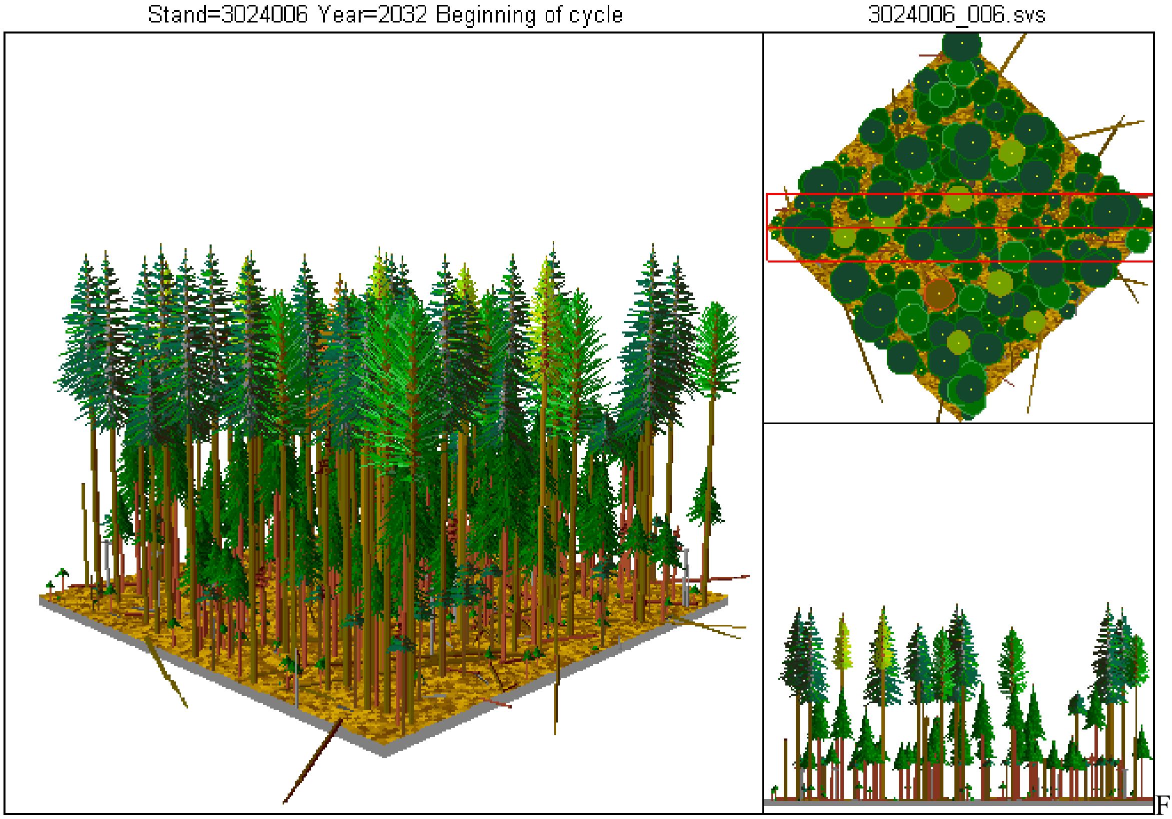

Figure 4—Example stand 30240006 shown at year 2032 without management using SVS (McGaughey 1997; http://www.fs.fed.us/pns/svs).

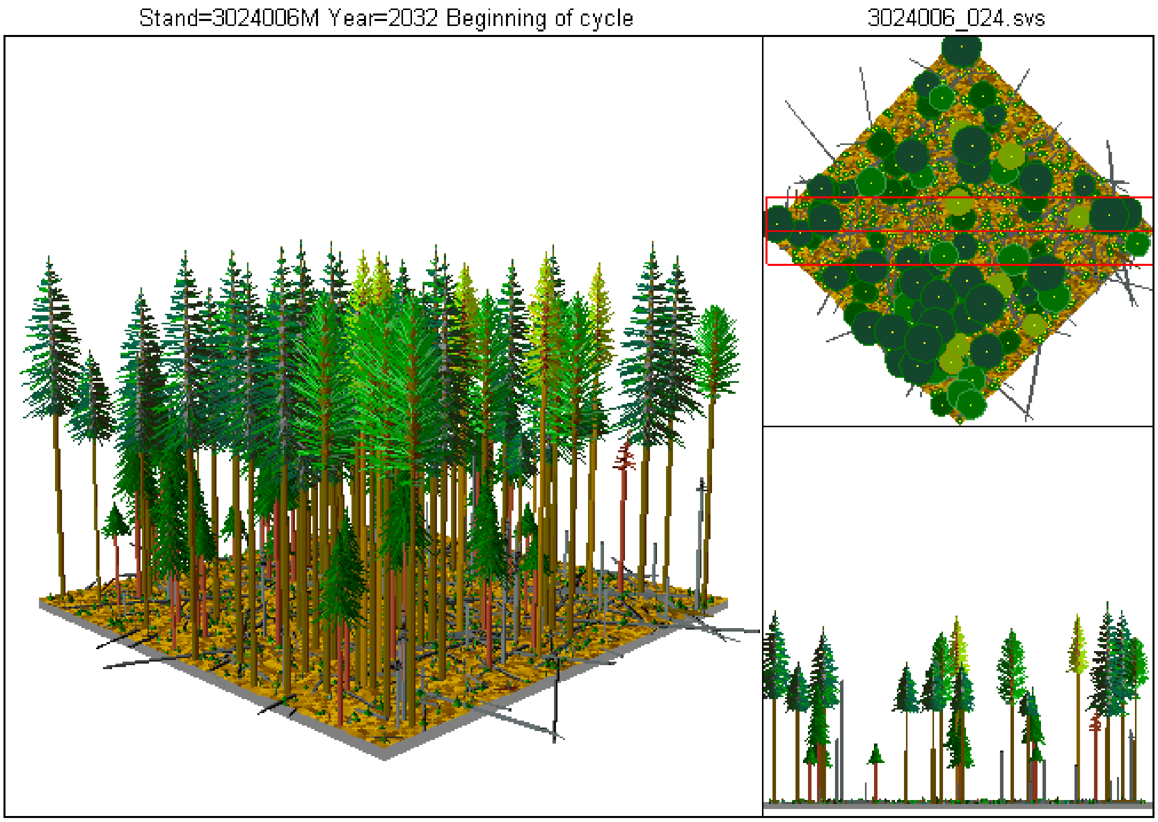

Figure 5—Example stand 30240006 shown at year 2032 with prescribed fires in 2002 and 2012.

3.2 Stand 300290023601

The second example is a young xeric Douglas-fir stand with lodgepole pine, growing on the Flathead National Forest in western Montana (Fig. 6). Stands like these have much shorter natural fire return intervals than stands like those used in the first example. Catastrophic losses can be avoided if the fires remain on the surface and are not intense. However, almost any fires burning in the early stages of this stands life would likely leave the stand poorly stocked.

Two scenarios demonstrate that unlike the first example, TI and P-Torch convey about the same information albeit in different ways. The reason is that the major driver of torching hazard in this example is surface fuel load rather than CBH.

Figure 7 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 (Fig. 8).

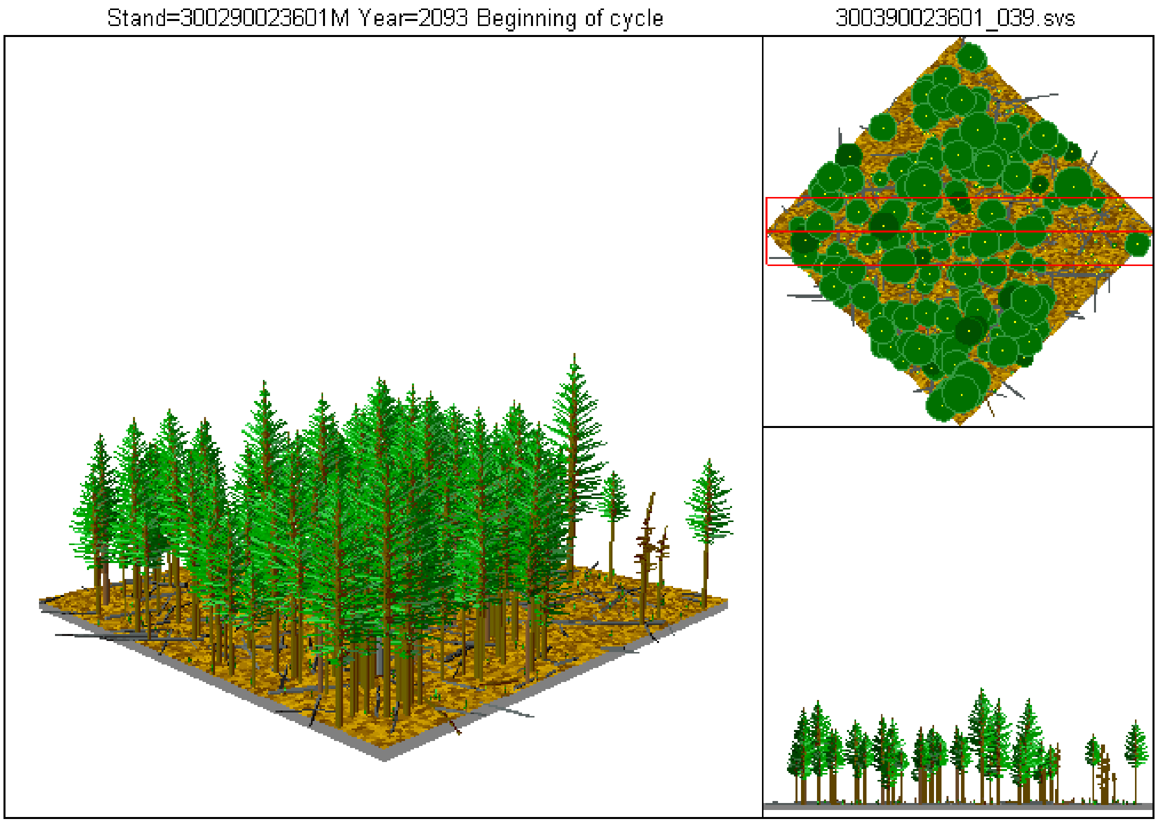

Figure 6—Stand 300290023601 at year 2093, after repeated prescribed surface fires. The appearance of this stand is about the same as it would be without the repeated prescribed fires and it is also about the same as it looks after an additional fire burns in year 2093 in severe fire conditions.

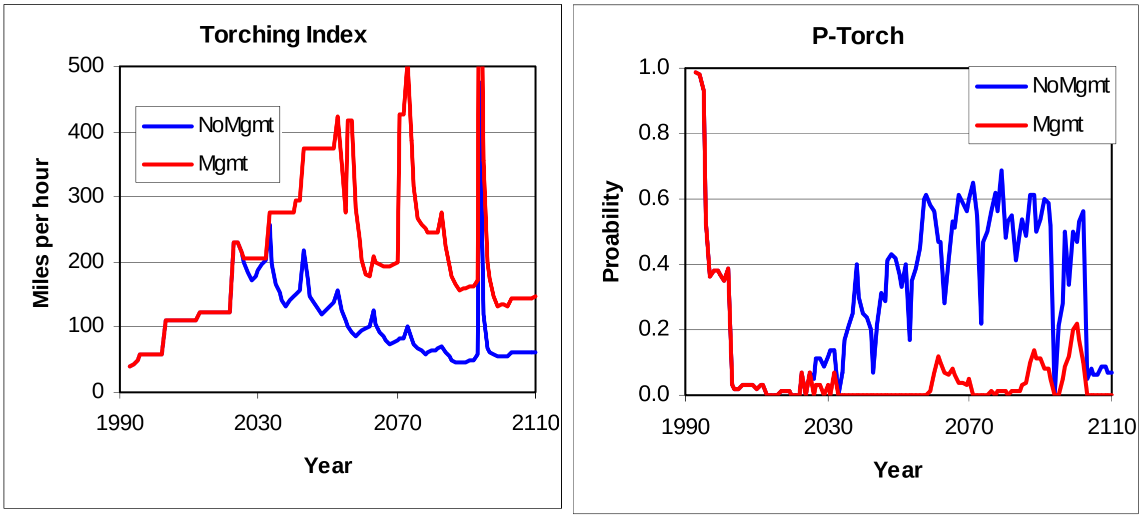

Figure 7—TI and P-Torch for stand 300290023601. Both indicates indicate that the hazard of torching is high in the beginning and that a series of prescribed fire reduced the hazard. The saw-tooth appearance of the lines is partly due to spikes in fine fuels loads caused by simulated fires but mostly caused by modeling artifacts related to the way fuels are modeled in the FFE.

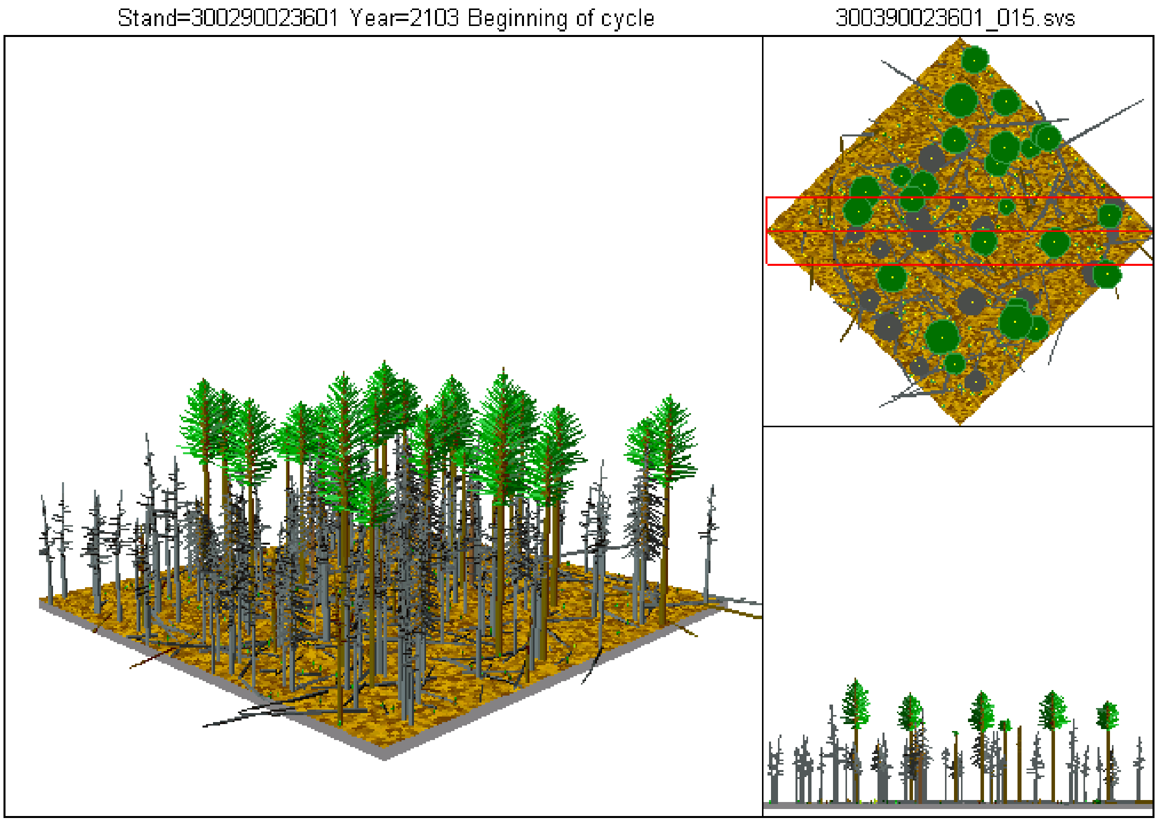

Figure 8—Stand 300290023601 in year 2103 given a fire burns with severe conditions in year 2093 and without any previous prescribed fire.

4.0 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 closure 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.

5.0 References

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Appendix B: Wood Density Values

Species	Ovendry lbs/ green cuft	Notes
Alaska yellow-cedar	26.2	
bigleaf maple	27.4	
bitter cherry	29.3	used black cherry
blue oak	37.4	used white oak
blue spruce	20.6	used Engelmann spruce
Brewer spruce	20.6	used Engelmann spruce
bristlecone pine	23.7	used lodgepole pine
California / coast live oak	49.9	used live oak
California black oak	34.9	
California buckeye	37.4	used white oak
California laurel	36.2	used tanoak
California nutmeg	34.9	used nutmeg hickory
California sycamore	28.7	used American sycamore
California white (valley) oak	37.4	used white oak
canyon live oak	49.9	used live oak
corkbark fir	19.3	used subalpine fir
cottonwood species	19.3	
Coulter pine	23.7	used lodgepole / ponderosa pine
Douglas-fir coast	28.1	used in pn and wc variants
Douglas-fir Interior north	28.1	ni, ie, em, kt, ci, and tt variants
Douglas-fir Interior south	26.8	cr and ut variants
Douglas-fir Interior west	28.7	ws, nc, ca, so, ec, and bm variants
Engelmann oak	37.4	used white oak
Engelmann spruce	20.6	
Gambel oak	39.6	from Chojnacky (1992)
giant chinkapin	36.2	used tanoak
giant sequoia	21.2	used redwood - young growth
grand fir	21.8	
gray pine	23.7	used lodgepole pine
hawthorn species	27.4	used bigleaf maple
incense-cedar	21.8	
interior live oak	49.9	used live oak
Jeffrey pine	21.2	
juniper species	34.9	from Chojnacky and Moisen (1993)
knobcone pine	23.7	used lodgepole / ponderosa pine
limber pine	22.5	used white pine
lodgepole pine	23.7	
monterey pine	23.7	used lodgepole / ponderosa pine
mountain hemlock	26.2	
mountain mahogany	21.8	used quaking aspen
mountain maple	30.6	used red maple
noble fir	23.1	
Oregon ash	31.2	

Oregon white oak	37.4	used white oak
Pacific dogwood	27.4	used bigleaf maple
Pacific madrone	36.2	used tanoak
Pacific silver fir	24.9	
Pacific yew	26.2	used baldcypress
paper birch	29.9	
pinyon pine	31.8	from Chojnacky and Moisen (1993)
ponderosa pine	23.7	
Port-Orford cedar	24.3	
quaking aspen	21.8	
red alder	23.1	
red fir	22.5	
redwood	21.2	used redwood - young growth
Sitka spruce	20.6	
southwestern white pine	22.5	used white pine
subalpine fir	19.3	
subalpine larch - IE	19.3	used subalpine fir
subalpine larch - PN, WC	29.9	used western larch
sugar pine	21.2	
tanoak	36.2	
walnut	31.8	
western hemlock	26.2	
western larch	29.9	
western redcedar	19.3	
western white pine	22.5	
white alder	23.1	used red alder
white fir	23.1	
white spruce	23.1	
whitebark pine	22.5	used white pine
willow species	22.5	

Appendix C: Adjusting the Fire Behavior Calculations

This appendix describes two new fire behavior modeling options in FFE-FVS. First, a method of using the modelled 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).

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 1 below. Larger dead and down fuel particles (1000-h timelag class) and duff are not considered in surface or crown fire modeling.

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.)

Table 1. Fuel pools used in creating a custom fire behavior fuel model or selecting a standard fire behavior fuel model.

The 13 parameters required for a fire behavior fuel model are listed in Table 2 below.

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.)

Table 2. Fuel model parameters, their standard English units, and how each is mapped to a fuel pool quantity, a default value, or a calculation.

Of the parameters listed in Table 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.

1.1 Fuelbed depth

Fuelbed depth is the fuel model parameter, but in reality the fire model is using that depth to compute bulk density and packing ratio; fuelbed depth itself is not a direct input to the Rothermel spread model. Spread rate and intensity is very sensitive to bulk density and packing ratio. In recognition of this, the procedure used in FFE-FVS to estimate fuelbed depth is really designed to estimate a reasonable bulk density—fuelbed depth is computed from that estimate.
Three intermediate quantities are needed in order to compute fuelbed depth for this custom fuel model: total fuel load (*TFL*), fine dead fuel load (*FDFL*) and fine fuel load (*FFL*). Total fuel load is the sum of all five fuel load parameters; fine dead fuel load is just the 1-h load; and fine fuel load is the sum of the 1-h load, herbaceous load, and live woody load parameters. All of these parameters are specified in Table 2. The fuelbed depth and bulk density are directly related:

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

where TFL is the total fuel load (t/ac) and BD is fuelbed bulk density (lb/ft^3). The factor 0.04591 is a unit conversion factor. Bulk density is the weighted-average of live and dead fuel bulk density values:

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

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

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

where $FDFL$ and FFL are as defined above (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}.

1.2 Dead fuel extinction moisture content

Dead fuel extinction moisture content (MX_{dead}) is calculated as a function of the fuelbed packing ratio, which itself is simply BD divided by particle density. For an assumed particle density value of 32 lb/ft^3, MX_{dead} is

$$MX_{dead} = 12 + 480 * \left(\frac{BD}{32} \right)$$

where MX_{dead} is in percent and BD is computed as described in the previous section (lb/ft^3).

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.

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.

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 ar 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 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 2.

HerbRatio is the ratio of the herbaceous load to the live woody load. Because it is possible for the herbaceous load to exceed the live woody load, HerbRatio is open-ended with a minimum possible value of 0.0. If the fuelbed has no live woody load, this ratio should be set to 10.
Once the above quantities have been computed, the following selection key identifies the fire carrying fuel type. (In the unlikely event that at fuelbed contains no fine fuel load—just 10- and 100-hr timelag class dead particles—then the fuel type is set to TL/SB.)

Fire-carrying Fuel Type Selection Guide

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

iii. IF **HerbRatio** <= 0.25 THEN the grass component is not enough to indicate a GS fuel model, and any SH or TU fuel model may be appropriate (FuelType=SH/TU)

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 the available fuel models are determined from the climate type. Each FFE-FVS variant was assigned to one of these climate types (Table 3).

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
Northern Idaho/Inland Empire (NI/IE)	Arid
East Cascades (EC)	Arid
KooKanTL (KT)	Arid

Table 3. Listing of climate type for each FFE-FVS variant. Climate type applies only to fuel modeling and was assigned based on generally expected MX_{dead} values. Arid means semi-arid to arid climate; humid means sub-humid to humid climate.

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:

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

Table 4 below identifies the standard fire behavior fuel models appropriate for each of the four fuel types, for both arid climates and for humid climates.

		arid climate fuel models				**humid climate fuel models**			
		GR	**GS**	**SH/TU**	**TL/SB**	**GR**	**GS**	**SH/TU**	**TL/SB**
Original 13 fuel models	1	X	X			X	X		
	2	X	X	X		X	X	X	
	3	X	X			X	X		
	4			X				X	
	5		X	X				X	
	6								
	7			X			X	X	
	8				X				X
	9				X				X
	10			X				X	
	11				X				X
	12				X				X
	13				X				X
New 40 fuel models	GR1	X				X			
	GR2	X	X						
	GR3					X	X		
	GR4	X	X						
	GR5					X	X		
	GR6					X	X		
	GR7	X							
	GR8					X			
	GR9					X			
	GS1		X						
	GS2		X						
	GS3						X		
	GS4						X		
	SH1		X	X			X		
	SH2		X	X					
	SH3						X	X	
	SH4						X	X	
	SH5			X					
	SH6							X	
	SH7			X					
	SH8							X	
	SH9							X	
	TU1			X				X	
	TU2							X	
	TU3							X	
	TU4			X					
	TU5			X					
	TL1				X				X
	TL2				X				X
	TL3				X				X
	TL4				X				X
	TL5				X				X
	TL6				X				X
	TL7				X				X
	TL8				X				X
	TL9				X				X
	SB1				X				X
	SB2				X				X
	SB3				X				X
	SB4				X				X

Table 4.
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.

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.

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} is the SAV of the subject fuelbed (ft^{-1})
SAV_{fm} is the SAV of the subject standard fuel model (ft^{-1})
405.2 is the standard deviation of SAV of the 53 standard fuel models (ft^{-1})
BD_{fuelbed} is the bulk density of the subject fuelbed (lb/ft^3)
BD_{fm} is the bulk density of the subject standard fuel model (lb/ft^3)
0.3992 is the standard deviation of the bulk density of the 53 standard fuel models (lb/ft^3)
FFL_{fuelbed} is the fine fuel load of the subject fuelbed (t/a)
FFL_{fm} is the fine fuel load of the subject standard fuel model (t/a)
3.051 is the standard deviation of the fine fuel load of the 53 standard fuel models (t/a)
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.

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.

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 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 DI_x is 25 and DI_y is 75, then WF_x is 0.75 and WF_y is 0.25.

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