Central Rockies (CR) Variant Overview of the Forest Vegetation Simulator

January 2025

Harney Peak, Black Hills National Forest
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Authors and Contributors:

The FVS staff has maintained model documentation for this variant in the form of a variant overview since its release in 1990. The original author was Gary Dixon. In 2008, the previous document was replaced with this updated variant overview. Gary Dixon, Christopher Dixon, Robert Havis, Chad Keyser, Stephanie Rebain, Erin Smith-Mateja, and Don Vandendriesche were involved with this major update. Don Vandendriesche cross-checked information contained in this variant overview with the FVS source code. In 2009, Gary Dixon, expanded the species list and made significant updates to this variant overview.

FVS Staff. 2008 (revised January 21, 2025). Central Rockies (CR) Variant Overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 81p.

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Quick Guide to Default Settings

Parameter or Attribute	**Default Setting**	
Number of Projection Cycles	1 (10 if using FVS GUI)	
Projection Cycle Length	10 years	
Location Code (National Forest)		
SM – Southwestern Mixed Conifers (Region 2/Region 3)	213 – San Juan / 303 – Cibola	
SP – Southwestern Ponderosa Pine (Region 2/Region 3)	213 – San Juan / 303 – Cibola	
BP – Black Hills Ponderosa Pine	203 – Black Hills	
SF – Spruce-fir	206 – Medicine Bow – Routt	
LP – Lodgepole Pine	206 – Medicine Bow – Routt	
If model type is not set	303 – Cibola, model type set to SP	
Model Type	location code specific	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation		
SM – Southwestern Mixed Conifers	88 (8800 feet)	
SP – Southwestern Ponderosa Pine	88 (8800 feet)	
BP – Black Hills Ponderosa Pine	55 (5500 feet)	
SF – Spruce-fir	90 (9000 feet)	
LP – Lodgepole Pine	90 (9000 feet)	
Latitude / Longitude	Latitude	Longitude
SM – Southwestern Mixed Conifers	38	107
SP – Southwestern Ponderosa Pine	38	107
BP – Black Hills Ponderosa Pine	44	107
SF – Spruce-fir; LP – Lodgepole Pine	40	107
Site Species		
SM – Southwestern Mixed Conifers	DF	
SP – Southwestern Ponderosa Pine	PP	
BP – Black Hills Ponderosa Pine	PP	
SF – Spruce-fir	ES	
LP – Lodgepole Pine	LP	
Site Index		
SM – Southwestern Mixed Conifers	70 feet (breast height age; 100 years)	
SP – Southwestern Ponderosa Pine	70 feet (breast height age; 100 years)	
BP – Black Hills Ponderosa Pine	57 feet (total age; 100 years)	
SF – Spruce-fir	75 feet (breast height age; 100 years)	
LP – Lodgepole Pine	65 feet (total age; 100 years)	
Maximum Stand Density Index	Species specific	

Parameter or Attribute	**Default Setting**	
Maximum Basal Area	Based on maximum stand density index	
Volume Equations	National Volume Estimator Library	
Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
SM – Southwestern Mixed Conifers SP – Southwestern Ponderosa Pine SF – Spruce-fir LP – Lodgepole Pine	5.0 / 4.0 inches	5.0 / 4.0 inches
BP – Black Hills Ponderosa Pine	9.0 / 6.0 inches	9.0 / 6.0 inches
Stump Height	1.0 foot	1.0 foot
Merchantable Board Foot Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
Region 2 Forests using these model types: SM – Southwestern Mixed Conifers SP – Southwestern Ponderosa Pine SF – Spruce-fir LP – Lodgepole Pine	7.0 / 6.0 inches	7.0 / 6.0 inches
Region 3 Forests using these model types: SM – Southwestern Mixed Conifers SP – Southwestern Ponderosa Pine SF – Spruce-fir LP – Lodgepole Pine	9.0 / 6.0 inches	9.0 / 6.0 inches
BP – Black Hills Ponderosa Pine	9.0 / 6.0 inches	9.0 / 6.0 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Large Trees (variable radius plot)	40 BAF	
Small Trees (fixed radius plot)	1/300th acre	
Breakpoint DBH	5.0 inches	

1.0 Introduction

The Forest Vegetation Simulator (FVS) is an individual tree, distance independent growth and yield model with linkable modules called extensions, which simulate various insect and pathogen impacts, fire effects, fuel loading, snag dynamics, and development of understory tree vegetation. FVS can simulate a wide variety of forest types, stand structures, and pure or mixed species stands.

New “variants” of the FVS model are created by imbedding new tree growth, mortality, and volume equations for a particular geographic area into the FVS framework. Geographic variants of FVS have been developed for most of the forested lands in the United States.

The Central Rockies (CR) variant of FVS was developed in 1990. It was based on growth equations and relationships from the GENGYM model (Edminster, Mowrer, Mathiasen, et. al. 1991). Although GENGYM is a diameter class model, and FVS is an individual tree model, results produced with FVS were consistent with those produced by GENGYM. While general model upgrades, enhancements, and error fixes, were made to the code since 1990, the variant essentially remained the same as when it was developed.

In late 1998, staff at the Forest Management Service Center began a major overhaul of the variant to correct known deficiencies and quirks, take advantage of advances in FVS technology, incorporate additional data into certain model relationships, and improve default values and surrogate species assignments. In addition, the model was expanded to include 24 species and allow all National Forests within the geographic range of the model to access all the imbedded model types.

In 2009 the variant was expanded from 24 species to 38 species. The juniper species group was dropped and in its place was added the individual juniper species: Utah juniper, alligator juniper, Rocky Mountain juniper, oneseed juniper, and eastern redcedar. These five individual species all use the growth equations that were originally used for the juniper species group in the 24 species version of the model. Similarly, the cottonwood species group was dropped and in its place was added the individual cottonwood species: narrowleaf cottonwood and plains cottonwood. Both of these individual species use the growth equations that were originally used for the cottonwood species group. The oak species group was also dropped and in its place was added the individual oak species: Gambel oak, Arizona white oak, Emory oak, bur oak, and silverleaf oak. All five oak species uses the growth equations that were originally used for the oak species group. Paper birch was added and uses growth equations for quaking aspen. Chihuahuan pine was added and uses growth equations for ponderosa pine. Singleleaf pinyon, border pinyon, and Arizona twoneedle pinyon were added and use growth equations for common twoneedle pinyon.

To fully understand how to use this variant, users should also consult the following publication:

- Essential FVS: A User’s Guide to the Forest Vegetation Simulator (Dixon 2002)

This publication may be downloaded from the Forest Management Service Center (FMSC), Forest Service website. Other FVS publications may be needed if one is using an extension that simulates the effects of fire, insects, or diseases.

2.0 Geographic Range

The CR variant was fit to data representing forest types in represented in the Wyoming, South Dakota, Colorado, New Mexico, and Arizona. Data used in initial model development came from growth samples from National Forests in these states.

The CR variant's original range covered all forested land in Forest Service Regions 2 and 3. This range extended from the northern border of Wyoming and Black Hills of South Dakota, down through Colorado and western Nebraska, and into Arizona and New Mexico. The suggested geographic range of use for the CR variant is shown in figure 2.0.1.

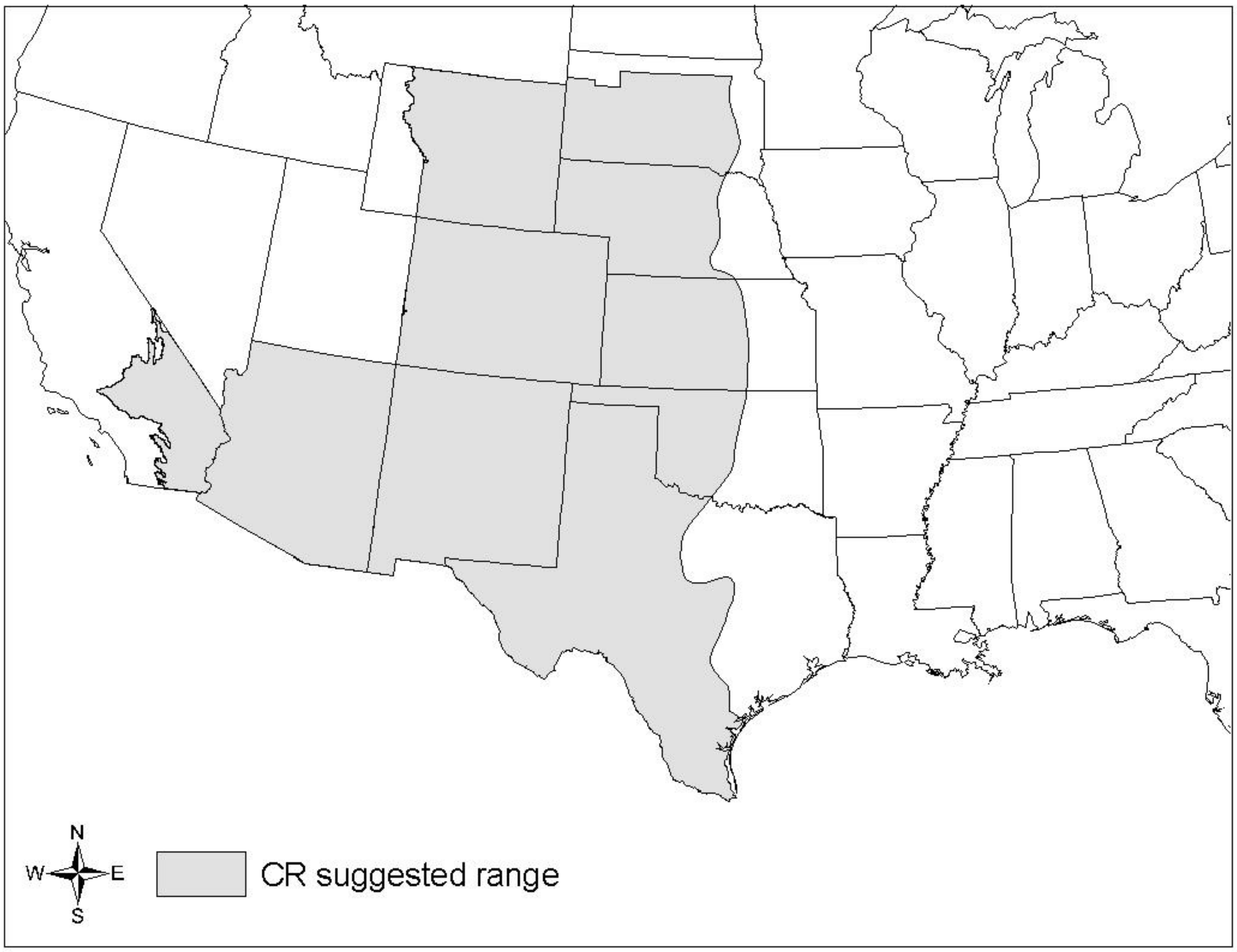

Figure 2.0.1 Suggested geographic range of use for the CR variant.

3.0 Control Variables

FVS users need to specify certain variables used by the CR variant to control a simulation. These are entered in parameter fields on various FVS keywords available in the FVS interface or they are read from an FVS input database using the Database Extension.

3.0.1 Model Types

The CR variant contains five different model types as shown in table 3.0.1.1. Model type may be entered directly or if missing or an incorrect value is entered, then the default model type is determined from the forest location code. The default model type by forest location code is shown in table 3.1.1.

Some equations, for some species, are different depending on which model type is selected. For example, ponderosa pine growth relationships are different if "Black Hills Ponderosa Pine" is selected as the model type, as opposed to Southwestern Ponderosa Pine. For other species, such as Douglas-fir, the growth equations are the same in all model types. The abbreviation shown in the second column of table 3.0.1.1 is used to identify the model type and in labeling some FVS output files.

Table 3.0.1.1 Model types used in the CR variant.

Model Type	Output Abbreviation	Description
1	SM	Southwestern Mixed Conifers
2	SP	Southwestern Ponderosa Pine
3	BP	Black Hills Ponderosa Pine
4	SF	Spruce-fir
5	LP	Lodgepole Pine

3.1 Location Codes

The location code is a 3- or 4-digit code where, in general, the first digit of the code represents the Forest Service Region Number, and the last two digits represent the Forest Number within that region. In some cases, a location code beginning with a "7" or "8" is used to indicate an administrative boundary that doesn't use a Forest Service Region number (for example, other federal agencies, state agencies, or other lands).

If the location code is missing or incorrect, the CR variant uses a default code depending on the model type. If the model type is also missing or incorrect, or if the model type is 1 or 2, the default forest is 303 (Cibola National Forest); if model type 3 is specified, the default forest code is 203 (Black Hills National Forest); and if model types 4 or 5 is specified, the default forest code is 206 (Medicine Bow – Routt National Forest). Location codes recognized in the CR variant are shown in tables 3.1.1 and 3.1.2.

Table 3.1.1 Location codes and default model types used by the CR variant.

Forest Code	National Forest	Default Model Type
202	Bighorn	Lodgepole Pine

Forest Code	National Forest	Default Model Type
203	Black Hills	Black Hills Ponderosa Pine
204	Grand Mesa, Uncompahgre, Gunnison	Spruce-fir
206	Medicine Bow - Routt	Lodgepole Pine
207	Nebraska	Black Hills Ponderosa Pine
209	Rio Grande	Spruce-fir
210	Arapaho, Roosevelt	Lodgepole Pine
212	Pike, San Isabel	Spruce-fir
213	San Juan	Spruce-fir
214	Shoshone	Lodgepole Pine
215	White River	Spruce-fir
301	Apache-Sitgreaves	Southwestern Ponderosa Pine
302	Carson	Southwestern Ponderosa Pine
303	Cibola	Southwestern Ponderosa Pine
304	Coconino	Southwestern Ponderosa Pine
305	Coronado	Southwestern Ponderosa Pine
306	Gila	Southwestern Ponderosa Pine
307	Kaibab	Southwestern Ponderosa Pine
308	Lincoln	Southwestern Ponderosa Pine
309	Prescott	Southwestern Ponderosa Pine
310	Sante Fe	Southwestern Ponderosa Pine
312	Tonto	Southwestern Ponderosa Pine
201	Arapahoe (mapped to 210)	Lodgepole Pine
205	Gunnison (mapped to 204)	Spruce-fir
208	Pike (mapped to 212)	Spruce-fir
211	Routt (mapped to 206)	Lodgepole Pine
216	Samuel R. McKelvie (mapped to 207)	Black Hills Ponderosa Pine
224	Grand Mesa (mapped to 204)	Spruce-fir
311	Sitgreaves (mapped to 301)	Southwestern Ponderosa Pina

Table 3.1.2 Bureau of Indian Affairs reservation codes used in the CR variant.

Location Code	Location
7101	Cheyenne River Reservation (mapped to 203)
7104	Pine Ridge Reservation (mapped to 203)
7105	Rosebud Indian Reservation (mapped to 203)
7106	Yankton Reservation (mapped to 203)
7108	Standing Rock Reservation (mapped to 203)
7111	Santee Reservation (mapped to 207)
7113	Crow Creek Reservation (mapped to 203)
7114	Lower Brule Reservation (mapped to 203)
7206	Cheyenne-Arapaho Otsa (mapped to 310)

Location Code	Location
7207	Kiowa-Comanche-Apache-Fort Sill Apache Otsa (mapped to 310)
7208	Kiowa-Comanche-Apache-Ft Sill-Apache/Caddo-Wichita-Delawarejoint-Use Otsa (mapped to 310)
7209	Caddo-Wichita-Delaware Otsa (mapped to 310)
7210	Kaw Otsa (mapped to 310)
7211	Otoe-Missouria Otsa (mapped to 310)
7213	Ponca Otsa (mapped to 310)
7214	Tonkawa Otsa (mapped to 310)
7217	Kickapoo (Tx/Mx) (mapped to 308)
7302	Crow Reservation (mapped to 202)
7305	Northern Cheyenne Off-Reservationtrust Land (mapped to 203)
7306	Wind River Reservation (mapped to 214)
7601	Chickasaw Otsa (mapped to 310)
7609	Osage Reservation (mapped to 310)
7701	Colorado River Indian Reservation (mapped to 312)
7702	Fort Mojave Reservation (mapped to 312)
7703	Chemehuevi Reservation (mapped to 312)
7704	Fort Apache Reservation (mapped to 301)
7705	Tohono O'Odham Nation Reservation (mapped to 312)
7706	Fort Mcdowell Yavapai Nation Reservation (mapped to 312)
7707	Salt River Reservation (mapped to 312)
7708	Maricopa, (Ak Chin Indian Res (mapped to 312)
7709	Gila River Indian Reservation (mapped to 312)
7710	San Carlos Reservation (mapped to 305)
7718	Uintah And Ouray Reservation (mapped to 215)
7719	Cocopah Reservation (mapped to 312)
7720	Fort Yuma Indian Reservation (mapped to 312)
7724	Hopi Reservation (mapped to 301)
7725	Havasupai Reservation (mapped to 307)
7726	Hualapai Indian Reservation (mapped to 307)
7727	Yavapai-Prescott Reservation (mapped to 309)
7728	Kaibab Indian Reservation (mapped to 307)
7835	Timbi-Sha Shoshone Reservation (mapped to 312)
7847	Agua Caliente Indian Reservation (mapped to 312)
7848	Augustine Reservation (mapped to 312)
7859	Morongo Reservation (mapped to 312)
7901	Acoma Pueblo (mapped to 303)
7902	Pueblo De Cochiti (mapped to 310)
7903	Isleta Pueblo (mapped to 303)
7904	Jemez Pueblo (mapped to 310)
7905	Sandia Pueblo (mapped to 303)

Location Code	Location
7906	San Felipe Pueblo (mapped to 310)
7907	Santa Ana Pueblo (mapped to 310)
7908	Santo Domingo Pueblo (mapped to 310)
7909	Zia Pueblo (mapped to 310)
7910	Laguna Pueblo (mapped to 303)
7911	Nambe Pueblo (mapped to 310)
7912	Picuris Pueblo (mapped to 302)
7913	Pueblo Of Pojoaque (mapped to 310)
7914	San Ildefonso Pueblo (mapped to 310)
7915	Ohkay Owingeh (mapped to 302)
7916	Santa Clara Pueblo (mapped to 310)
7917	Taos Pueblo (mapped to 302)
7918	Tesuque Pueblo (mapped to 310)
7919	Southern Ute Reservation (mapped to 213)
7920	Ute Mountain Reservation (mapped to 213)
7921	Jicarilla Apache Nation Reservation (mapped to 302)
7922	Mescalero Reservation (mapped to 308)
7923	Fort Sill Apache Indian Reservation (mapped to 306)
7924	Zuni Reservation (mapped to 303)
7925	Ramah-Navajo (mapped to 303)
8001	Navajo Nation Reservation (mapped to 301)

3.2 Species Codes

The CR variant recognizes 36 species, plus two other composite species categories. You may use FVS species codes, Forest Inventory and Analysis (FIA) species codes, or USDA Natural Resources Conservation Service PLANTS symbols to represent these species in FVS input data. Any valid western species code identifying species not recognized by the variant will be mapped to a similar species in the variant. The species mapping crosswalk is available on the FVS website variant documentation webpage. Any non-valid species code will default to the “other hardwood” category.

Either the FVS sequence number or species code must be used to specify a species in FVS keywords and Event Monitor functions. FIA codes or PLANTS symbols are only recognized during data input and may not be used in FVS keywords. Table 3.2.1 shows the complete list of species codes recognized by the EM variant.

When entering tree data, users should substitute diameter at root collar (DRC) for diameter at breast height (DBH) for woodland species (pinyons, junipers, and oaks other than bur oak).

Table 3.2.1 Species codes used in the CR variant.

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name[1]	Common Name[1]
1	AF	019	ABLA	*Abies lasiocarpa*	subalpine fir
2	CB	018	ABLAA	*Abies lasiocarpa var. arizonica*	corkbark fir
3	DF	202	PSME	*Pseudotsuga menziesii*	Douglas-fir
4	GF	017	ABGR	*Abies grandis*	grand fir
5	WF	015	ABCO	*Abies concolor*	white fir
6	MH	264	TSME	*Tsuga mertensiana*	mountain hemlock
7	RC	242	THPL	*Thuja plicata*	western redcedar
8	WL	073	LAOC	*Larix occidentalis*	western larch
9	BC	102	PIAR	*Pinus aristata*	bristlecone pine
10	LM	113	PIFL2	*Pinus flexilis*	limber pine
11	LP	108	PICO	*Pinus contorta*	lodgepole pine
12	PI	106	PIED	*Pinus edulis*	twoneedle pinyon
13	PP	122	PIPO	*Pinus ponderosa*	ponderosa pine
14	WB	101	PIAL	*Pinus albicaulis*	whitebark pine
15	SW	114	PIST3	*Pinus strobiformis*	southwestern white pine
16	UJ	065	JUOS	*Juniperus osteosperma*	Utah juniper
17	BS	096	PIPU	*Picea pungens*	blue spruce
18	ES	093	PIEN	*Picea engelmannii*	Engelmann spruce
19	WS	094	PIGL	*Picea glauca*	white spruce
20	AS	746	POTR5	*Populus tremuloides*	quaking aspen
21	NC	749	POAN3	*Populus angustifolia*	narrowleaf cottonwood
22	PW	745	PODEM	*Populus deltoides* ssp. *monilifera*	plains cottonwood
23	GO	814	QUGA	*Quercus gambelii*	Gambel oak
24	AW	803	QUAR	*Quercus arizonica*	Arizona white oak
25	EM	810	QUEM	*Quercus emoryi*	Emory oak
26	BK	823	QUMA2	*Quercus macrocarpa*	bur oak
27	SO	843	QUHY	*Quercus hypoleucoides*	silverleaf oak
28	PB	375	BEPA	*Betula papyrifera*	paper birch
29	AJ	063	JUDE2	*Juniperus deppeana*	alligator juniper
30	RM	066	JUSC2	*Juniperus scopulorum*	Rocky Mountain juniper
31	OJ	069	JUMO	*Juniperus monosperma*	oneseed juniper
32	ER	068	JUVI	*Juniperus virginiana*	eastern redcedar
33	PM	133	PIMO	*Pinus monophylla*	singleleaf pinyon
34	PD	134	PIDI3	*Pinus discolor*	border pinyon
35	AZ	143	PIMOF	*Pinus monophylla* var. *fallax*	Arizona twoneedle pinyon[3]

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name[1]	Common Name[1]
36	CI	118	PILE	*Pinus leiophylla*	Chihuahuan pine
37	OS	299	2TN		other softwood[2]
38	OH	998	2TB		other hardwood[2]

[1]Set based on the USDA Forest Service NRM TAXA lists and the USDA Plants database.
[2]Other categories use FIA codes and NRM TAXA codes that best match the other category.
[3]Common name is from FIA master species list, January, 1 2021.

3.3 Habitat Type, Plant Association, and Ecological Unit Codes

In the CR variant, plant association codes are used in the Fire and Fuels Extension (FFE) to set fuel loading in cases where there are no trees in the first cycle. Codes recognized in the CR variant are the NRIS Common Stand Exam codes (US Forest Service 2000). Valid codes are shown in Appendices A and B. Region 2 codes originate from Johnson (1987), and Region 3 codes from US Forest Service (1997). Users may enter the plant association code or the plant association FVS sequence number on the STDINFO keyword, when entering stand information from a database, or when using the SETSITE keyword without the PARMS option. If using the PARMS option with the SETSITE keyword, users must use the FVS sequence number for the plant association.

3.4 Site Index

Site index is used in the growth equations for the CR variant. When possible, users should enter their own values instead of relying on the default values assigned by FVS. If site index information is available, a single site index can be specified for the whole stand, a site index for each individual species can be specified, or a combination of these can be entered. If the user does not supply site index values, then default values will be used. When entering site index in the CR variant, the sources shown in table 3.4.1 should be used if possible. Default values for site species and site index, by model type, are shown in table 3.4.2.

When site index is not specified for a species, a relative site index value is calculated from the site index of the site species using equations {3.4.1} and {3.4.2}. Minimum and Maximum site indices used in equation {3.4.1} may be found in table 3.4.3. If the site index for the stand is less than or equal to the lower site limit, it is set to the lower limit + 0.5 for the calculation of *RELSI*. Similarly, if the site index for the stand is greater than the upper site limit, it is set to the upper site limit for the calculation of *RELSI*.

{3.4.1} $RELSI = (SI_{site} - SITELO_{site}) / (SITEHI_{site} - SITELO_{site})$

{3.4.2} $SI_i = SITELO_i + RELSI * (SITEHI_i - SITELO_i)$

where:

RELSI	is the relative site index of the site species
SI	is species site index
SITELO	is the lower bound of the *SI* range for a species

SITEHI is the upper bound of the *SI* range for a species
site is the site species
i is the species for which site index is to be calculated

Table 3.4.1 Recommended site index references for use with the CR variant.

Model Type	Reference Species	Ref Age	Age Type	Reference
SW Mixed Conifers	DF	100	Breast Height	Edminster, Mathiasen, Olsen 1991
SW Ponderosa Pine	PP	100	Breast Height	Minor 1964
BHills Ponderosa Pine	PP	100	Total	Meyer 1961
Spruce-fir	ES / AF	100	Breast Height	Alexander 1967
Lodgepole Pine	LP	100	Total	Alexander, Tackle, Dahms 1967

Table 3.4.2 Default values for site species and site index, by model type, for the CR variant.

Model Type	Site Species	Site Index
SW Mixed Conifers	DF	70
SW Ponderosa Pine	PP	70
Black Hills Ponderosa Pine	PP	57
Spruce-fir	ES	75
Lodgepole Pine	LP	65

Table 3.4.3 Default *SITELO* and *SITEHI* values for equation {3.4.1} in the CR variant.

Species Code	*SITELO*	*SITEHI*
AF	40	105
CB	30	100
DF	40	120
GF	30	130
WF	40	105
MH	40	70
RC	20	125
WL	40	120
BC	20	60
LM	10	60
LP	30	95
PI	6	40
PP	30	100
WB	20	60
SW	30	130
UJ	6	30
BS	30	110
ES	40	120
WS	30	85

Species Code	*SITELO*	*SITEHI*
AS	20	100
NC	30	120
PW	30	120
GO	6	40
AW	6	40
EM	6	40
BK	6	40
SO	6	40
PB	20	100
AJ	6	30
RM	6	30
OJ	6	30
ER	6	30
PM	6	40
PD	6	40
AZ	6	40
CI	30	100
OS	30	95
OH	20	100

3.5 Maximum Density

Maximum stand density index (SDI) and maximum basal area (BA) are important variables in determining density related mortality and crown ratio change. Maximum basal area is a stand level metric that can be set using the BAMAX or SETSITE keywords. If not set by the user, a default value is calculated from maximum stand SDI each projection cycle. Maximum stand density index can be set for each species using the SDIMAX or SETSITE keywords. If not set by the user, a default value is assigned as discussed below.

The default maximum SDI is set based on species or a user specified basal area maximum. If a user specified basal area maximum is present, the maximum SDI for all species is computed using equation {3.5.1}; otherwise, species SDI maximums are assigned from the SDI maximums shown in table 3.5.1. Maximum stand density index at the stand level is a weighted average, by basal area, of the individual species SDI maximums.

Stand SDI is calculated using the Zeide calculation method (Dixon 2002).

{3.5.1} $SDIMAX_i = BAMAX / (0.5454154 * SDIU)$

where:

$SDIMAX_i$	is the species-specific SDI maximum
BAMAX	is the user-specified stand basal area maximum
SDIU	is the proportion of theoretical maximum density at which the stand reaches actual maximum density (default 0.85, changed with the SDIMAX keyword)

Table 3.5.1 Default stand density index maximums by species in the CR variant.

Species Code	SDI Maximum*	Mapped to
AF	602	
CB	423	
DF	570	
GF	562	
WF	634	
MH	687	
RC	762	
WL	423	
BC	621	whitebark pine
LM	409	
LP	679	
PI	348	
PP	446	
WB	621	
SW	529	eastern white pine
UJ	497	
BS	620	Engelmann spruce
ES	620	
WS	412	
AS	562	
NC	452	black cottonwood
PW	452	black cottonwood
GO	652	
AW	403	
EM	284	
BK	423	
SO	284	Emory oak
PB	466	
AJ	395	
RM	411	
OJ	408	
ER	354	
PM	358	
PD	348	twoneedle pinyon
AZ	358	singleleaf pinyon
CI	446	ponderosa pine
OS	348	twoneedle pinyon
OH	452	black cottonwood

*Source of SDI maximums is an unpublished analysis of FIA data by John Shaw.

4.0 Growth Relationships

This chapter describes the functional relationships used to fill in missing tree data and calculate incremental growth. In FVS, trees are grown in either the small tree sub-model or the large tree sub-model depending on the diameter.

4.1 Height-Diameter Relationships

Height-diameter relationships in FVS are primarily used to estimate tree heights missing in the input data and occasionally to estimate diameter growth on trees smaller than a given threshold diameter. In the CR variant, height-diameter relationships are a logistic functional form, as shown in equation {4.1.1} (Wykoff, et.al 1982). The equation was fit to data of the same species used to develop other FVS variants. Default coefficients for equation {4.1.1} are shown are shown in table 4.1.1.

When heights are given in the input data for 3 or more trees of a given species, the value of B_1 in equation {4.1.1} for that species is recalculated from the input data and replaces the default value shown in table 4.1.1. In the event that the calculated value is less than zero, the default is used.

{4.1.2} Wykoff functional form

$HT = 4.5 + \exp(B_1 + B_2 / (DBH + 1.0))$

where:

HT	is tree height
DBH	is tree diameter at breast height
B_1 - B_2	are species-specific coefficients shown in table 4.1.1

Table 4.1.1 Default coefficients for the height-diameter relationship equation in the CR variant.

Species Code	B_1	B_2
AF	4.4717	-6.7387
CB	4.4717	-6.7387
DF	4.5879	-8.9277
GF	5.0271	-11.2168
WF	4.3008	-6.8139
MH	4.8740	-10.4050
RC	5.1631	-9.2566
WL	5.1631	-9.2566
BC	4.1920	-5.1651
LM	4.1920	-5.1651
LP	4.3767	-6.1281
PI	4.1920	-5.1651

Species Code	B_1	B_2
PP	4.6024	-11.4693
WB	4.1920	-5.1651
SW	5.1999	-9.2672
UJ	4.1920	-5.1651
BS	4.5293	-7.7725
ES	4.5293	-7.7725
WS	4.5293	-7.7725
AS	4.4421	-6.5405
NC	4.4421	-6.5405
PW	4.4421	-6.5405
GO	4.1920	-5.1651
AW	4.1920	-5.1651
EM	4.1920	-5.1651
BK	4.1920	-5.1651
SO	4.1920	-5.1651
PB	4.4421	-6.5405
AJ	4.1920	-5.1651
RM	4.1920	-5.1651
OJ	4.1920	-5.1651
ER	4.1920	-5.1651
PM	4.1920	-5.1651
PD	4.1920	-5.1651
AZ	4.1920	-5.1651
CI	4.6024	-11.4693
OS	4.2597	-9.3949
OH	4.4421	-6.5405

For the Black Hills Ponderosa Pine model type, the default height-diameter relationships for all species are shown in the equations {4.1.2} and {4.1.3}. Trees with a DBH greater than 0.5 inches use equation {4.1.2} and trees with a DBH less than or equal to 0.5 inches use equation {4.1.3}.

{4.1.2} $HT = 32.108633 * (SI^{0.276926}) * [(1 - \exp(-0.057766*DBH))^{1.0026686}] + 4.5$

{4.1.3} $HT = DBH * [12.41173 + 0.04633 * SI - 0.000158 * SI^2]$

where:

HT	is tree height
DBH	is tree diameter at breast height
SI	is species site index

However, the calibrated logistic function is used for a given species when there are enough observations to get a satisfactory estimate of the “a” parameter for that species.

4.2 Bark Ratio Relationships

Bark ratio estimates are used to convert between diameter outside bark and diameter inside bark in various parts of the model. The equation is shown in equation {4.2.1} and coefficients (b_1 and b_2) for this equation by species are shown in table 4.2.1.

{4.2.1} $BRATIO = b_1 + b_2 * (1 / DBH)$

Note: if a species has a b_2 value equal to 0, then $BRATIO = b_1$

where:

BRATIO is species-specific bark ratio (bounded to $0.80 \leq BRATIO \leq 0.99$)
DBH is tree diameter at breast height (bounded to $DBH \geq 1.0$)
b_1 - b_2 are species-specific coefficients shown in table 4.2.1

Table 4.2.1 Default coefficients for the bark ratio equation {4.2.1} in the CR variant.

Species Code	Model Type	b_1	b_2	Equation Source
AF	all	0.890	0	PP from Wykoff, et. al. 1982
CB	all	0.890	0	PP from Wykoff, et. al. 1982
DF	all	0.867	0	Wykoff, et. al. 1982
GF	all	0.890	0	PP from Wykoff, et. al. 1982
WF	all	0.890	0	PP from Wykoff, et. al. 1982
MH	all	0.9497	0	Wykoff, et. al. 1982
RC	all	0.9497	0	Wykoff, et. al. 1982
WL	all	0.87407	-0.185	Schmidt, et. al. 1976
BC	all	0.9625	-0.1141	Uses LP equation
LM	all	0.9625	-0.1141	Uses LP equation
LP	all	0.9625	-0.1141	Myers 1964
PI	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
PI	BP, SF, LP	0.9002	-0.3089	Uses PP equation
PP	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
PP	BP, SF, LP	0.9002	-0.3089	Myers & Van Deusen 1958
WB	all	0.9625	-0.1141	Uses LP equation
SW	all	0.9643	0	Wykoff, et. al. 1982
UJ	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
UJ	BP, SF, LP	0.9002	-0.3089	Uses PP equation
BS	all	0.9502	-0.2528	Uses ES equation
ES	all	0.9502	-0.2528	Myers & Alexander 1972
WS	all	0.9502	-0.2528	Uses ES equation
AS	all	0.950	0	Utah FVS variant
NC	all	0.892	-0.086	Edminster, et. al. 1977
PW	all	0.892	-0.086	Edminster, et. al. 1977
GO		0.93789	-0.24096	Clark, et. al. 1991

Species Code	Model Type	b_1	b_2	Equation Source
AW		0.93789	-0.24096	Clark, et. al. 1991
EM		0.93789	-0.24096	Clark, et. al. 1991
BK		0.93789	-0.24096	Clark, et. al. 1991
SO		0.93789	-0.24096	Clark, et. al. 1991
PB		0.950	0	Uses AS equation
AJ	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
AJ	BP, SF, LP	0.9002	-0.3089	Uses PP equation
RM	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
RM	BP, SF, LP	0.9002	-0.3089	Uses PP equation
OJ	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
OJ	BP, SF, LP	0.9002	-0.3089	Uses PP equation
ER	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
ER	BP, SF, LP	0.9002	-0.3089	Uses PP equation
PM	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
PM	BP, SF, LP	0.9002	-0.3089	Uses PP equation
PD	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
PD	BP, SF, LP	0.9002	-0.3089	Uses PP equation
AZ	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
AZ	BP, SF, LP	0.9002	-0.3089	Uses PP equation
CI	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
CI	BP, SF, LP	0.9002	-0.3089	Uses PP equation
OS	SM, SP	0.8967	-0.4448	PP from Dolph PSW-368
OS	BP, SF, LP	0.9002	-0.3089	Uses PP equation
OH	all	0.892	-0.086	Uses CO equation

* *DBH* is bounded between 1.0 and 19.0 for species using the PP equation (coefficients 0.9002 and -0.3089).

4.3 Crown Ratio Relationships

Crown ratio equations are used for three purposes in FVS: (1) to estimate tree crown ratios missing from the input data for both live and dead trees; (2) to estimate change in crown ratio from cycle to cycle for live trees; and (3) to estimate initial crown ratios for regenerating trees established during a simulation.

4.3.1 Crown Ratio Dubbing

In the CR variant, all species except mountain hemlock, western redcedar, and western larch use equations from GENGYM which predict crown length as a function of tree and stand attributes using equation {4.3.1.1}. Coefficients for this equation are shown in table 4.3.1.1. Crown length is then converted to crown ratio by dividing crown length by total tree height as shown in equation {4.3.1.2}.

{4.3.1.1} $CL = a_0 + (a_1 * HT) + (a_2 * DBH) + (a_3 * BA) + (a_4 * BAU)$

{4.3.1.2} $CR = CL / HT$

where:

CL	is tree crown length
HT	is tree height
DBH	is tree diameter at breast height
BA	is total stand basal area
BAU	is total basal area in trees above the diameter class of the subject tree
CR	is predicted crown ratio expressed as a proportion at the end of the cycle
$a_0 - a_4$	are species-specific coefficients shown in table 4.3.1.1

Table 4.3.1.1 Default coefficients to predict crown length for equation {4.3.1.1} in the CR variant.

Species Code	Model Type	a_0	a_1	a_2	a_3	a_4
AF	SM, SP	0.50706	0.73070	0	0	0
AF	BP, SF, LP	0.36135	0.57085	0	0	0
CB	SM, SP	0.50706	0.73070	0	0	0
CB	BP, SF, LP	0.36135	0.57085	0	0	0
DF	ALL	6.47479	0.50703	0.54482	-0.03326	0
GF	ALL	6.22959	0.67587	0	-0.03098	0
WF	ALL	6.22959	0.67587	0	-0.03098	0
MH	*					
RC	*					
WL	*					
BC	ALL	-0.59373	0.67703	0	0	0
LM	ALL	-0.59373	0.67703	0	0	0
LP	ALL	5.00215	0.06334	0.88236	0	-0.03821
PI	ALL	-0.59373	0.67703	0	0	0
PP	SM	5.63367	0.56252	0	-0.06411	0
PP	SP	4.35671	0.32549	0.84714	-0.03802	0
PP	BP, SF, LP	3.49178	0.17421	0.80767	-0.03272	0
WB	ALL	-0.59373	0.67703	0	0	0
SW	ALL	3.03832	0.65587	0	-0.01792	0
UJ	ALL	-0.59373	0.67703	0	0	0
BS	ALL	3.61635	0.61547	0.93639	-0.02360	0
ES	SM, SP	1.05857	0.68442	0	0	0
ES	BP, SF, LP	3.22244	0.44315	0.44755	0	0
WS	ALL	0.15768	0.74697	0	0	0
AS	ALL	5.17281	0.32552	0	-0.01675	0
NC	ALL	5.17281	0.32552	0	-0.01675	0
PW	ALL	5.17281	0.32552	0	-0.01675	0
GO	ALL	-0.59373	0.67703	0	0	0

Species Code	Model Type	a_0	a_1	a_2	a_3	a_4
AW	ALL	-0.59373	0.67703	0	0	0
EM	ALL	-0.59373	0.67703	0	0	0
BK	ALL	-0.59373	0.67703	0	0	0
SO	ALL	-0.59373	0.67703	0	0	0
PB	ALL	5.17281	0.32552	0	-0.01675	0
AJ	ALL	-0.59373	0.67703	0	0	0
RM	ALL	-0.59373	0.67703	0	0	0
OJ	ALL	-0.59373	0.67703	0	0	0
ER	ALL	-0.59373	0.67703	0	0	0
PM	ALL	-0.59373	0.67703	0	0	0
PD	ALL	-0.59373	0.67703	0	0	0
AZ	ALL	-0.59373	0.67703	0	0	0
CI	SM	5.63367	0.56252	0	-0.06411	0
CI	SP	4.35671	0.32549	0.84714	-0.03802	0
CI	BP, SF, LP	3.49178	0.17421	0.80767	-0.03272	0
OS	ALL	-0.59373	0.67703	0	0	0
OH	ALL	5.17281	0.32552	0	-0.01675	0

*Crown ratio equations for MH, RC, and WL are described below

The remaining three species use equations from other variants that predict crown ratio directly. The equation for mountain hemlock is given in equation {4.3.1.3}. This equation is from the North Idaho (NI) variant for Bitterroot National Forest and habitat type set to 710. The equation for western red cedar is shown in equation {4.3.1.4}. This equation is from the NI variant with habitat type set to 550. The equation for western larch is shown in equation {4.3.1.5}. This equation is also from the NI variant for Bitterroot National Forest and habitat type set to 260.

{4.3.1.3} $CR = 0.3450 – (0.00264 * BA) + (0.00000512 * CCF^2) – (0.25138 * \ln(HT)) + (0.05140 * \ln(PCT))$

{4.3.1.4} $CR = -1.6053 + (0.17479 * \ln(BA)) – (0.00183 * CCF) – (0.00560 * DBH) + (0.11050 * \ln(PCT))$

{4.3.1.5} $CR = 0.03441 – (0.00204 * BAT) + (0.30066 * \ln(DBH)) – (0.59302 * \ln(HT))$

where:

CR is predicted crown ratio expressed as a proportion at the end of the cycle
BA is total stand basal area
CCF is stand crown competition factor
HT is tree height at the beginning of the cycle
PCT is the subject tree's percentile in the basal area distribution of the stand
DBH is tree diameter at breast height
BAT is total stand basal area (subject to restrictions)

BAT is subject to the following restrictions:

Southwestern Mixed Conifers model type:

$BAT \geq 1.0$

If *BAT* is less than 65, then *BAL* is set to 0.

Southwestern Ponderosa Pine model type:

$BAT \geq 21$

Black Hills Ponderosa Pine and Spruce-Fir model types:

$BAT \geq 5$

Lodgepole pine model type:

$BAT \geq 14$

4.3.2 Crown Ratio Change

Crown ratio change is estimated after growth, mortality and regeneration are estimated during a projection cycle. Crown ratio change is the difference between the crown ratio at the beginning of the cycle and the predicted crown ratio at the end of the cycle. Crown ratio predicted at the end of the projection cycle is estimated for live tree records using the equations outlined above. Once crown ratio is predicted, it is bounded to a change of no more than 1% per year, and to no more than the potential change in crown ratio if all the height growth contributed to the crown change during the cycle.

4.3.3 Crown Ratio for Newly Established Trees

Crown ratios for newly established trees during regeneration are estimated using equation {4.3.3.1}. A random component is added in equation {4.3.3.1} to ensure that not all newly established trees are assigned exactly the same crown ratio.

{4.3.3.1} $CR = 0.89722 – 0.0000461 * PCCF + RAN$

where:

CR	is crown ratio expressed as a proportion (bounded to $0.2 \leq CR \leq 0.9$)
PCCF	is crown competition factor on the inventory point where the tree is established
RAN	is a small random component

4.4 Crown Width Relationships

The CR variant calculates the maximum crown width for each individual tree based on individual tree and stand attributes. Crown width for each tree is reported in the tree list output table and used for percent canopy cover (*PCC*) calculations in the model. Crown width is calculated using equations {4.4.1} – {4.4.5}, and coefficients for these equations are shown in table 4.4.1. The minimum diameter and bounds for certain data values are given in table 4.4.2. Equation numbers in table 4.4.1 are given with the first three digits representing the FIA species code and the last two digits representing the equation source.

{4.4.1} Bechtold (2004); Equation 01

$DBH \geq MinD: CW = a_1 + (a_2 * DBH) + (a_3 * DBH^2)$

$DBH < MinD: CW = [a_1 + (a_2 * MinD) * (a_3 * MinD^2)] * (DBH / MinD)$

{4.4.2} Bechtold (2004); Equation 02

$DBH \geq MinD: CW = a_1 + (a_2 * DBH) + (a_3 * DBH^2) + (a_4 * CR) + (a_5 * BA) + (a_6 * HI)$

$DBH < MinD: CW = [a_1 + (a_2 * MinD) + (a_3 * MinD^2) + (a_4 * CR) + (a_5 * BA) + (a_6 * HI)] * (DBH / MinD)$

{4.4.3} Crookston (2003); Equation 03 (used only for Mountain Hemlock)

$HT < 5.0: CW = [0.8 * HT * MAX(0.5, CR * 0.01)] * [1 - (HT - 5) * 0.1] * a_1 * DBH^{a_2} * HT^{a_3} * CL^{a_4} * (HT-5) * 0.1$

$5.0 \leq HT < 15.0: CW = 0.8 * HT * MAX(0.5, CR * 0.01)$

$HT \geq 15.0: CW = a_1 * (DBH^{a_2}) * (HT^{a_3}) * (CL^{a_4})$

{4.4.4} Crookston (2003); Equation 03

$DBH \geq MinD: CW = [a_1 * \exp[a_2 + (a_3 * \ln(CL)) + (a_4 * \ln(DBH)) + (a_5 * \ln(HT)) + (a_6 * \ln(BA))]]$

$DBH < MinD: CW = [a_1 * \exp[a_2 + (a_3 * \ln(CL)) + (a_4 * \ln(MinD)) + (a_5 * \ln(HT)) + (a_6 * \ln(BA))]] * (DBH / MinD)$

{4.4.5} Crookston (2005); Equation 05

$DBH \geq MinD: CW = (a_1 * BF) * DBH^{a_2} * HT^{a_3} * CL^{a_4} * (BA + 1.0)^{a_5} * (\exp(EL))^{a_6}$

$DBH < MinD: CW = [(a_1 * BF) * MinD^{a_2} * HT^{a_3} * CL^{a_4} * (BA + 1.0)^{a_5} * (\exp(EL))^{a_6}] * (DBH / MinD)$

where:

BF	is a species-specific coefficient based on forest code (*BF* = 1.0 in the CR variant)
CW	is tree maximum crown width
CL	is tree crown length
DBH	is tree diameter at breast height
HT	is tree height
BA	is total stand basal area
EL	is stand elevation in hundreds of feet
MinD	is the minimum diameter
HI	is the Hopkins Index *HI* = (ELEVATION - 5449) / 100) * 1.0 + (LATITUDE - 42.16) * 4.0 + (-116.39 - LONGITUDE) * 1.25
$a_1 - a_6$	are species-specific coefficients shown in table 4.4.1

Table 4.4.1 Default coefficients for crown width equations {4.4.1} – {4.4.5} in the CR variant.

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
AF	01905	5.8827	0.51479	-0.21501	0.17916	0.03277	-0.00828
CB	01801	6.073	0.3756	0	0	0	0

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
DF	20205	6.0227	0.54361	-0.20669	0.20395	-0.00644	-0.00378
GF	01703	1.0303	1.14079	0.20904	0.38787	0	0
WF	01505	5.0312	0.53680	-0.18957	0.16199	0.04385	-0.00651
MH	26403	6.90396	0.55645	-0.28509	0.20430	0	0
RC	24205	6.2382	0.29517	-0.10673	0.23219	0.05341	-0.00787
WL	07303	1.02478	0.99889	0.19422	0.59423	-0.09078	-0.02341
BC	10201	7.4251	0.8991	0	0	0	0
LM	11301	4.0181	0.8528	0	0	0	0
LP	10805	6.6941	0.81980	-0.36992	0.17722	-0.01202	-0.00882
PI	10602	-5.4647	1.9660	0	-0.0395	0.0427	-0.0259
PP	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
WB	10105	2.2354	0.66680	-0.11658	0.16927	0	0
SW	11905	5.3822	0.57896	-0.19579	0.14875	0	-0.00685
UJ	06602	-4.1599	1.3528	0	-0.0233	0.0633	-0.0423
BS	09305	6.7575	0.55048	-0.25204	0.19002	0	-0.00313
ES	09305	6.7575	0.55048	-0.25204	0.19002	0	-0.00313
WS	09305	6.7575	0.55048	-0.25204	0.19002	0	-0.00313
AS	74605	4.7961	0.64167	-0.18695	0.18581	0	0
NC	74902	4.1687	1.5355	0	0	0	0.1275
PW	74902	4.1687	1.5355	0	0	0	0.1275
GO	81402	0.3309	0.8918	0	0	0.0510	0
AW	81402	0.3309	0.8918	0	0	0.0510	0
EM	81402	0.3309	0.8918	0	0	0.0510	0
BK	81402	0.3309	0.8918	0	0	0.0510	0
SO	81402	0.3309	0.8918	0	0	0.0510	0
PB	74605	4.7961	0.64167	-0.18695	0.18581	0	0
AJ	06602	-4.1599	1.3528	0	-0.0233	0.0633	-0.0423
RM	06602	-4.1599	1.3528	0	-0.0233	0.0633	-0.0423
OJ	06602	-4.1599	1.3528	0	-0.0233	0.0633	-0.0423
ER	06602	-4.1599	1.3528	0	-0.0233	0.0633	-0.0423
PM	10602	-5.4647	1.9660	0	-0.0395	0.0427	-0.0259
PD	10602	-5.4647	1.9660	0	-0.0395	0.0427	-0.0259
AZ	10602	-5.4647	1.9660	0	-0.0395	0.0427	-0.0259
CI	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
OS	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
OH	74902	4.1687	1.5355	0	0	0	0.1275

*Equation number is a combination of the species FIA code (###) and source (##).

Table 4.4.2 Default *MinD* values and data bounds for equations {4.4.1} – {4.4.5} in the CR variant.

Species Code	Equation Number*	*MinD*	*EL min*	*EL* max	*HI* min	*HI* max	*CW* max
AF	01905	1.0	10	85	n/a	n/a	30
CB	01801	5.0	n/a	n/a	n/a	n/a	15
DF	20205	1.0	1	75	n/a	n/a	80
GF	01703	1.0	n/a	n/a	n/a	n/a	40
WF	01505	1.0	2	75	n/a	n/a	35
MH	26403	n/a	n/a	n/a	n/a	n/a	45
RC	24205	1.0	1	72	n/a	n/a	45
WL	07303	1.0	n/a	n/a	n/a	n/a	40
BC	10201	5.0	n/a	n/a	n/a	n/a	25
LM	11301	5.0	n/a	n/a	n/a	n/a	25
LP	10805	1.0	1	79	n/a	n/a	40
PI	10602	5.0	n/a	n/a	-40	11	25
PP	12205	1.0	13	75	n/a	n/a	50
WB	10105	1.0	n/a	n/a	n/a	n/a	40
SW	11905	1.0	10	75	n/a	n/a	35
UJ	06602	5.0	n/a	n/a	-37	19	29
BS	09305	1.0	1	85	n/a	n/a	40
ES	09305	1.0	1	85	n/a	n/a	40
WS	09305	1.0	1	85	n/a	n/a	40
AS	74605	1.0	n/a	n/a	n/a	n/a	45
NC	74902	5.0	n/a	n/a	-26	-2	35
PW	74902	5.0	n/a	n/a	-26	-2	35
GO	81402	5.0	n/a	n/a	n/a	n/a	19
AW	81402	5.0	n/a	n/a	n/a	n/a	19
EM	81402	5.0	n/a	n/a	n/a	n/a	19
BK	81402	5.0	n/a	n/a	n/a	n/a	19
SO	81402	5.0	n/a	n/a	n/a	n/a	19
PB	74605	1.0	n/a	n/a	n/a	n/a	45
AJ	06602	5.0	n/a	n/a	-37	19	29
RM	06602	5.0	n/a	n/a	-37	19	29
OJ	06602	5.0	n/a	n/a	-37	19	29
ER	06602	5.0	n/a	n/a	-37	19	29
PM	10602	5.0	n/a	n/a	-40	11	25
PD	10602	5.0	n/a	n/a	-40	11	25
AZ	10602	5.0	n/a	n/a	-40	11	25
CI	12205	1.0	13	75	n/a	n/a	50
OS	12205	1.0	13	75	n/a	n/a	50
OH	74902	5.0	n/a	n/a	-26	-2	35

4.5 Crown Competition Factor

The CR variant uses crown competition factor (*CCF*) as a predictor variable in some growth relationships. Crown competition factor (Krajicek and others 1961) is a relative measurement of stand density that is based on tree diameters. Individual tree CCF_t values estimate the percentage of an acre that would be covered by the tree's crown if the tree were open-grown. Stand *CCF* is the summation of individual tree (CCF_t) values. A stand *CCF* value of 100 theoretically indicates that tree crowns will just touch in an unthinned, evenly spaced stand. Crown competition factor for an individual tree is calculated using equation {4.5.1}. For Douglas-fir and ponderosa pine greater than 1.0 inch DBH the coefficients were derived from Paine and Hann (1982). Chihuahuan pine uses the ponderosa pine coefficients. All others use the NI variant coefficients (Wykoff, et.al 1982). In the CR variant, each species uses a different "equation index" to determine the coefficients for the crown competition factor equations depending on which model type is being used. All coefficients by equation index are shown in table 4.5.1, and the corresponding species and model types are shown in table 4.5.2.

{4.5.1} CCF_t equations

$DBH \geq 10.0''$: $CCF_t = R_1 + (R_2 * DBH) + (R_3 * DBH^2)$

$0.1'' < DBH < 10.0''$: $CCF_t = R_4 * DBH^{R_5}$

$DBH \leq 0.1''$: $CCF_t = 0.001$

where:

CCF_t	is crown competition factor for an individual tree
DBH	is tree diameter at breast height
$R_1 - R_5$	are species-specific coefficients shown in table 4.5.1

Table 4.5.1 Default coefficients ($R_1 - R_5$) for Crown Competition Factor equations {4.5.1}, {4.5.2}, and {4.5.3} in the CR variant.

Equation Index	Model Coefficients				
	R_1	R_2	R_3	R_4	R_5
1	0.01925	0.01676	0.00365	0.009187	1.7600
2	0.11	0.0333	0.00259	0.017299	1.5571
3	0.04	0.0270	0.00405	0.015248	1.7333
4	0.03	0.0215	0.00363	0.011109	1.7250
5	0.03	0.0238	0.00490	0.008915	1.7800
6	0.03	0.0173	0.00259	0.007875	1.7360
7	0.03	0.0216	0.00405	0.011402	1.7560
8	0.03	0.0180	0.00281	0.007813	1.7680

Table 4.5.2 Corresponding equation index values by species and model type in the CR variant.

Species Code	Equation Index by model type				
	SM	SP	BP	SF	LP
AF	7	3	1	7	7

Species Code	Equation Index by model type				
	SM	SP	BP	SF	LP
CB	7	3	1	7	7
DF	2	2	2	2	2
GF	7	3	1	7	7
WF	3	3	1	7	7
MH	1	1	1	1	1
RC	1	1	1	1	1
WL	1	1	1	1	1
BC	1	1	1	1	1
LM	1	1	1	1	1
LP	1	1	1	1	1
PI	1	7	1	1	1
PP	8	8	8	1	8
WB	1	1	1	1	1
SW	1	1	1	1	1
UJ	1	1	1	1	1
BS	1	1	6	6	6
ES	6	1	6	6	6
WS	6	1	6	6	6
AS	5	5	5	5	5
NC	4	4	1	4	4
PW	4	4	1	4	4
GO	4	6	4	4	4
AW	4	6	4	4	4
EM	4	6	4	4	4
BK	4	6	4	4	4
SO	4	6	4	4	4
PB	5	5	5	5	5
AJ	1	1	1	1	1
RM	1	1	1	1	1
OJ	1	1	1	1	1
ER	1	1	1	1	1
PM	1	7	1	1	1
PD	1	7	1	1	1
AZ	1	7	1	1	1
CI	8	8	8	1	8
OS	1	1	1	1	1
OH	4	4	4	4	4

4.6 Small Tree Growth Relationships

Trees are considered “small trees” for FVS modeling purposes when they are smaller than some threshold diameter. The threshold diameter is set to 3.0” for grand fir, mountain hemlock, western redcedar, western larch, and whitebark pine; 2.0” for limber pine; and1.0” for subalpine fir, corkbark fir, Douglas-fir, white fir, lodgepole pine, ponderosa pine, Southwestern white pine, blue spruce, Engelmann spruce, white spruce, quaking aspen, narrowleaf cottonwood, plains cottonwood, paper birch, Chihuahuan pine, other softwood and other hardwood. Bristlecone pine, twoneedle pinyon, Utah juniper, Gambel oak, Arizona white oak, Emory oak, bur oak, silverleaf oak, alligator juniper, Rocky Mountain juniper, oneseed juniper, Eastern redcedar, singleleaf pinyon, border pinyon, and Arizona twoneedle pinyon only use the small-tree relationships to predict height and diameter growth for trees of all sizes.

The small tree model is height-growth driven, meaning height growth is estimated first and diameter growth is estimated from height growth. These relationships are discussed in the following sections.

4.6.1 Small Tree Height Growth

The small-tree height increment model predicts 10-year height growth (*HTG*) for small trees based on site index in the CR variant. Data was not available to fit small tree height growth models for species other than aspen. Paper birch uses the aspen equations. As a result, for all species except aspen and paper birch, the CR variant uses a blend of theoretical models and small tree height growth modifier equations from the Utah (UT) variant. Potential height growth is estimated as a function of site index and then is modified to account for density effects and tree vigor. Potential height growth is estimated using equation {4.6.1.1}.

{4.6.1.1} $POTHTG = SI / [c * (15.0 - (4.0 * RELSI))]$

where:

POTHTG	is potential height growth
RELSI	is the relative site index of the site species
SI	is species site index
c	is a species-specific constant shown, set to 1.1 for western redcedar and western larch and set to 1.0 for all other species

Potential height growth is then adjusted based on stand density (*PCTRED*) and crown ratio (*VIGOR*) as shown in equations {4.6.1.2} and {4.6.1.3} respectively, to determine an estimated height growth as shown in equation {4.6.1.5}. Bristlecone pine, twoneedle pinyon, Utah juniper, Gambel oak, Arizona white oak, Emory oak, bur oak, silverleaf oak, alligator juniper, Rocky Mountain juniper, oneseed juniper, eastern redcedar, singleleaf pinyon, border pinyon, and Arizona twoneedle pinyon use equation {4.6.1.4} to estimate *VIGOR*.

For all species, a small random error is added to the height growth estimate. The estimated height growth (*HTG*) is then adjusted to account for cycle length, user defined small-tree height growth adjustments, and adjustments due to small tree height model calibration from the input data.

Height growth for small quaking aspen and paper birch is obtained from a height-age curve from Shepperd (1995). Because Shepperd's original curve seemed to overestimate height growth, the CR variant reduces the estimated height growth by 25 percent (shown in equation {4.6.1.6}). A height is estimated from the tree's current age, and then its current age plus 10 years. Height growth is the difference between these two height estimates adjusted to account for cycle length and any user defined small-tree height growth adjustments for aspen, and converted from centimeters to feet. An estimate of the tree's current age is obtained at the start of a projection using the tree's height and solving equation {4.6.1.6} for age.

{4.6.1.2} $PCTRED = 1.1144 – 0.0115*Z + 0.4301E\text{-}04 * Z^2 – 0.7222E\text{-}07 * Z^3 + 0.5607E\text{-}10 * Z^4 – 0.1641E\text{-}13 * Z^5$

$Z = HT_{Avg} * (CCF / 100)$

{4.6.1.3} $VIGOR = (150 * CR^3 * \exp(-6 * CR)) + 0.3$

{4.6.1.4} $VIGOR = 1 – [(1 – (150 * CR^3 * \exp(-6 * CR)) + 0.3) / 3]$

{4.6.1.5} Used for all species other than quaking aspen and paper birch

$HTG = POTHTG * PCTRED * VIGOR$

{4.6.1.6} Used for quaking aspen and paper birch ; Source: Sheppherd (1995)

$HTG = (26.9825 * A^{1.1752}) * 0.75$

where:

PCTRED	is reduction in height growth due to stand density (bounded to $0.01 \leq PCTRED \leq 1$)
HT_{Avg}	is average height of the 40 largest diameter trees in the stand
CCF	is stand crown competition factor
VIGOR	is reduction in height growth due to tree vigor (bounded to $VIGOR \leq 1.0$)
CR	is a tree's live crown ratio (compacted) expressed as a proportion
HTG	is estimated height growth for the cycle
POTHTG	is potential height growth
A	is tree age

Height growth estimates from the small-tree model are weighted with the height growth estimates from the large tree model over a range of diameters (X_{min} and X_{max}) in order to smooth the transition between the two models. For example, the closer a tree's *DBH* value is to the minimum diameter (X_{min}), the more the growth estimate will be weighted towards the small-tree growth model. The closer a tree's *DBH* value is to the maximum diameter (X_{max}), the more the growth estimate will be weighted towards the large-tree growth model. If a tree's *DBH* value falls outside of the range given by X_{min} and X_{max}, then the model will use only the small-tree or large-tree growth model in the growth estimate. The weight applied to the growth estimate is calculated using equation {4.6.1.7}, and applied as shown in equation {4.6.1.8}. The range of diameters for each species is shown in table 4.6.1.2.

{4.6.1.7}

$DBH \leq X_{min}$: $XWT = 0$
$X_{min} < DBH < X_{max}$: $XWT = (DBH - X_{min}) / (X_{max} - X_{min})$
$DBH \geq X_{max}$: $XWT = 1$

{4.6.1.8} Estimated growth = $[(1 - XWT) * STGE] + [XWT * LTGE]$

where:

XWT	is the weight applied to the growth estimates
DBH	is tree diameter at breast height
X_{max}	is the maximum *DBH* is the diameter range
X_{min}	is the minimum *DBH* in the diameter range
STGE	is the growth estimate obtained using the small-tree growth model
LTGE	is the growth estimate obtained using the large-tree growth model

Table 4.6.1.2 Default diameter bounds by species in the CR variant.

Species Code	X_{min}	X_{max}
AF	0.5	2.0
CB	0.5	2.0
DF	0.5	2.0
GF	2.0	5.0
WF	0.5	2.0
MH	2.0	4.0
RC	2.0	5.0
WL	2.0	5.0
BC	99.0	199.0
LM	0.5	4.0
LP	0.5	2.0
PI	99.0	199.0
PP	0.5	2.0
WB	2.0	5.0
SW	0.5	2.0
UJ	99.0	199.0
BS	0.5	2.0
ES	0.5	2.0
WS	0.5	2.0
AS	0.5	2.0
NC	0.5	2.0
PW	0.5	2.0
GO	99.0	199.0
AW	99.0	199.0
EM	99.0	199.0
BK	99.0	199.0
SO	99.0	199.0

Species Code	X_{min}	X_{max}
PB	0.5	2.0
AJ	99.0	199.0
RM	99.0	199.0
OJ	99.0	199.0
ER	99.0	199.0
PM	99.0	199.0
PD	99.0	199.0
AZ	99.0	199.0
CI	0.5	2.0
OS	0.5	2.0
OH	0.5	2.0

*There is only one growth relationship that applies to trees of all sizes for these species. These relationships are contained in the "small" tree portion of FVS.

4.6.2 Small Tree Diameter Growth

As stated previously, for trees being projected with the small tree equations, height growth is predicted first, and then diameter growth. So both height at the beginning of the cycle and height at the end of the cycle are known when predicting diameter growth. Small tree diameter growth for trees over 4.5 feet tall is calculated as the difference of predicted diameter at the start of the projection period and the predicted diameter at the end of the projection period, adjusted for bark ratio. These two predicted diameters are estimated using the species-specific height-diameter relationships discussed in section 4.1. for all species except ponderosa pine, bristlecone pine, twoneedle pinyon, Utah juniper, Gambel oak, Arizona white oak, Emory oak, bur oak, silverleaf oak, alligator juniper, Rocky Mountain juniper, oneseed juniper, Eastern redcedar, singleleaf pinyon, border pinyon, Arizona twoneedle pinyon, and Chihuahuan pine. By definition, diameter growth is zero for trees less than 4.5 feet tall.

Ponderosa pine and Chihuahuan pine use equation {4.6.2.1} in the same manner as just described for the other species.

{4.6.2.1} $DBH = (HT - 4.17085) / 3.03659$

Bristlecone pine, twoneedle pinyon, Utah juniper, Gambel oak, Arizona white oak, Emory oak, bur oak, silverleaf oak, alligator juniper, Rocky Mountain juniper, oneseed juniper, Eastern redcedar, singleleaf pinyon, border pinyon, and Arizona twoneedle pinyon use equation {4.6.2.2} as previously described.

{4.6.2.2} $DBH = 10 * (HT - 4.5) / (SI - 4.5)$

where:

DBH	is tree diameter at breast height
HT	is tree height
SI	is species site index

4.7 Large Tree Growth Relationships

Trees are considered “large trees” for FVS modeling purposes when they are equal to or greater than some threshold diameter. The threshold diameter is set to 3.0” for grand fir, mountain hemlock, western redcedar, western larch, and whitebark pine; 2.0” for limber pine; and1.0” for subalpine fir, corkbark fir, Douglas-fir, white fir, lodgepole pine, ponderosa pine, Southwestern white pine, blue spruce, Engelmann spruce, white spruce, quaking aspen, narrowleaf cottonwood, plains cottonwood, paper birch, Chihuahuan pine, other softwood and other hardwood. Bristlecone pine, twoneedle pinyon, Utah juniper, Gambel oak, Arizona white oak, Emory oak, bur oak, silverleaf oak, alligator juniper, Rocky Mountain juniper, oneseed juniper, Eastern redcedar, singleleaf pinyon, border pinyon, and Arizona twoneedle pinyon only use the small-tree relationships to predict height and diameter growth for trees of all sizes.

The large-tree model is driven by diameter growth meaning diameter growth is estimated first and then height growth is estimated from diameter growth and other variables. These relationships are discussed in the following sections.

Most of the large tree diameter equations are from Edminster’s GENGYM growth and yield model. However, equations from other variants are used for certain species not represented very well in the data used to develop GENGYM, or in cases where the GENGYM equations did not perform satisfactorily. Species not represented well in the data, are generally found at the extreme northern range of the Central Rockies variant. These are a relatively minor component of the area covered by this variant. In GENGYM, a single equation was used to estimate the diameter growth for bristlecone pine, twoneedle pinyon, juniper species, and oak species. This equation did not perform satisfactorily for these species and is not used in this variant. However, this equation is used in both GENGYM and this variant for estimating diameter growth on trees classified as “other softwood”.

4.7.1 Large Tree Diameter Growth

The large tree diameter growth model used in most FVS variants is described in section 7.2.1 in Dixon (2002). For most variants, instead of predicting diameter increment directly, the natural log of the periodic change in squared inside-bark diameter (ln(*DDS*)) is predicted (Dixon 2002; Wykoff 1990; Stage 1973; and Cole and Stage 1972). For variants predicting diameter increment directly, diameter increment is converted to the *DDS* scale to keep the FVS system consistent across all variants.

Of the 38 species in this variant, 17 use the GENGYM diameter growth equations. Equations from GENGYM predict a tree’s future diameter based on stand and tree variables. The GENGYM equation form is shown in equation {4.7.1.1} and coefficients for this equation are shown in table 4.7.1.1. The species listed in table 4.7.1.1 are the 17 species that use the GENGYM diameter growth equations.

For bristlecone pine, twoneedle pinyon, Utah juniper, Gambel oak, Arizona white oak, Emory oak, bur oak, silverleaf oak, alligator juniper, Rocky Mountain juniper, oneseed juniper, Eastern redcedar, singleleaf pinyon, border pinyon, and Arizona twoneedle pinyon the equations described in the small-tree model section (section 4.6.2) are used for predicting diameter growth in trees of all sizes. Because small tree models are used for these species, diameter increment measurements will never be used to calibrate diameter growth.

{4.7.1.1} $DF = b_1 + (b_2 * DBH) + (b_3 * BA) + (b_4 * SI) + (b_5 * (\ln(DBH))^2) + (b_6 * BAU / BAT) + (b_7 * \ln(BAT)) + (b_8 * DBH^2)$

where:

DF	is tree diameter at breast height at the end of the cycle (bounded DF $\leq$ DBHMAX)
DBH	is tree diameter at breast height
DBHMAX	is the maximum tree diameter at breast height by species and model type (table 4.7.1.2)
BA	is total stand basal area
SI	is species site index
BAU	is total basal area in trees above the diameter class of the subject tree
BAT	is total stand basal area (subject to the following restrictions) Southwestern Mixed Conifers model type: If *BAT* is less than 65, then *BAU* is set to 0 *BAT* $\geq$ 1.0 Southwestern Ponderosa Pine model type: *BAT* $\geq$ 21 Black Hills Ponderosa Pine and Spruce-Fir model types: *BAT* $\geq$ 5 Lodgepole pine model type: *BAT* $\geq$ 14
$b_1 - b_8$	are species specific coefficients shown in table 4.7.1.1

Table 4.7.1.1 Default coefficients ($b_1 - b_8$) for the GENGYM equation {4.7.1.1} in the CR variant.

Species Code	Model Type	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8
AF	SM, SP	0.50283	0.93999	-0.00168	0.00791	0.16235	0	0	0
AF	BP, SF, LP	2.19459	0.94659	0	0.00615	0.11326	-0.20410	-0.35970	0
CB	SM, SP	0.50283	0.93999	-0.00168	0.00791	0.16235	0	0	0
CB	BP, SF, LP	2.19459	0.94659	0	0.00615	0.11326	-0.20410	-0.35970	0
DF	ALL	0.58234	0.94542	-0.00251	0.00705	0.15738	-0.14044	0	0
WF	ALL	0.46172	1.04089	-0.00200	0.00659	0	-0.09197	0	-0.00114
LP	ALL	1.32652	0.96279	0	0.00590	0.06298	-0.17138	-0.21827	0
PP	SM*	0.26265	0.94001	-0.00164	0.00601	0.16328	0	0	0
PP	SP	4.10552	0.88872	0	0.01378	0.23834	-0.52784	-0.83531	0
PP	BP*	2.50428	0.94573	0	0.01354	0.05940	-0.46350	-0.45765	0
PP	LP, SF	2.50428	0.94573	0	0.01354	0.05940	-0.46350	-0.45765	0
SW	ALL	0.89451	0.95435	-0.00122	0.00159	0.09987	-0.20815	0	0
BS	ALL	0.50941	1.02697	-0.00358	0.01022	0	0	0	-0.00099
ES	SM, SP	0.67074	1.03068	-0.00201	0.00633	0	0	0	-0.00109
ES	BP, SF, LP	2.28652	0.94475	0	0.01295	0.10778	-0.48056	-0.41632	0
WS	ALL	2.94734	0.88423	0	0.01207	0.25363	0	-0.64449	0

Species Code	Model Type	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8
AS	SM, SP	0.24506	1.01291	-0.00085	0.00631	0	0	0	0
AS	BP, SF, LP	1.55986	1.01825	0	0.00672	0	-0.00073	-0.29342	0
NC	SM, SP	0.24506	1.01291	-0.00085	0.00631	0	0	0	0
NC	BP, SF, LP	1.55986	1.01825	0	0.00672	0	-0.00073	-0.29342	0
PW	SM, SP	0.24506	1.01291	-0.00085	0.00631	0	0	0	0
PW	BP, SF, LP	1.55986	1.01825	0	0.00672	0	-0.00073	-0.29342	0
PB	SM, SP	0.24506	1.01291	-0.00085	0.00631	0	0	0	0
PB	BP, SF, LP	1.55986	1.01825	0	0.00672	0	-0.00073	-0.29342	0
CI	SM*	0.26265	0.94001	-0.00164	0.00601	0.16328	0	0	0
CI	SP	4.10552	0.88872	0	0.01378	0.23834	-0.52784	-0.83531	0
CI	BP*	2.50428	0.94573	0	0.01354	0.05940	-0.46350	-0.45765	0
CI	LP, SF	2.50428	0.94573	0	0.01354	0.05940	-0.46350	-0.45765	0
OS	ALL	0.25897	1.03129	-0.00020	0.00177	0	0	0	0
OH	SM, SP	0.24506	1.01291	-0.00085	0.00631	0	0	0	0
OH	BP, SF, LP	1.55986	1.01825	0	0.00672	0	-0.00073	-0.29342	0

*See discussion below

Table 4.7.1.2 Maximum tree diameters in inches (DBHMAX) for the GENGYM equation {4.7.1.1} in the CR variant.

Species Code	Model Type				
	SM	SP	BP	SF	LP
AF	36.0	36.0	20.0	28.0	28.0
CB	36.0	36.0	20.0	28.0	28.0
DF	50.0	50.0	20.0	42.0	42.0
WF	40.0	40.0	20.0	30.0	30.0
LP	20.0	20.0	24.0	36.0	36.0
PP	50.0	50.0	32.0	32.0	32.0
SW	36.0	36.0	20.0	36.0	36.0
BS	40.0	40.0	24.0	36.0	36.0
ES	46.0	46.0	24.0	46.0	46.0
WS	20.0	20.0	30.0	36.0	36.0
AS	30.0	30.0	24.0	30.0	30.0
NC	36.0	36.0	48.0	24.0	24.0
PW	36.0	36.0	48.0	24.0	24.0
PB	30.0	30.0	24.0	30.0	30.0
CI	50.0	50.0	32.0	32.0	32.0
OS	20.0	20.0	20.0	20.0	20.0
OH	20.0	20.0	20.0	20.0	20.0

For quaking aspen, narrowleaf cottonwood, plains cottonwood, paper birch, and other hardwood, the estimate of DF from equation 4.7.1.1 is multiplied by 1.05 to better represent observed growth rates.

In the Southwestern Mixed Conifer (SM) model type, the estimated future diameter for ponderosa pine and Chihuahuan pine is a blend of the estimate using the equation shown for the SM model type and an estimate from the equation shown for the Southwestern Ponderosa Pine (SP) model type. This relationship is shown in equation {4.7.1.2}.

{4.7.1.2} $DF = ((1.0 - FACTOR) * SMDF) + (FACTOR * SPDF)$

where:

DF	is tree diameter at breast height at the end of the cycle (blended)
SMDF	is estimated future diameter using the SM model type equation
SPDF	is estimated future diameter using the SP model type equation
FACTOR	is an adjustment factor that is the maximum of *ADJB* and *ADJR*:

$$
\begin{aligned}
ADJB &= 0.0 && BA \geq 100 \\
&= 2.5 - 0.025 * BA && 60 < BA < 100 \\
&= 1.0 && BA \leq 60
\end{aligned}
$$

where: *BA* is the total stand basal area

$$
\begin{aligned}
ADJR &= 0.0 && PP_{ratio} \leq 0.3 \\
&= -1.5 + (5.0 * PP_{ratio}) && 0.3 < PP_{ratio} < 0.5 \\
&= 1.0 && 0.5 \leq PP_{ratio}
\end{aligned}
$$

PP_{ratio} is ponderosa pine basal area divided by the stand basal area
where: *BA* is stand basal area

Similarly, in the Black Hills Ponderosa pine (BP) model type the estimated future diameter for ponderosa pine and Chihuahuan pine is a blend if certain conditions are met and a direct estimate otherwise. Those conditions are:

1. Whether the stand is considered uneven-aged. A stand is considered uneven-aged if the range in age between the 5th percentile tree and the 95th percentile tree exceeds 40 years.
2. Whether the tree exists in an overtopped condition. A tree is considered overtopped if at least 30 percent of the stand basal area is in diameter classes larger than this trees' diameter class (1 inch classes).
3. Whether the estimated future diameter using the BP equation is greater than the estimated future diameter using the SP equation.

If all three of these conditions are met, the estimated future diameter is a blend of the estimate using equation {4.7.1.3} for the Black Hills Ponderosa Pine (BP) model type and an estimate from the equation shown for the Southwestern Ponderosa Pine (SP) model type.

{4.7.1.3}

$BA_{ratio} \geq 0.5$: $DF = SPDF$
$0.3 < BA_{ratio} < 0.5$: $DF = ((2.5 - 5.0 * BA_{ratio}) * BHDF) + ((-1.5 + 5.0 * BA_{ratio}) * SPDF)$
$BA_{ratio} = (BAU / BA)$

where:

DF	is tree diameter at breast height at the end of the cycle (blended)
SPDF	is estimated future diameter using the SP model type equation

BHDF	is estimated future diameter using the BH model type equation
BAU	is total basal area in trees above the diameter class of the subject tree
BA	is total stand basal area

Since the FVS large tree model logic is based on the natural logarithm of change in diameter squared (*DDS*), estimated future diameter is converted to this basis by first calculating diameter growth (inside bark) using equation {4.7.1.4}, adjusting this value to account for a stagnation effect using equation {4.7.1.5}, and then converting the result to a DDS basis using equation {4.7.1.6}. By default, the stagnation multiplier is turned off.

{4.7.1.4} $DIAGR = (DF - DBH) * BRATIO$

{4.7.1.5} Stagnation effect

for species other than Black Hills ponderosa pine: $DIAGR = DIAGR * STAG$
for ponderosa pine and Chihuahuan pine in the Black Hills model type: $DIAGR = DIAGR * STAG * 0.8$

{4.7.1.6} $\ln(DDS) = \ln[(DIAGR * \{(2.0 * DBH * BRATIO) + DIAGR\})]$

where:

DIAGR	is diameter growth (inside bark) of the cycle
DDS	is the squared inside bark diameter
DBH	is tree diameter at breast height
DF	is tree diameter at breast height at the end of the cycle (blended)
BRATIO	is species-specific bark ratio
STAG	is a stagnation multiplier based on the following equation: STAG = 3.33333*(1-RELSDI) for 0.7 < RELSDI $\leq$ 0.85 STAG = 1.0 for RELSDI $\leq$ 0.70 STAG = 0.5 for RELSDI > 0.85

Grand fir, mountain hemlock, western redcedar, western larch, limber pine, and whitebark pine use diameter growth equations from other variants, which predict the value of *DDS* directly. The grand fir equation is from the Central Idaho (CI) variant. Equations for mountain hemlock, western redcedar, and western larch are from the North Idaho (NI) variant for elevation set at 6000 feet and habitat types set to 710 (TSME/XETE), 550 (THPL/OPHO), and 260 (PSME/PHMA) respectively. The limber pine equation is from the Utah (UT) variant. The whitebark pine equation is from the Eastern Montana (EM) variant for elevation set at 8000 feet and habitat type set to 850 (PIAL-ABLA). The equation form for all these species is shown in equation {4.7.1.7} with species-specific coefficients shown in table {4.7.1.3}

{4.7.1.7} $\ln(DDS) = b_1 + (b_2 * \sin(ASP) * SL) + (b_3 * \cos(ASP) * SL) + (b_4 * SL) + (b_5 * SL^2) + (b_6 * \ln(DBH)) + (b_7 * DBH^2) + (b_8 * BAL) + (b_9 * CR) + (b_{10} * CR^2) + (b_{11} * \ln(BA)) + (b_{12} * PCCF) + (b_{13} * BAL / (\ln(DBH + 1.0))) + (b_{14} * PBAL / (\ln(DBH + 1.0))) + (b_{15} * \ln(CCF)) + (b_{16} * CCF) + (b_{17} * SI)$

where:

DDS	is the squared inside bark diameter

ASP	is stand aspect (use (ASP – 0.7854) instead of ASP for limber pine)
SL	is stand slope
DBH	is tree diameter at breast height
BAL	is total basal area in trees larger than the subject tree
CR	is crown ratio expressed as a proportion
BA	is total stand basal area
PCCF	is crown competition factor on the inventory point where the tree is established
PBAL	is point basal area in trees larger than the subject tree
b_1- b_{17}	are species-specific coefficients shown in table 4.7.1.3

Table 4.7.1.3 Default coefficients (b_1- b_{17}) for equation 4.7.1.7 in the CR variant.

Coefficient	Species Code					
	GF	MH	RC	WL	LM	WB
b_1	0.88728	0.19489	1.26832	1.39215	1.911884	1.13095
b_2	0.009335	0.13363	0.05534	0.03430	-0.01752	-0.00161
b_3	-0.004469	0.17935	-0.06625	-0.21337	-0.609774	0.00027
b_4	-0.033374	0.07628	0.11931	0.33523	-2.05706	-0.02001
b_5	-0.418343	0	0	-0.70216	2.113263	0
b_6	1.286963	0.89778	0.58705	0.54140	0.213947	0.80110
b_7	-0.0004408	-0.000484	0	-0.000310	-0.0006538	0
b_8	0	0	0.0074596	0.0043637	-0.00358634	0.00064
b_9	1.175105	1.28403	1.29360	1.03478	1.523464	1.02878
b_{10}	0.219013	0	0	0.07509	0	-0.45448
b_{11}	-0.217923	0	0	0	0	0
b_{12}	-0.000512	0	0	0	0	0
b_{13}	0	-0.006611	-0.0228375	-0.0203256	0	-0.00328
b_{14}	-0.000578	0	0	0	0	0
b_{15}	0	0	0	0	0	-0.25717
b_{16}	0	-0.0010744	-0.0015356	-0.0005438	-0.00199592	0
b_{17}	0	0	0	0	0.001766	0

Once *DDS* is estimated using equation {4.7.1.7}, it must be transformed into a real scale diameter growth using equation {4.7.1.8}, adjusted for the stagnation effect {4.7.1.9}, and then converted back to *DDS* scale using equation {4.7.1.6} for further processing.

{4.7.1.8} *DIAGR* = sqrt(exp(*DDS)* + (*DBH* * *BRATIO*)^2) – *DBH* * *BRATIO*

{4.7.1.9} *DIAGR = DIAGR * STAG*

where:

DIAGR	is diameter growth (inside bark) of the cycle
DBH	is tree diameter at breast height
BRATIO	is species-specific bark ratio
STAG	is a stagnation multiplier

4.7.2 Large Tree Height Growth

Height growth equations for large trees in the CR variant are different by species. Equations for 18 of the species come from the GENGYM model, equations for 5 species come from other variants, and 15 species use the equations described in the small tree model section.

4.7.2.1 Height Growth estimate for species using GENGYM equations

Large tree height growth for subalpine fir, corkbark fir, Douglas-fir, white fir, lodgepole pine, ponderosa pine, whitebark pine, southwestern white pine, blue spruce, Engelmann spruce, white spruce, quaking aspen, narrowleaf cottonwood, plains cottonwood, paper birch, Chihuahuan pine, other softwood, and other hardwood is estimated using equations from the Central Rockies variant. The equations predict height growth from site index curves for even-aged stands and height growth from a regression equation for uneven-aged stands. These estimates get blended when certain conditions are met, and in some instances a growth reduction due to stand stagnation may be applied. A stand is considered uneven-aged if the range in ages between the 5th percentile and 95th percentile trees in the basal area distribution exceeds 40 years.

Four tree heights are estimated: height at the beginning of the projection cycle and 10-years into the future using the equations for even-aged stands, and height at the beginning of the projection cycle and 10-years into the future using the equations for uneven-aged stands. Two 10-year height growth estimates are obtained. An even-aged height growth estimate is obtained from the difference between the two estimated heights using equations for even-aged stands, and an uneven-aged height growth estimate is obtained from the difference between the two estimated heights using equations for uneven-aged stands.

The final height growth estimate for a tree depends on whether the stand is even-aged or uneven-aged, total stand basal area, the tree's position in the stand, and whether the stand is considered as stagnated. Equation {4.7.2.1.1} is used when the stand is even-aged, or the total stand basal area is less than 70 square feet, or when the stand is uneven-aged with total stand basal area at least 70 square feet and the tree's percentile in the basal area distribution is at least 40. Equation {4.7.2.1.2} is used when the stand is uneven-aged with stand basal area at least 70 square feet and the tree's percentile in the basal area distribution is less than 40. Equation {4.7.2.1.3} is used when the stand is uneven-aged with stand basal area at least 70 square feet and the tree's percentile in the basal area distribution is at least 10 but no larger than 40. For quaking aspen and paper birch, the height growth estimate is further adjusted for site index using equation {4.7.2.1.4}. For all species, a small random increment is added and the height growth estimate is adjusted for stagnation effects using equation {4.7.2.1.5}.

{4.7.2.1.1} $HTG = (HHE2 - HHE1) * ADJUST$

{4.7.2.1.2} $HTG = HHU2 - HHU1$

{4.7.2.1.3} $HTG = XWT * ((HHE2 - HHE1) * ADJUST) + (1 - XWT) * (HHU2 - HHU1)$

{4.7.2.1.4} $HTG = [HTG * ASPFAC]$

$ASPFAC = 0.6253 + 0.00583 * \mathrm{SI}$

{4.7.2.1.5} $HTG = [HTG + (ZZRAN * 0.1)] * [(DSTAG + 1) * 0.5]$

where:

HTG	is estimated 10-year height growth
HHE1	is estimated tree height at the beginning of the cycle using the even-aged equations
HHE2	is estimated tree height 10-years in the future using the even-aged equations
HHU1	is estimated tree height at the beginning of the cycle using the uneven-aged equations
HHU2	is estimated tree height 10-years in the future using the uneven-aged equations
ADJUST	is a multiplier so open-grown trees will reach the site height at the index age (table 4.7.2.1.1)
ZZRAN	is a random number in the range $-2 \leq ZZRAN \leq 2$ (i.e. the limits for *ZZRAN* are the number of standard deviations specified using the DGSTDEV keyword, default 2)
DSTAG	is an adjustment for stagnated stand conditions (turned on using the SDIMAX keyword, default 1.0)
XWT	is a weight used to blend even-aged and uneven-aged height growth estimates ($XWT = ((PCT - 10) * (10 / 3)) / 100$
PCT	is the tree's percentile in the basal area distribution

Table 4.7.2.1.1 Height growth adjustment factors for equations {4.7.2.1.1}, {4.7.2.1.3} and {4.7.2.2.2} in the CR variant.

Species Code	***MOD* values by model type**				
	SM	**SP**	**BP**	**SF**	**LP**
AF	1.25	1.25	1.13	1.15	1.25
CB	1.25	1.25	1.13	1.15	1.25
DF	1.18	1.18	1.10	1.18	1.25
GF	1.00	1.00	1.10	1.00	1.10
WF	1.20	1.20	1.13	1.15	1.25
MH	1.00	1.00	1.10	1.00	1.10
RC	1.00	1.00	1.10	1.00	1.10
WL	1.00	1.00	1.10	1.00	1.10
BC	-	-	-	-	-
LM	1.00	1.00	1.07	1.00	1.07
LP	1.20	1.15	1.13	1.10	1.30
PI	-	-	-	-	-
PP	1.20	1.20	1.10	1.15	1.25
WB	1.20	1.15	1.10	1.05	1.20
SW	1.20	1.20	1.10	1.15	1.20
UJ	-	-	-	-	-
BS	1.20	1.20	1.15	1.10	1.20
ES	1.20	1.20	1.15	1.10	1.20
WS	1.20	1.20	1.15	1.10	1.20
AS	1.00	1.00	1.00	1.00	1.00
NC	1.15	1.15	1.05	1.05	1.18

Species Code	*MOD* values by model type				
	SM	**SP**	**BP**	**SF**	**LP**
PW	1.15	1.15	1.05	1.05	1.18
GO	-	-	-	-	-
AW	-	-	-	-	-
EM	-	-	-	-	-
BK	-	-	-	-	-
SO	-	-	-	-	-
PB	1.00	1.00	1.00	1.00	1.00
AJ	-	-	-	-	-
RM	-	-	-	-	-
OJ	-	-	-	-	-
ER	-	-	-	-	-
PM	-	-	-	-	-
PD	-	-	-	-	-
AZ	-	-	-	-	-
CI	1.20	1.20	1.10	1.15	1.25
OS	1.15	1.15	1.05	1.05	1.15
OH	1.15	1.15	1.15	1.05	1.20

4.7.2.1.1 Southwestern Mixed Conifers Model Type

For the Southwestern Mixed Conifers Model Type, the even-aged height growth estimation sequence is a four-step process: (1) an age is determined; (2) heights from the guide curve and the lower 95 percent confidence interval are estimated; (3) these estimates are combined; (4) a reduction is made for a tree's position in the canopy. A detailed description of formula derivation is contained in Edminster, Mathiasen, and Olsen (1991).

The first step is determining an age (*AGETEM*) to use in the calculation. *AGETEM* is set to the tree's estimated age, or 210 years, whichever is less. If the site index is less than 80 and the value of (110 – Site Index) is greater than the value of *AGETEM* as just determined, then *AGETEM* is set to the value (110 – Site Index). The second step is determining total tree height on the appropriate guide curve (*HG*) using equation {4.7.2.1.1.1}. The estimated height of the lower bound of the 95 percent confidence interval (*HL*) is determined using equation {4.7.2.1.1.2}. The third step combines the estimates into a final height estimate using equation {4.7.2.1.1.3}.

{4.7.2.1.1.1} $HG = 4.5 + 109.559129 * (1.0 – 0.975884 * \exp(-0.014377 * AGETEM))^{1.289266}$

{4.7.2.1.1.2} $HL = 72.512644 * (1.0 – 0.876961 * \exp(-0.020066 * AGETEM))^{2.016632}$

{4.7.2.1.1.3} $HTE = -1.0 * [(HG - HL) * ((82.488 – SI) / 26.279)] + HG$

where:

HG	is total tree height on the appropriate guide curve
HL	is the estimated height on the lower bound of the 95% confidence interval
AGETEM	is the tree's estimated age, bounded at $AGETEM \leq 210$

HTE	is the even-aged height estimate
SI	is species site index

If site index is 80, or greater, and the tree's age is less than *AGETEM* as determined above, the height estimate is further modified using equation {4.7.2.1.1.4}. If site index is greater than or equal to 80 and *AGETEM* is less than 20, then the height estimate using equations {4.7.2.1.1.3} and {4.7.2.1.1.4}, is replaced by a height estimate using equation {4.7.2.1.1.5}. The fourth and final step is multiplying the estimated height by an adjustment factor using equation {4.7.2.1.1.6} to account for a tree's position in the canopy.

{4.7.2.1.1.4} $HTE = 4.5 + [(HTE - 4.5) / AGETEM] * A$

{4.7.2.1.1.5} $HTE = 4.5 + [(0.02348 * SI) - 0.93429] * AGETEM$

{4.7.2.1.1.6} $HTE = HT * FACTOR$

$FACTOR = (1 - (BAL / BA)), 0.768 \leq FACTOR \leq 1$

where:

HTE	is the even-aged height estimate
AGETEM	is the tree's estimated age, bounded at $AGETEM \leq 210$
A	is estimated tree age
BAL	is total basal area in trees in 1-inch diameter classes larger than the diameter class of the subject tree
BA	is total stand basal area
FACTOR	is a reduction factor based on canopy position
SI	is species site index

4.7.2.1.2 Southwestern Ponderosa Pine Model Type

The even-aged height growth estimation sequence is similar to that for the SM model type. First, an age is determined to use in the calculation. Second, heights from the guide curve and the lower 95 percent confidence interval are estimated. Third, these estimates are combined. Finally, a reduction is made for a trees position in the canopy. A detailed description of formula derivation is contained in Minor (1964).

The first step is determining an age (*AGETEM*) to use in the calculation. *AGETEM* is set to the tree's estimated age, or 210 years, whichever is less. If the site index is less than 80 and the value of (120 – Site Index) is greater than the value of *AGETEM* as just determined, then *AGETEM* is set to the value (120 – Site Index). The second step is determining total tree height on the appropriate guide curve (*HG*) using equation {4.7.2.1.2.1}. The estimated height of the lower bound of the 95 percent confidence interval (*HL*) is determined using equation {4.7.2.1.2.2}. The third step combines the estimates into a final height estimate using equation {4.7.2.1.2.3}.

{4.7.2.1.2.1} $HG = 4.5 + 106.493954 * (1.0 - 0.938775 * \exp(-0.016066 * AGETEM))^{1.550720}$

{4.7.2.1.2.2} $HL = 78.078735 * (1.0 - 0.843715 * \exp(-0.020412 * AGETEM))^{2.280435}$

{4.7.2.1.2.3} $HTE = -1.0 * [(HG - HL) * ((81.5585 - SI) / 21.7149)] + HG$

where:

HG	is total tree height on the appropriate guide curve
HL	is the estimated height on the lower bound of the 95% confidence interval
AGETEM	is the tree's estimated age, bounded at $AGETEM \leq 210$
HTE	is the even-aged height estimate
SI	is species site index

If site index is 80, or greater, and the tree's age is less than *AGETEM* as determined above, *HTE* is further modified using equation {4.7.2.1.2.4}. If site index is greater than or equal to 80 and *AGETEM* is less than 20, then the estimate of *HTE*, using equations {4.7.2.1.2.3} and {4.7.2.1.2.4}, is replaced by an estimate of *HTE* using equation {4.7.2.1.2.5}. The fourth and final step is multiplying the estimated *HTE* by an adjustment factor using equation {4.7.2.1.2.6} to account for a tree's position in the canopy.

{4.7.2.1.2.4} $HTE = 4.5 + [(HTE - 4.5) / AGETEM] * A$

{4.7.2.1.2.5} $HTE = 4.5 + [(0.02463 * SI) - 1.1025] * AGETEM$

{4.7.2.1.2.6} $HTE = HTE * FACTOR$

$$FACTOR = (1 - (BAL / BA)),\ 0.768 \leq FACTOR \leq 1$$

where:

HTE	is the even-aged height estimate
AGETEM	is the tree's estimated age, bounded at $AGETEM \leq 210$
A	is estimated tree age
BAL	is total basal area in trees in 1-inch diameter classes larger than the diameter class of the subject tree
BA	is total stand basal area
FACTOR	is a reduction factor based on canopy position
SI	is species site index

4.7.2.1.3 Black Hills Ponderosa Pine Model Type

Even-aged height growth is estimated using Meyer's (1961) ponderosa pine site curves. If the tree's height is above the height at which the site curve flattens off (equation {4.7.2.1.3.1}), or the tree is over 165 years old, 10-year height growth is set to 0.1 foot. Otherwise, an estimated tree height at the beginning of the projection cycle is calculated using equation {4.7.2.1.3.2} using the estimated tree age at the beginning of the projection cycle and species site index. Estimated tree height 10 years in the future is estimated using equation {4.7.2.1.3.2} and the estimated tree age at the beginning of the projection cycle plus 10 years and species site index. Potential height growth is estimated by subtracting the estimated current height from the estimated height 10 years in the future as shown in equation {4.7.2.1.3.3}. Finally, the estimated height growth is multiplied by an adjustment factor in equation {4.7.2.1.3.4} to account for a tree's position in the canopy.

{4.7.2.1.3.1} If tree height is greater than *HG*, then $HTG = 0.1$

$$HG = (SI + 0.3846) * 1.2999886$$

{4.7.2.1.3.2} $HTE = (SI + 0.3846) * (-0.5234 + (1.8234 * \exp-(1.0989 - 0.006105 * A)^{2.35}))$

{4.7.2.1.3.3} $PHTG = H10 - HTS$

{4.7.2.1.3.4} $HTG = PHTG * FACTOR$

$FACTOR = (1 - (BAL / BA)), 0.793 \leq FACTOR \leq 1$

where:

HG	is total tree height on the appropriate guide curve
A	is tree age
HTE	is estimated height of the tree
HTS	is estimated height of the tree at the start of the projection cycle
H10	is estimated height of the tree in ten years
PHTG	is estimated potential 10-year height growth
HTG	is estimated 10-year height growth
SI	is species site index
FACTOR	is a reduction factor based on canopy position
BAL	is total basal area in trees in 1-inch diameter classes larger than the diameter class of the subject tree
BA	is total stand basal area

Since the estimate in the Black Hills model type is actually a height growth estimate, rather than a height estimate, values needed to combine the even-aged and uneven-aged estimates shown above are assigned as shown in equations {4.7.2.1.3.5} and {4.7.2.1.3.6}.

{4.7.2.1.3.5} $HHE1 = HT$

{4.7.2.1.3.6} $HHE2 = HT + HTG$

where:

HHE1	is estimated tree height at the beginning of the projection cycle using the even-aged equations (in this case set to the tree height at the beginning of the projection cycle)
HHE2	is estimated tree height 10-years in the future using the even-aged equations
HT	is height of the tree at the beginning of the projection cycle
HTG	is estimated 10-year height growth

4.7.2.1.4 Spruce-Fir Model Type

Even-aged height is estimated using Alexander's (1967) site curves for Engelmann spruce and sub-alpine fir. Height is estimated using equation {4.7.2.1.4.1}. If the tree age is less than 30 years, then the height estimate is modified using equation {4.7.2.1.4.2}. Finally, the estimated height is multiplied by an adjustment factor in equation {4.7.2.1.4.3} to account for a tree's position in the canopy.

{4.7.2.1.4.1} $HTE = 4.5 + (2.75780 * SI^{0.83312}) * [1 - \exp((-0.015701 * A))]^{(22.71944 * SI^{-0.63557})}$

{4.7.2.1.4.2} $HTE = 4.5 + [(HTE - 4.5) / AGETEM] * A$

{4.7.2.1.4.3} $HTE = HTE * FACTOR$

$FACTOR = (1 – (BAL / BA)), 0.728 \leq FACTOR \leq 1$

where:

HTE	is the even-aged height estimate
A	is estimated tree age
SI	is species site index
AGETEM	is the tree's estimated age, bounded at $AGETEM \geq 30$
BAL	is total basal area in trees in 1-inch diameter classes larger than the diameter class of the subject tree
BA	is total stand basal area
FACTOR	is a reduction factor based on canopy position

4.7.2.1.5 Lodgepole Pine Model Type

Even-aged height is estimated using Alexander, Tackle, and Dahms (1967) lodgepole pine site index curves. Height is estimated using equation {4.7.2.1.5.1} with AGETEM being the tree age constrained to the interval (30 – 200 years). If the tree age is less than 30 years, the height estimate is further modified using equation {4.7.2.1.5.2}. Finally, the estimated height is multiplied by an adjustment factor in equation {4.7.2.1.5.3} to account for a tree's position in the canopy.

{4.7.2.1.5.1} $HTE = 9.89331 + (-0.19177 * AGETEM) + (0.00124 * AGETEM^2) + (-0.00082 * CTEM * SI) + (0.01387 * AGETEM * SI) + (-0.0000455 * AGETEM^2 * SI)$

$CTEM = CCF – 125$ bounded $CTEM \geq 0$

{4.7.2.1.5.2} $HTE = (HTE / AGETEM) * A$

{4.7.2.1.5.3} $HTE = HTE * FACTOR$

$FACTOR = (1 – (BAL / BA)), 0.742 \leq FACTOR \leq 1$

where:

HTE	is the even-aged height estimate
A	is estimated tree age
SI	is species site index
AGETEM	is the tree's estimated age, bounded at $30 \leq AGETEM \leq 200$
CCF	is stand crown competition factor
CTEM	is stand crown competition factor minus 125 and bounded $CTEM \geq 0$
BAL	is total basal area in trees in 1-inch diameter classes larger than the diameter class of the subject tree
BA	is total stand basal area
FACTOR	is a reduction factor based on canopy position

4.7.2.1.6 Height Growth estimate for Uneven-Aged Stands

Equations from GENGYM predict a tree's future height based on stand and tree variables. For subalpine fir, corkbark fir, Engelmann spruce, quaking aspen, narrowleaf cottonwood, plains cottonwood, paper birch, and other hardwood, equation {4.7.2.1.6.1} is used for model types 1 and 2, and equation {4.7.2.1.6.2} is used for model types 3, 4, and 5. For Douglas-fir, white fir, ponderosa pine, southwestern white pine, blue spruce, white spruce, and Chihuahuan pine, equation {4.7.2.1.6.1} is used for all model types. For lodgepole pine and whitebark pine, equation {4.7.2.1.6.2} is used for all model types. For other softwood, equation {4.7.2.1.6.3} is used for all model types.

{4.7.2.1.6.1} $HTU = 4.5 + a_1 * SI\hat{\ }a_2 * [(1 – \exp(a_3 * DBH)) \hat{\ } (a_4 * BAT)\hat{\ }a_5]$

{4.7.2.1.6.2} $HTU = 4.5 + (a_1 + a_2 * SI) * [(1 – \exp(a_3 * DBH)) \hat{\ } (a_4 * BAT)\hat{\ }a_5]$

{4.7.2.1.6.3} $HTU = 4.5 + a_1 * [(1 – \exp(a_3 * DBH)) \hat{\ } a_4]$

where:

HTU is the uneven-aged height estimate
SI is species site index
DBH is tree diameter at breast height
BAT is total stand basal area (subject to restrictions)
BAT is subject to the following restrictions:
Southwestern Mixed Conifers model type:
If *BAT* is less than 80, then *BAL* is set to 0
$BAT \geq 0.8$
Southwestern Ponderosa Pine model type:
$BAT \geq 21$
Black Hills Ponderosa Pine and Spruce-Fir model types:
$BAT \geq 5$
Lodgepole pine model type:
$BAT \geq 14$
$a_1 – a_5$ are species-specific coefficients shown in table 4.7.2.1.6.1

Table 4.7.2.1.6.1 Default coefficients ($a_1 – a_5$), by species, used in the uneven-aged height estimate equations {4.7.2.1.6.1}, {4.7.2.1.6.2}, and {4.7.2.1.6.3} in the CR variant.

Species Code	Model Type	Equation Number	a_1	a_2	a_3	a_4	a_5
AF	SM, SP	4.7.2.1.6.1	4.514294	0.755380	-0.080869	1.409884	0.003919
AF	BP, SF, LP	4.7.2.1.6.2	15.5	1.1	-0.097152	4.698567	-0.252630
CB	SM, SP	4.7.2.1.6.1	4.514294	0.755380	-0.080869	1.409884	0.003919
CB	BP, SF, LP	4.7.2.1.6.2	15.5	1.1	-0.097152	4.698567	-0.252630
DF	ALL	4.7.2.1.6.1	13.096420	0.480509	-0.077408	1.237589	-0.063297
GF	*		0	0	0	0	0
WF	ALL	4.7.2.1.6.1	13.822088	0.462393	-0.075766	1.312638	-0.040708
MH	*		0	0	0	0	0
RC	*		0	0	0	0	0
WL	*		0	0	0	0	0
BC	**		-	-	-	-	-

Species Code	Model Type	Equation Number	a_1	a_2	a_3	a_4	a_5
LM	*		0	0	0	0	0
LP	ALL	4.7.2.1.6.2	8.5	1.1	-0.085004	1.709643	-0.163186
PI	**		-	-	-	-	-
PP	SM	4.7.2.1.6.1	24.244690	0.343864	-0.069180	1.251384	-0.272018
PP	SP	4.7.2.1.6.1	40.78321	0.332614	-0.021471	0.922811	-0.133923
PP	BP, SF, LP	4.7.2.1.6.1	32.108633	0.276926	-0.057766	0.984340	-0.169876
WB	ALL	4.7.2.1.6.2	8.5	1.1	-0.085004	1.709643	-0.163186
SW	ALL	4.7.2.1.6.1	18.967185	0.379790	-0.071482	1.159608	-0.099449
UJ	**		-	-	-	-	-
BS	ALL	4.7.2.1.6.1	54.180173	0.177962	-0.089253	1.533535	-0.028852
ES	SM, SP	4.7.2.1.6.1	10.616238	0.549461	-0.087283	1.488355	-0.027226
ES	BP, SF, LP	4.7.2.1.6.2	15.5	1.1	-0.110383	6.262899	-0.286055
WS	ALL	4.7.2.1.6.1	54.18017	0.177962	-0.089253	1.533535	-0.028852
AS	SM, SP	4.7.2.1.6.1	14.187987	0.416525	-0.126806	1.310744	-0.245126
AS	BP, SF, LP	4.7.2.1.6.2	-2.04	1.4534	-0.058112	1.894400	-0.192979
NC	SM, SP	4.7.2.1.6.1	14.187987	0.416525	-0.126806	1.310744	-0.245126
NC	BP, SF, LP	4.7.2.1.6.2	-2.04	1.4534	-0.058112	1.894400	-0.192979
PW	SM, SP	4.7.2.1.6.1	14.187987	0.416525	-0.126806	1.310744	-0.245126
PW	BP, SF, LP	4.7.2.1.6.2	-2.04	1.4534	-0.058112	1.894400	-0.192979
GO	**		-	-	-	-	-
AW	**		-	-	-	-	-
EM	**		-	-	-	-	-
BK	**		-	-	-	-	-
SO	**		-	-	-	-	-
PB	SM, SP	4.7.2.1.6.1	14.187987	0.416525	-0.126806	1.310744	-0.245126
PB	BP, SF, LP	4.7.2.1.6.2	-2.04	1.4534	-0.058112	1.894400	-0.192979
AJ	**		-	-	-	-	-
RM	**		-	-	-	-	-
OJ	**		-	-	-	-	-
ER	**		-	-	-	-	-
PM	**		-	-	-	-	-
PD	**		-	-	-	-	-
AZ	**		-	-	-	-	-
CI	SM	4.7.2.1.6.1	24.244690	0.343864	-0.069180	1.251384	-0.272018
CI	SP	4.7.2.1.6.1	40.78321	0.332614	-0.021471	0.922811	-0.133923
CI	BP, SF, LP	4.7.2.1.6.1	32.108633	0.276926	-0.057766	0.984340	-0.169876
OS	ALL	4.7.2.1.6.3	42.269377	0	-0.165687	1.184734	0
OH	SM, SP	4.7.2.1.6.1	14.187987	0.416525	-0.126806	1.310744	-0.245126
OH	BP, SF, LP	4.7.2.1.6.2	-2.04	1.4534	-0.058112	1.894400	-0.192979

*These species use equations from other variants, as described below

**These species use small tree growth equations for all sizes of trees

4.7.2.2 Height Growth Estimate for Species using Equations from Other Variants

Grand fir, mountain hemlock, western redcedar, western larch, and limber pine use large-tree height growth relationships from other variants to estimate height growth. These relationships predict height growth directly. The grand fir equation is from the Central Idaho (CI) variant. Equations for mountain hemlock, western redcedar, and western larch are from the North Idaho (NI) variant with elevation set to 6000 feet and habitat type set to 710 (TSME/XETE), 550 (THPL/OPHO), and 260 (PSME/PHMA) respectively. The limber pine equation is from the Utah (UT) variant.

Grand fir, mountain hemlock, western redcedar, and western larch use equation {4.7.2.2.1} with species-specific coefficients shown in table 4.7.2.2.1.

{4.7.2.2.1} $HTG = \exp[a_1 + (a_2 * HT\text{^}2) + (a_3 * \ln(DBH)) + (a_4 * \ln(HT)) + (a_5 * \ln(DG))] + 0.4809$

where:

HTG is estimated 10-year height growth
HT is tree height at the beginning of the projection cycle
DBH is tree diameter at breast height at the beginning of the projection cycle
DG is estimated 10-year diameter growth
$a_1 - a_5$ are species-specific coefficients shown in table 4.7.2.2.1

Table 4.7.2.2.1 Coefficients ($a_1 - a_5$) for the height-growth equation {4.7.2.2.1} used for grand fir, mountain hemlock, western redcedar, and western larch in the CR variant.

Species Code	a_1	a_2	a_3	a_4	a_5
GF	1.38455	-0.0001336	-0.09775	0.23315	0.62144
MH	1.0951	-0.0000446	-0.09775	0.23315	0.34003
RC	1.21694	-0.0000363	-0.1219	0.23315	0.37042
WL	1.96089	-0.0000261	-0.3899	0.23315	0.75756

Once height growth is estimated using equation {4.7.2.2.1}, equation {4.7.2.2.2} is used to adjust the estimate for site index and apply the adjustment factor shown in table 4.7.2.1.1. A small random increment is added and an adjustment for stagnated stands is applied if this feature has been turned on using field 7 of the SDIMAX keyword.

{4.7.2.2.2} $HTG = [((HTG * FACTOR) * ADJUST) + (ZZRAN * 0.1)] * [(DSTAG + 1) * 0.5]$

$FACTOR = a + (b * SI)$ bounded for western redcedar $FACTOR \geq 1$

where:

HTG is estimated 10-year height growth
FACTOR is an adjustment factor based on site index
SI is species site index (bounded by *SITELO* and *SITEHI* shown in table 4.7.2.2.2)

ADJUST	is a multiplier so open-grown trees will reach the site height at the index age (table 4.7.2.1.1)
ZZRAN	is a random number in the range $-2 \le ZZRAN \le 2$ (i.e. the limits for *ZZRAN* are the number of standard deviations specified using the DGSTDEV keyword, default 2)
DSTAG	is an adjustment for stagnated stand conditions (turned on using the SDIMAX keyword, default 1.0)
a, b	are species and site index specific coefficients shown in table 4.7.2.2.2

Table 4.7.2.2.2 Coefficients (a and b), *SITELO* and *SITEHI* values for the height-growth adjustment, variable *FACTOR* in equation {4.7.2.2.2}, in the CR variant.

Common Name	a	b	*SITELO*	*SITEHI*
grand fir; $SI \le 80$	0.1	0.0125	40	120
grand fir; $SI > 80$	-0.7	0.0225	40	120
mountain hemlock	0.36	0.012	40	70
western redcedar	0.0875	0.01375	40	110
western larch	0.23337	0.008333	40	120
limber pine; $SI < 40$	0.2	0.015	20	60
limber pine; $SI \ge 40$	-0.1	0.0225	20	60

The equation for limber pine predicts future height and is more complex. If the diameter at the beginning or end of the projection cycle is greater than 45.1, or the beginning of cycle height is greater than 94.5, then height growth is set to 0.1 foot. If the tree dimensions are smaller than those limits, then estimated height 10 years later is calculated using equation {4.7.2.2.3} and 10-year height growth is calculated by subtraction using equation {4.7.2.2.4} and adjusted for site index and species-specific adjustment factor using equation {4.7.2.2.2} as shown above.

{4.7.2.2.3} $H10 = [(PSI / (1 + PSI)) * 90] + 4.5$

$PSI = 2.4648 * [(D10 - 0.1) / (45.1 - D10)]^{1.00316} * [\exp(0.74842 * Z)]$
$Z = [0.30546 + (0.94823 * FBY2) - 7.0453 * (1.6477 + (1.35015 * FBY1))] * 1.4091$
$FBY1 = \ln[Y1 / (1 - Y1)]$
$Y1 = (DBH - 0.1) / 45$
$FBY2 = \ln[Y2 / (1 - Y2)]$
$Y2 = (HT - 4.5) / 90$

{4.7.2.2.4} Height growth

$H10 > HT$: $HTG = H10 - HT$
$H10 \le HT$: $HTG = 0.1$

where:

H10	is estimated height of the tree in ten years
DBH	is tree diameter at breast height at the start of the projection cycle
HT	is tree height at the start of the projection cycle
D10	is estimated diameter at breast height of the tree in ten years
HTG	is estimated 10-year height growth

4.7.2.3 Height growth using the Small Tree Equations

Bristlecone pine, twoneedle pinyon, Utah juniper, Gambel oak, Arizona white oak, Emory oak, bur oak, silverleaf oak, alligator juniper, Rocky Mountain juniper, oneseed juniper, Eastern redcedar, singleleaf pinyon, border pinyon, and Arizona twoneedle pinyon, use the small-tree height growth equations described in section 4.6.1 for trees of all sizes.

5.0 Mortality Model

The CR variant uses an SDI-based mortality model as described in Section 7.3.2 of Essential FVS: A User's Guide to the Forest Vegetation Simulator (Dixon 2002, referred to as EFVS). This SDI-based mortality model is comprised of two steps: 1) determining the amount of stand mortality (section 7.3.2.1 of EFVS) and 2) dispersing stand mortality to individual tree records (section7.3.2.2 of EFVS). In determining the amount of stand mortality, the summation of individual tree background mortality rates is used when stand density is below the minimum level for density dependent mortality (default is 55% of maximum SDI), while stand level density-related mortality rates are used when stands are above this minimum level.

The equation used to calculate individual tree background mortality rates for all species is shown in equation {5.0.1}, and this is then adjusted to the length of the cycle by using a compound interest formula as shown in equation {5.0.2}. Coefficients for these equations are shown in table 5.0.1. The overall amount of mortality calculated for the stand is the summation of the final mortality rate (*RIP*) across all live tree records.

{5.0.1} $RI = [1 / (1 + \exp(p_0 + p_1 * DBH))] * 0.5$

{5.0.2} $RIP = 1 – (1 – RI)^Y$

where:

RI	is the proportion of the tree record attributed to mortality
RIP	is the final mortality rate adjusted to the length of the cycle
DBH	is tree diameter at breast height
Y	is length of the current projection cycle in years
p_0 and p_1	are species-specific coefficients shown in table 5.0.1

Table 5.0.1 Coefficients used in the background mortality equation {5.0.1} in the CR variant.

Species Code	p_0	p_1
AF	5.1677	-0.00777
CB	5.1677	-0.00777
DF	7.2985	-0.01291
GF	5.1677	-0.00777
WF	5.1677	-0.00777
MH	9.6943	-0.01273
RC	5.1677	-0.00777
WL	6.5112	-0.00525
BC	5.1677	-0.00777
LM	5.1677	-0.00777
LP	5.9617	-0.03401
PI	5.1677	-0.00777
PP	5.5877	-0.00535
WB	5.1677	-0.00777

Species Code	p_0	p_1
SW	6.5112	-0.00525
UJ	5.1677	-0.00777
BS	9.6943	-0.01273
ES	9.6943	-0.01273
WS	9.6943	-0.01273
AS	5.9617	-0.03401
NC	5.9617	-0.03401
PW	5.9617	-0.03401
GO	5.9617	-0.03401
AW	5.9617	-0.03401
EM	5.9617	-0.03401
BK	5.9617	-0.03401
SO	5.9617	-0.03401
PB	5.9617	-0.03401
AJ	5.1677	-0.00777
RM	5.1677	-0.00777
OJ	5.1677	-0.00777
ER	5.1677	-0.00777
PM	5.1677	-0.00777
PD	5.1677	-0.00777
AZ	5.1677	-0.00777
CI	5.5877	-0.00535
OS	5.1677	-0.00777
OH	5.9617	-0.03401

When stand density-related mortality is in effect, the total amount of stand mortality is determined based on the trajectory developed from the relationship between stand SDI and the maximum SDI for the stand. This is explained in section 7.3.2.1 of EFVS.

Once the amount of stand mortality is determined based on either the summation of background mortality rates or density-related mortality rates, mortality is dispersed to individual tree records i in relation to a tree's percentile in the basal area distribution (PCT) using equation {5.0.3}. This value is then adjusted by a species-specific mortality modifier representing the species shade tolerance shown in equation {5.0.4}.

The mortality model makes multiple passes through the tree records multiplying a record's trees-per-acre value times the final mortality rate (*MORT*), accumulating the results, and reducing the trees-per-acre representation until the desired mortality level has been reached. If the stand still exceeds the basal area maximum sustainable on the site the mortality rates are proportionally adjusted to reduce the stand to the specified basal area maximum.

{5.0.3} $MR = 0.84525 - (0.01074 * PCT) + (0.0000002 * PCT^3)$

{5.0.4} $MORT = MR * MWT * ((100 - CR\%) / 100) * 0.01$

where:

MR is the proportion of the tree record attributed to mortality (bounded: $0.01 \le MR \le 1$)
PCT is the subject tree's percentile in the basal area distribution of the stand
MORT is the final mortality rate of the tree record
MWT is a mortality weight value based on a species' tolerance shown in table 5.0.2
CR% is crown ratio expressed as a percent

Table 5.0.2 *MWT* values for the mortality equation {5.0.4} in the CR variant.

Species Code	MWT	Species Code	MWT
AF	0.1	AS	0.9
CB	0.1	NC	0.9
DF	0.5	PW	0.9
GF	0.3	GO	0.7
WF	0.3	AW	0.7
MH	0.3	EM	0.7
RC	0.1	BK	0.7
WL	0.9	SO	0.7
BC	0.9	PB	0.9
LM	0.9	AJ	0.7
LP	0.7	RM	0.7
PI	0.7	OJ	0.7
PP	0.7	ER	0.7
WB	0.9	PM	0.7
SW	0.5	PD	0.7
UJ	0.7	AZ	0.7
BS	0.5	CI	0.7
ES	0.3	OS	0.7
WS	0.3	OH	0.9

6.0 Regeneration

The CR variant contains a partial establishment model which may be used to input regeneration and ingrowth into simulations. A more detailed description of how the partial establishment model works can be found in section 5.4.5 of the Essential FVS Guide (Dixon 2002).

The regeneration model is used to simulate stand establishment from bare ground, or to bring seedlings and sprouts into a simulation with existing trees. Sprouts are automatically added to the simulation following harvest or burning of known sprouting species (see table 6.0.1 for sprouting species).

Table 6.0.1 Default regeneration parameters by species in the CR variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
AF	No	0.3	0.5	7.0
CB	No	0.3	0.5	7.0
DF	No	0.3	1.0	10.0
GF	No	0.3	0.5	7.0
WF	No	0.3	0.5	7.0
MH	No	0.3	0.5	10.0
RC	No	0.3	0.5	9.0
WL	No	0.3	1.0	10.0
BC	No	0.4	0.5	9.0
LM	No	0.4	0.5	9.0
LP	No	0.4	1.0	10.0
PI	No	0.4	0.5	6.0
PP	No	0.5	1.0	10.0
WB	No	0.4	1.0	9.0
SW	No	0.4	1.0	9.0
UJ	No	0.3	0.5	6.0
BS	No	0.3	0.5	7.0
ES	No	0.3	0.5	7.0
WS	No	0.3	0.5	7.0
AS	Yes	0.2	3.0	16.0
NC	Yes	0.3	3.0	16.0
PW	Yes	0.3	3.0	16.0
GO	Yes	0.3	0.5	10.0
AW	Yes	0.3	0.5	10.0
EM	Yes	0.3	0.5	10.0
BK	Yes	0.3	0.5	10.0
SO	Yes	0.3	0.5	10.0
PB	Yes	0.2	3.0	16.0

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
AJ	Yes	0.3	0.5	6.0
RM	No	0.3	0.5	6.0
OJ	No	0.3	0.5	6.0
ER	No	0.3	0.5	6.0
PM	No	0.4	0.5	6.0
PD	No	0.4	0.5	6.0
AZ	No	0.4	0.5	6.0
CI	Yes	0.5	1.0	10.0
OS	No	0.2	1.0	9.0
OH	No	0.2	0.5	12.0

The number of sprout records created for each sprouting species is found in table 6.0.2. For more prolific stump sprouting hardwood species, logic rule {6.0.1} is used to determine the number of sprout records, with logic rule {6.0.2} being used for root suckering species. The trees-per-acre represented by each sprout record is determined using the general sprouting probability equation {6.0.3}. See table 6.0.2 for species-specific sprouting probabilities, number of sprout records created, and reference information.

Users wanting to modify or turn off automatic sprouting can do so with the SPROUT or NOSPROUT keywords, respectively. Sprouts are not subject to maximum and minimum tree heights found in table 6.0.1 and do not need to be grown to the end of the cycle because estimated heights and diameters are end of cycle values.

{6.0.1} For stump sprouting hardwood species

$DSTMP_i \leq 5$: $NUMSPRC = 1$
$5 < DSTMP_i \leq 10$: $NUMSPRC = \mathrm{NINT}(0.2 * DSTMP_i)$
$DSTMP_i > 10$: $NUMSPRC = 2$

{6.0.2} For root suckering hardwood species

$DSTMP_i \leq 5$: $NUMSPRC = 1$
$5 < DSTMP_i \leq 10$: $NUMSPRC = \mathrm{NINT}(-1.0 + 0.4 * DSTMP_i)$
$DSTMP_i > 10$: $NUMSPRC = 3$

{6.0.3} $TPA_s = TPA_i * PS$

{6.0.4} $PS = (TPA_i / (ASTPAR * 2)) * ((ASBAR / 198) * (40100.45 - 3574.02 * RSHAG^2 + 554.02 * RSHAG^3 - 3.5208 * RSHAG^5 + 0.011797 * RSHAG^7))$

{6.0.5} $PS = ((97.4306 - 2.3492 * DSTMP_i) / 100)$

where:

$DSTMP_i$ is the diameter at breast height of the parent tree
$NUMSPRC$ is the number of sprout tree records
NINT rounds the value to the nearest integer
TPA_s is the trees per acre represented by each sprout record

TPA_i is the trees per acre removed/killed represented by the parent tree
PS is a sprouting probability (see Table 6.0.2)
$ASBAR$ is the aspen basal area removed
$ASTPAR$ is the aspen trees per acre removed
$RSHAG$ is the age of the sprouts at the end of the cycle in which they were created

Table 6.0.2 Sprouting algorithm parameters for sprouting species in the CR variant.

Species Code	Sprouting Probability	Number of Sprout Records	Source
AS	{6.0.2}	2	Keyser 2001
NC	0.8	[B]	Simonin 2001
PW	0.9	[B]	Taylor 2001
GO	0.8	[A]	Simonin 2000
AW	0.7	[A]	Pavek 1994
EM	0.8	[A]	Pavek 1994
BK	0.8	[A]	Gucker 2011
SO	0.9	[A]	Barton 2002
PB	0.7	1	Hutnik and Cunningham 1965 Bjorkbom 1972
AJ	{6.0.3}	1	Jameson and Johnson 1964
CI	0.3	1	Barton 2002

Regeneration of seedlings must be specified by the user with the partial establishment model by using the PLANT or NATURAL keywords. Height of the seedlings is estimated in two steps. First, the height is estimated when a tree is 5 years old (or the end of the cycle – whichever comes first) by using the small-tree height growth equations found in section 4.6.1. Users may override this value by entering a height in field 6 of the PLANT or NATURAL keyword; however the height entered in field 6 is not subject to minimum height restrictions and seedlings as small as 0.05 feet may be established. The second step also uses the equations in section 4.6.1, which grow the trees in height from the point five years after establishment to the end of the cycle.

Seedlings and sprouts are passed to the main FVS model at the end of the growth cycle in which regeneration is established. Unless noted above, seedlings being passed are subject to minimum and maximum height constraints and a minimum budwidth constraint shown in table 6.0.1. After seedling height is estimated, diameter growth is estimated using equations described in section 4.6.2. Crown ratios on newly established trees are estimated as described in section 4.3.1.

Regenerated trees and sprouts can be identified in the treelist output file with tree identification numbers beginning with the letters “ES”.

7.0 Volume

In the CR variant, volume is calculated for three merchantability standards: total stem cubic feet, merchantable stem cubic feet, and merchantable stem board feet (Scribner Decimal C). Volume estimation is based on methods contained in the National Volume Estimator Library maintained by the Forest Products Measurements group in the Forest Management Service Center (Volume Estimator Library Equations 2009). The default volume merchantability standards and equation numbers for the CR variant are shown in tables 7.0.1-7.0.3.

Table 7.0.1 Volume merchantability standards for the CR variant.

Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
SM – Southwestern Mixed Conifers SP – Southwestern Ponderosa Pine SF – Spruce-fir LP – Lodgepole Pine	5.0 / 4.0 inches	5.0 / 4.0 inches
BP – Black Hills Ponderosa Pine	9.0 / 6.0 inches	9.0 / 6.0 inches
Stump Height	1.0 foot	1.0 foot
Merchantable Board Foot Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
Region 2 Forests using these model types: SM – Southwestern Mixed Conifers SP – Southwestern Ponderosa Pine SF – Spruce-fir LP – Lodgepole Pine	7.0 / 6.0 inches	7.0 / 6.0 inches
Region 3 Forests using these model types: SM – Southwestern Mixed Conifers SP – Southwestern Ponderosa Pine SF – Spruce-fir LP – Lodgepole Pine	9.0 / 6.0 inches	9.0 / 6.0 inches
BP – Black Hills Ponderosa Pine	9.0 / 6.0 inches	9.0 / 6.0 inches
Stump Height	1.0 foot	1.0 foot

Table 7.0.2 Volume equation defaults for each species at specific location codes with model name.

Common Name	**Location Code**	**Equation Number**	**Reference**
subalpine fir	All of Region 2	I00FW2W019	Flewelling's 2-Point Profile Model
subalpine fir	All of Region 3	300DVEW093	Hann and Bare Equations
corkbark fir	All of Region 2	I00FW2W019	Flewelling's 2-Point Profile Model

Common Name	Location Code	Equation Number	Reference
corkbark fir	All of Region 3	NVB0000015	FIA National Scale Volume and Biomass Estimators
Douglas-fir	All of Region 2	200FW2W202	Flewelling's 2-Point Profile Model
Douglas-fir	All of Region 3	300FW2W202	Flewelling's 2-Point Profile Model
grand fir	All of Region 2	I00FW2W019	Flewelling's 2-Point Profile Model
grand fir	All of Region 3	300DVEW093	Hann and Bare Equations
white fir	All of Region 2	200FW2W015	Flewelling's 2-Point Profile Model
white fir	All of Region 3	NVB0000015	FIA National Scale Volume and Biomass Estimators
mountain hemlock	All of Region 2	407FW2W093	Flewelling's 2-Point Profile Model
mountain hemlock	All of Region 3	301DVEW015	Hann and Bare Equations
western redcedar	All of Region 2	407FW2W093	Flewelling's 2-Point Profile Model
western redcedar	All of Region 3	301DVEW015	Hann and Bare Equations
western larch	All of Region 2	407FW2W093	Flewelling's 2-Point Profile Model
western larch	All of Region 3	301DVEW015	Hann and Bare Equations
bristlecone pine	All of Region 2	200FW2W122	Flewelling's 2-Point Profile Model
bristlecone pine	All of Region 3	300DVEW113	Hann and Bare Equations
limber pine	All of Region 2	200FW2W122	Flewelling's 2-Point Profile Model
limber pine	All of Region 3	300DVEW113	Hann and Bare Equations
lodgepole pine	202, 214	202FW2W108	Flewelling's 2-Point Profile Model
lodgepole pine	Rest of Region 2	200FW2W108	Flewelling's 2-Point Profile Model
lodgepole pine	All of Region 3	301DVEW202	Hann and Bare Equations
twoneedle pinyon	All of Region 2	200DVEW106	Chojnacky Equations
twoneedle pinyon	All of Region 3	300DVEW106	Chojnacky Equations
ponderosa pine	203	203FW2W122	Flewelling's 2-Point Profile Model
ponderosa pine	213	213FW2W122	Flewelling's 2-Point Profile Model

Common Name	Location Code	Equation Number	Reference
ponderosa pine	Rest of Region 2	200FW2W122	Flewelling's 2-Point Profile Model
ponderosa pine	301, 304, 307, 312	300FW2W122	Flewelling's 2-Point Profile Model
ponderosa pine	310	301FW2W122	Flewelling's 2-Point Profile Model
ponderosa pine	Rest of Region 3	300DVEW122	Eager Mill Study
whitebark pine	All of Region 2	200FW2W122	Flewelling's 2-Point Profile Model
whitebark pine	All of Region 3	300DVEW113	Hann and Bare Equations
southwestern white pine	All of Region 2	200FW2W122	Flewelling's 2-Point Profile Model
southwestern white pine	All of Region 3	NVBM240119	FIA National Scale Volume and Biomass Estimators
Utah juniper	All of Region 2	200DVEW065	Chojnacky Equations
Utah juniper	All of Region 3	300DVEW060	Chojnacky Equations
blue spruce	All of Region 2	407FW2W093	Flewelling's 2-Point Profile Model
blue spruce	All of Region 3	300DVEW093	Hann and Bare Equations
Engelmann spruce	All of Region 2	407FW2W093	Flewelling's 2-Point Profile Model
Engelmann spruce	All of Region 3	NVBM330093	FIA National Scale Volume and Biomass Estimators
white spruce	All of Region 2	407FW2W093	Flewelling's 2-Point Profile Model
white spruce	All of Region 3	300DVEW093	Hann and Bare Equations
quaking aspen	All of Region 2	200FW2W746	Flewelling's 2-Point Profile Model
quaking aspen	All of Region 3	NVB0000746	FIA National Scale Volume and Biomass Estimators
narrowleaf cottonwood	All	300DVEW999	Chojnacky Equations
plains cottonwood	All	300DVEW999	Chojnacky Equations
Gambel oak	All	300DVEW800	Chojnacky Equations
Arizona white oak	All	300DVEW800	Chojnacky Equations
emory oak	All	300DVEW800	Chojnacky Equations
bur oak	All of Region 2	200DVEW823	Chojnacky Equations
bur oak	All of Region 3	300DVEW800	Chojnacky Equations
silverleaf oak	All	300DVEW800	Chojnacky Equations
paper birch	All	300DVEW999	Chojnacky Equations
alligator juniper	All	300DVEW060	Chojnacky Equations

Common Name	Location Code	Equation Number	Reference
Rocky mountain juniper	All	300DVEW060	Chojnacky Equations
oneseed juniper	All of Region 2	200DVEW069	Chojnacky Equations
oneseed juniper	All of Region 3	300DVEW060	Chojnacky Equations
eastern red cedar	All	300DVEW060	Chojnacky Equations
singleleaf pinyon	All	300DVEW106	Chojnacky Equations
border pinyon	All	300DVEW106	Chojnacky Equations
Arizone twoneedle pinyon	All	300DVEW106	Chojnacky Equations
Chihuahuan pine	All of Region 2	200FW2W122	Chojnacky Equations
Chihuahuan pine	All of Region 3	300DVEW122	Chojnacky Equations
other softwood	All	300DVEW060	Chojnacky Equations
other hardwood	All of Region 2	200DVEW998	Chojnacky Equations
other hardwood	All of Region 3	300DVEW999	Chojnacky Equations

Table 7.0.3 Citations by Volume Model

Model Name	Citation
Chojnacky Equations	Chojnacky, David. 1985. Pinyon-Juniper Volume Equations for the Central Rocky Mountain States. Intermountain Research Station Research Paper INT-339.
Eager Mill Study	Unpublished. Timber Cruising Handbook, Region 3 Supplement.
Hann and Bare Equations	Hann, David W. and B. Bruce Bare 1978. Comprehensive Tree Volume Equations for Major Species of New Mexico and Arizona. Intermountain Forest and Range Experiment Station Research Paper INT-209.
Flewelling 2-Point Profile Model	Unpublished. Based on work presented by Flewelling and Raynes. 1993. Variable-shape stem-profile predictions for western hemlock. Canadian Journal of Forest Research Vol 23. Part I and Part II.

8.0 Fire and Fuels Extension (FFE-FVS)

The Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) (Reinhardt and Crookston 2003) integrates FVS with models of fire behavior, fire effects, and fuel and snag dynamics. This allows users to simulate various management scenarios and compare their effect on potential fire hazard, surface fuel loading, snag levels, and stored carbon over time. Users can also simulate prescribed burns and wildfires and get estimates of the associated fire effects such as tree mortality, fuel consumption, and smoke production, as well as see their effect on future stand characteristics. FFE-FVS, like FVS, is run on individual stands, but it can be used to provide estimates of stand characteristics such as canopy base height and canopy bulk density when needed for landscape-level fire models.

For more information on FFE-FVS and how it is calibrated for the CR variant, refer to the updated FFE-FVS model documentation (Rebain, comp. 2010) available on the FVS website.

9.0 Insect and Disease Extensions

FVS Insect and Pathogen models for dwarf mistletoe and western root disease have been developed for the CR variant through the participation and contribution of various organizations led by Forest Health Protection. These models are currently maintained by the Forest Management Service Center and regional Forest Health Protection specialists. Additional details regarding each model may be found in chapter 8 of the Essential FVS Users Guide (Dixon 2002).

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11.0 Appendices

11.1 Appendix A: Plant Association Codes for Region 2 Forests

Table 11.1.1 Plant association codes recognized in the CR variant in region 2 forests.

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
1	00101	White fir-Douglas-fir/Rocky Mountain maple
2	001010	White fir-Douglas-fir/Rocky Mountain maple/Rocky Mountain Maple
3	001011	White fir-Douglas-fir/Rocky Mountain maple/Oregon-grape
4	001012	White fir-Douglas-fir/Rocky Mountain maple/ocean spray
5	001013	White fir-Douglas-fir/Rocky Mountain maple/thinleaf alder
6	00102	White fir-Douglas-fir/sparse undergrowth
7	00103	White fir-Douglas-fir/forest fleabane
8	00104	White fir-Douglas-fir/Arizona fescue
9	001040	White fir-Douglas-fir/Arizona fescue/Arizona fescue
10	001041	White fir-Douglas-fir/Arizona fescue/Parry oatgrass
11	00105	White fir-Douglas-fir/Gambel oak
12	001050	White fir-Douglas-fir/Gambel oak/Gambel oak
13	001052	White fir-Douglas-fir/Gambel oak/Arizona fescue
14	001053	White fir-Douglas-fir/Gambel oak/fragrant bedstraw
15	001054	White fir-Douglas-fir/Gambel oak/mountain lover
16	00109	White fir-Douglas-fir/bearberry
17	00110	White fir-Douglas-fir/Rocky Mountain whortleberry
18	00111	White fir-Douglas-fir/Saskatoon serviceberry
19	00112	White fir-Douglas-fir/greenleaf manzanita
20	00113	White fir-Douglas-fir/ocean spray
21	00114	White fir-Douglas-fir/mountain snowberry
22	00115	White fir-limber pine/Arizona fescue
23	00116	White fir-Douglas-fir/common juniper
24	00117	White fir-Douglas-fir/Oregon-grape
25	00118	White fir-Douglas-fir/mallow ninebark
26	00201	Subalpine fir/elk sedge
27	00203	Subalpine fir/mountain lover
28	00301	Subalpine fir-Engelmann spruce/red baneberry
29	00302	Subalpine fir-Engelmann spruce/heartleaf arnica
30	003020	Subalpine fir-Engelmann spruce/heartleaf arnica/heartleaf arnica
31	003021	Subalpine fir-Engelmann spruce/heartleaf arnica/weedy milkvetch

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
32	003022	Subalpine fir-Engelmann spruce/heartleaf arnica/russet buffaloberry
33	003023	Subalpine fir-Engelmann spruce/heartleaf arnica/Engelmann spruce
34	00303	Subalpine fir-Engelmann spruce/broadleaf arnica
35	00304	Subalpine fir-Engelmann spruce/Oregon-grape
36	00305	Subalpine fir-Engelmann spruce/bluejoint reedgrass
37	00306	Subalpine fir-Engelmann spruce/mountain bluebells
38	00307	Subalpine fir-Engelmann spruce/elk sedge
39	00308	Subalpine fir-Engelmann spruce/forest fleabane
40	00309	Subalpine fir-Engelmann spruce/common juniper
41	00310	Subalpine fir-Engelmann spruce/American twinflower
42	003100	Subalpine fir-Engelmann spruce/American twinflower/American twinflower
43	003101	Subalpine fir-Engelmann spruce/American twinflower/broom huckleberry
44	00311	Subalpine fir-Engelmann spruce/moss species
45	00313	Subalpine fir-Engelmann spruce/mountain lover
46	003130	Subalpine fir-Engelmann spruce/mountain lover/mountain lover
47	003131	Subalpine fir-Engelmann spruce/mountain lover/Douglas-fir
48	003132	Subalpine fir-Engelmann spruce/mountain lover/mountain gooseberry
49	00315	Subalpine fir-Engelmann spruce/Wheeler bluegrass
50	00316	Subalpine fir-Engelmann spruce/arrowleaf groundsel
51	00318	Subalpine fir-Engelmann spruce/western meadow-rue
52	00319	Subalpine fir-Engelmann spruce/globe huckleberry
53	003190	Subalpine fir-Engelmann spruce/globe huckleberry/globe huckleberry
54	003191	Subalpine fir-Engelmann spruce/globe huckleberry/broom huckleberry
55	00320	Subalpine fir-Engelmann spruce/Rocky Mountain whortleberry
56	003200	Subalpine fir-Engelmann spruce/Rocky Mountain whortleberry/Rocky Mountain whortleberry
57	003201	Subalpine fir-Engelmann spruce/Rocky Mountain whortleberry/Jacob's ladder
58	00321	Subalpine fir-Engelmann spruce/broom huckleberry
59	003210	Subalpine fir-Engelmann spruce/broom huckleberry/broom huckleberry

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
60	003211	Subalpine fir-Engelmann spruce/broom huckleberry/whitebarkpine
61	003212	Subalpine fir-Engelmann spruce/broom huckleberry/Jacob's ladder
62	003213	Subalpine fir-Engelmann spruce/broom huckleberry/elk sedge
63	003216	Subalpine fir-Engelmann spruce/broom huckleberry/russet buffaloberry
64	003217	Subalpine fir-Engelmann spruce/broom huckleberry/heartleafarnica
65	00322	Subalpine fir-Engelmann spruce/currant species
66	003220	Subalpine fir-Engelmann spruce/currant species/currant species
67	003221	Subalpine fir-Engelmann spruce/currant species/Fendler meadow-rue
68	00323	Subalpine fir-Engelmann spruce/grayleaf willow
69	00324	Subalpine fir-Engelmann spruce/western thimbleberry
70	003240	Subalpine fir-Engelmann spruce/western thimbleberry/western thimbleberry
71	003241	Subalpine fir-Engelmann spruce/western thimbleberry/broom huckleberry
72	00325	Subalpine fir-Engelmann spruce/shiny-leaf spirea
73	00326	Subalpine fir-Engelmann spruce/Ross sedge
74	00327	Subalpine fir-Engelmann spruce/Rocky Mountain maple
75	00328	Subalpine fir-Engelmann spruce/pinegrass
76	003280	Subalpine fir-Engelmann spruce/pinegrass/pinegrass
77	003281	Subalpine fir-Engelmann spruce/pinegrass/mountain lover
78	00329	Subalpine fir-Engelmann spruce/dwarf bilberry
79	00330	Subalpine fir-Engelmann spruce/mallow ninebark
80	00401	Engelmann spruce/heartleaf arnica
81	00402	Engelmann spruce/elkslip marsh-marigold
82	00403	Engelmann spruce/soft leaved sedge
83	00405	Engelmann spruce-blue spruce/fragrant bedstraw
84	00406	Engelmann spruce/moss species
85	00407	Engelmann spruce/common juniper
86	00408	Engelmann spruce/American twinflower
87	00409	Engelmann spruce/mallow ninebark
88	00413	Engelmann spruce/whiproot clover
89	00414	Engelmann spruce/broom huckleberry
90	004140	Engelmann spruce/broom huckleberry/broom huckleberry
91	004141	Engelmann spruce/broom huckleberry/American bistort

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
92	004142	Engelmann spruce/broom huckleberry/silvery lupine
93	004145	Engelmann spruce/broom huckleberry/Jacob's ladder
94	00415	Engelmann spruce/Rocky Mountain whortleberry
95	004150	Engelmann spruce/Rocky Mountain whortleberry/Rocky Mountain whortleberry
96	004151	Engelmann spruce/Rocky Mounatin whortleberry/Jacob's ladder
97	00416	Engelmann spruce/Thurber fescue
98	00417	Engelmann spruce-Douglas-fir/common juniper
99	00418	Engelmann spruce/dwarf bilberry
100	00501	White spruce/sedge
101	00502	White spruce/common juniper
102	00503	White spruce/American twinflower
103	005030	White spruce/American twinflower/American twinflower
104	005031	White spruce/American twinflower/broom huckleberry
105	005032	White spruce/American twinflower/shiny-leaf spirea
106	00601	Blue spruce/Saskatoon serviceberry-redosier
107	006010	Blue spruce/Saskatoon serviceberry-redosier/Saskatoon serviceberry
108	006011	Blue spruce/Saskatoon serviceberry-redosier/redosier
109	00602	Blue spruce/heartleaf arnica
110	00603	Blue spruce/bluegrass species
111	00604	Blue spruce-Douglas-fir/American twinflower
112	006040	Blue spruce-Douglas-fir/American twinflower/American twinflower
113	006043	Blue spruce-Douglas-fir/American twinflower/common juniper
114	00605	Blue spruce/thinleaf alder
115	00606	Blue spruce-Douglas-fir/silvertop sedge
116	00607	Blue spruce-Douglas-fir/forest fleabane
117	00608	Blue spruce-Douglas-fir/bearberry
118	00609	Blue spruce-Douglas-fir/Arizona fescue
119	006090	Blue spruce-Douglas-fir/Arizona fescue/Arizona fescue
120	006091	Blue spruce-Douglas-fir/Arizona fescue/Parry oatgrass
121	00610	Blue spruce-Douglas-fir/Oregon-grape
122	00611	Blue spruce-Engelmann spruce/field horsetail
123	00612	Blue spruce-Douglas-fir/common juniper
124	006120	Blue spruce-Douglas-fir/common juniper/common juniper
125	006121	Blue spruce-Douglas-fir/common juniper/elk sedge

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
126	00701	Whitebark pine/elk sedge
127	007010	Whitebark pine/elk sedge/elk sedge
128	007011	Whitebark pine/elk sedge/lodgepole pine
129	00702	Whitebark pine/Ross sedge
130	007020	Whitebark pine/Ross sedge/Ross sedge
131	007021	Whitebark pine/Ross sedge/lodgepole pine
132	00703	Whitebark pine-limber pine/varileaf cinquefoil
133	00704	Whitebark pine/Idaho fescue
134	00705	Whitebark pine/common juniper
135	007050	Whitebark pine/common juniper/common juniper
136	007051	Whitebark pine/common juniper/buffaloberry
137	00706	Whitebark pine/broom huckleberry
138	00801	Bristlecone pine/Thurber fescue
139	00802	Bristlecone pine/Arizona fescue
140	00803	Bristlecone pine/whiproot clover
141	00804	Bristlecone pine/mountain gooseberry
142	00805	Bristlecone pine/common juniper
143	00901	Lodgepole pine/bearberry
144	00903	Lodgepole pine/elk sedge
145	009030	Lodgepole pine/elk sedge/elk sedge
146	009031	Lodgepole pine/elk sedge/mountain lover
147	00905	Lodgepole pine/common juniper
148	00907	Lodgepole pine/Wheeler bluegrass
149	00908	Lodgepole pine/russet buffaloberry
150	009080	Lodgepole pine/russet buffaloberry/russet buffaloberry
151	009081	Lodgepole pine/russet buffaloberry/mountain lover
152	00909	Lodgepole pine/Rocky Mountain whortleberry
153	00910	Lodgepole pine/broom huckleberry
154	00911	Lodgepole pine/Ross sedge
155	00912	Lodgepole pine/dwarf bilberry
156	01001	Limber pine/bluebunch wheatgrass
157	01002	Limber pine/purple pinegrass
158	01003	Limber pine/Idaho fescue
159	01004	Limber pine/spike-fescue
160	010040	Limber pine/spike-fescue/spike-fescue
161	010041	Limber pine/spike-fescue/American pasque-flower
162	010042	Limber pine/spike-fescue/prairie junegrass
163	01005	Limber pine/common juniper
164	01006	Limber pine/whiproot clover

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
165	01007	Limber pine/curlleaf mountain-mahogany
166	01008	Limber pine/creeping juniper
167	01009	Limber pine/Thurber fescue
168	01010	Limber pine/common chokecherry
169	01101	Ponderosa pine-juniper species/bluebunch wheatgrass
170	01102	Ponderosa pine/little bluestem-western wheatgrass
171	01103	Ponderosa pine-juniper species/blue grama
172	01104	Ponderosa pine/sideoats grama
173	01105	Ponderosa pine/elk sedge
174	011050	Ponderosa pine/elk sedge/elk sedge
175	011051	Ponderosa pine/elk sedge/silvery lupine
176	011052	Ponderosa pine/elk sedge/yellow stonecrop
177	01106	Ponderosa pine/Ross sedge
178	01107	Ponderosa pine/true mountain-mahogany
179	01108	Ponderosa pine/timber oatgrass
180	01109	Ponderosa pine/Arizona fescue
181	011090	Ponderosa pine/Arizona fescue/Arizona fescue
182	011091	Ponderosa pine/Arizona fescue/Parry oatgrass
183	011092	Ponderosa pine/Arizona fescue/blue grama
184	01110	Ponderosa pine/Idaho fescue
185	011100	Ponderosa pine/Idaho fescue/Idaho fescue
186	011101	Ponderosa pine/Idaho fescue/greenleaf manzanita
187	01111	Ponderosa pine/spike-fescue
188	01112	Ponderosa pine/common juniper
189	01113	Ponderosa pine/common juniper-common snowberry
190	01115	Ponderosa pine-juniper species/true mountain-mahogany
191	01117	Ponderosa pine-Douglas-fir/mountain muhly
192	011170	Ponderosa pine-Douglas-fir/mountian muhly/mountain muhly
193	011171	Ponderosa pine-Douglas-fir/mountain muhly/Fendler ceanothus
194	011172	Ponderosa pine-Douglas-fir/mountain muhly/thickspike wheatgrass
195	01118	Ponderosa pine/pinyon-Gambel oak
196	01119	Ponderosa pine/mountain ninebark
197	01120	Ponderosa pine/antelope bitterbrush
198	01121	Ponderosa pine/Gambel oak
199	011210	Ponderosa pine/Gambel oak/Gambel oak
200	011211	Ponderosa pine/Gambel oak/Arizona fescue
201	011214	Ponderosa pine/Gambel oak/mountain snowberry

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
202	011215	Ponderosa pine/Gambel oak/inland box-elder
203	01122	Ponderosa pine/common chokecherry
204	011220	Ponderosa pine/common chokecherry/common chokecherry
205	011221	Ponderosa pine/common chokecherry/silvertop sedge
206	011222	Ponderosa pine/common chokecherry/Saskatoon serviceberry
207	011224	Ponderosa pine/common chokecherry/Oregon-grape
208	011225	Ponderosa pine/common chokecherry/bur oak
209	011226	Ponderosa pine/common chokecherry/big bluestem
210	01123	Ponderosa pine/shiny spirea
211	01124	Ponderosa pine/common snowberry
212	011240	Ponderosa pine/common snowberry/common snowberry
213	011242	Ponderosa pine/common snowberry/roughleaf ricegrass
214	011243	Ponderosa pine/common snowberry/Oregon-grape
215	01125	Ponderosa pine/bluebunch wheatgrass
216	011250	Ponderosa pine/bluebunch wheatgrass/bluebunch wheatgrass
217	011251	Ponderosa pine/bluebunch wheatgrass/big sagebrush
218	01126	Ponderosa pine/sun sedge
219	01127	Ponderosa pine/blue grama
220	011270	Ponderosa pine/blue grama/blue grama
221	011272	Ponderosa pine/blue grama/sand bluestem
222	011273	Ponderosa pine/blue grama/big sagebrush
223	011274	Ponderosa pine/Blue grama/pinyon
224	01128	Ponderosa pine/little bluestem
225	011280	Ponderosa pine/little bluestem/little bluestem
226	011281	Ponderosa pine/little bluestem/wavyleaf oak
227	01129	Ponderosa pine/greenleaf manzanita
228	011290	Ponderosa pine/greenleaf manzanita/greenleaf manzanita
229	011291	Ponderosa pine/greenleaf manzanita/true mountain-mahogany
230	01131	Ponderosa pine/black sagebrush
231	01132	Ponderosa pine/curlleaf mountain-mahogany
232	01140	Ponderosa pine/bearberry
233	01150	Ponderosa pine-juniper species/western snowberry
234	01151	Ponderosa pine/bur oak
235	01201	Douglas-fir/Rocky Mountain maple
236	012010	Douglas-fir/Rocky Mountain maple/Rocky Mountain maple
237	012011	Douglas-fir/Rocky Mountain maple/mountain lover

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
238	012012	Douglas-fir/Rocky Moutain maple/mountain snowberry
239	01202	Douglas-fir/heartleaf arnica
240	012020	Douglas-fir/heartleaf arnica/heartleaf arnica
241	012021	Douglas-fir/heartleaf arnica/weedy milkvetch
242	01203	Douglas-fir/Oregon-grape
243	012030	Douglas-fir/Oregon-grape/Oregon-grape
244	012032	Douglas-fir/Oregon-grape/common juniper
245	01204	Douglas-fir/Ross sedge
246	01205	Douglas-fir/pinegrass
247	012050	Douglas-fir/pinegrass/pinegrass
248	012052	Douglas-fir/pinegrass/Idaho fescue
249	012053	Douglas-fir/pinegrass/ponderosa pine
250	01206	Douglas-fir/elk sedge
251	01207	Douglas-fir/true mountain-mahogany
252	01208	Douglas-fir/Idaho fescue
253	01209	Douglas-fir/waxflower
254	01210	Douglas-fir/common juniper
255	01211	Douglas-fir/mountain lover
256	01212	Douglas-fir/mallow ninebark
257	01213	Douglas-fir/mountain ninebark
258	01214	Douglas-fir/Gambel oak
259	012140	Douglas-fir/Gambel oak/Gambel oak
260	012141	Douglas-fir/Gambel oak/Arizona fescue
261	01215	Douglas-fir/shiny-leaf spirea
262	012150	Douglas-fir/shiny-leaf spirea/shiny-leaf spirea
263	012151	Douglas-fir/shiny-leaf spirea/pinegrass
264	012153	Douglas-fir/shiny-leaf spirea/ponderosa pine
265	01216	Douglas-fir/common snowberry
266	01217	Douglas-fir/mountain snowberry
267	012170	Douglas-fir/mountain snowberry/mountain snowberry
268	012171	Douglas-fir/mountain snowberry/Oregon-grape
269	012172	Douglas-fir/mountain snowberry/elk sedge
270	012173	Douglas-fir/mountain snowberry/spike-fescue
271	012174	Douglas-fir/mountain snowberry/bluebunch wheatgrass
272	01218	Douglas-fir/globe huckleberry
273	01219	Douglas-fir/bearberry-common juniper
274	01220	Douglas-fir/greenleaf manzanita
275	01221	Douglas-fir/antelope bitterbrush
276	01222	Douglas-fir/Saskatoon serviceberry

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
277	01223	Douglas-fir/curlleaf mountain-mahogany
278	01233	Douglas-fir/Arizona fescue
279	01241	Douglas-fir/ocean spray
280	01702	Green ash/common chokecherry
281	10202	Ironwood/succulent hawthorn
282	10203	Ironwood-bur oak/sparse understory
283	10301	Narrowleaf cottonwood/Saskatoon serviceberry
284	103010	Narrowleaf cottonwood/Saskatoon serviceberry/Saskatoon serviceberry
285	103011	Narrowleaf cottonwood/Saskatoon serviceberry/inland box-elder
286	10302	Narrowleaf cottonwood/sandbar willow-river birch
287	10303	Narrowleaf cottonwood/river birch-currant species
288	10304	Narrowleaf cottonwood/mountain ninebark-common chokecherry
289	10305	Narrowleaf cottonwood-Engelmann spruce/bush honeysuckle
290	10306	Narrowleaf cottonwood/thinleaf alder-redosier
291	10401	Plains cottonwood/western snowberry-giant wildrye
292	104010	Plains cottonwood/western snowberry-giant wildrye/western snowberry
293	104011	Plains cottonwood/western snowberry-giant wildrye/redosier
294	10402	Plains cottonwood-narrowleaf cottonwood/willow species
295	10403	Plains cottonwood/willow species
296	10404	Plains cottonwood/American black currant
297	10405	Plains cottonwood/western snowberry-sandbar willow
298	10501	Quaking aspen/elk sedge
299	10502	Quaking aspen/beaked hazel
300	105020	Quaking aspen/beaked hazel/beaked hazel
301	105021	Quaking aspen/beaked hazel/bracken
302	105022	Quaking aspen/beaked hazel/wild sarsaparilla
303	10503	Quaking aspen/Thurber fescue
304	10504	Quaking aspen/common cow-parsnip
305	10505	Quaking aspen/aspen peavine
306	10507	Quaking aspen/silvery lupine
307	10508	Quaking aspen/common juniper
308	10510	Quaking aspen/bracken
309	10511	Quaking aspen/mountain snowberry
310	10512	Quaking aspen/Fendler meadow-rue
311	105120	Quaking aspen/Fendler meadow-rue/Fendler meadow-rue

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
312	105121	Quaking aspen/Fendler meadow-rue/golden banner
313	105123	Quaking aspen/Fendler meadow-rue/stinging nettle
314	10513	Quaking aspen/false-hellebore
315	10514	Quaking aspen/big sagebrush
316	10515	Quaking aspen/Saskatoon serviceberry
317	105150	Quaking aspen/Saskatoon serviceberry/Saskatoon serviceberry
318	105151	Quaking aspen/Saskatoon serviceberry/Rocky Mountain maple
319	105152	Quaking aspen/Saskatoon serviceberry/Gambel oak
320	105153	Quaking aspen/Saskatoon serviceberry/Engelmann aster
321	105154	Quaking aspen/Saskatoon serviceberry/balsam poplar
322	10516	Quaking aspen/sticky-laurel
323	10517	Quaking aspen/pinegrass
324	10518	Quaking aspen/lovage species
325	10519	Quaking aspen/common chokecherry
326	105190	Quaking aspen/common chokecherry/common chokecherry
327	105191	Quaking aspen/common chokecherry/common snowberry
328	10520	Quaking aspen/Oregon-grape
329	10521	Quaking aspen/bearberry
330	10522	Quaking aspen/Arizona fescue
331	10523	Quaking aspen/black elderberry
332	10601	Bur oak/western snowberry
333	106010	Bur oak/western snowberry/western snowberry
334	106011	Bur oak/western snowberry/quaking aspen
335	10603	Bur oak/hazelnut species
336	10701	Green ash/western snowberry
337	107010	Green ash/western snowberry/western snowberry
338	107011	Green ash/western snowberry/prairie sandreed
339	107020	Green ash/common chokecherry/common chokecherry
340	107021	Green ash/common chokecherry/Sprengel's sedge
341	10801	Paper birch/beaked hazel
342	10901	Balsam poplar/redosier
343	12051	Douglas-fir/pinegrass/mountain lover
344	20101	Oneseed juniper/sideoats grama
345	20102	Oneseed juniper/blue grama
346	20103	Oneseed juniper/western wheatgrass
347	20201	Pinyon-Utah juniper/beardless bluebunch wheatgrass
348	20202	Utah juniper/big sagebrush

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
349	20203	Utah juniper/true mountain-mahogany-squaw-apple
350	202030	Utah juniper/true mountain-mahogany-squaw-apple/true mountain-mahogany
351	202031	Utah juniper/true mountain-mahogany-squaw-apple/Wyoming big sagebrush
352	20204	Utah juniper/Indian ricegrass
353	20205	Utah juniper/yellow-wood
354	20206	Utah juniper/Salina wildrye
355	20301	Rocky Mountain juniper/western wheatgrass
356	20302	Rocky Mountain juniper/big sagebrush
357	20303	Rocky Mountain juniper/bluebunch wheatgrass
358	20304	Rocky Mountain juniper/true mountain-mahogany
359	20306	Rocky Mountain juniper/antelope bitterbrush
360	20307	Rocky Mountain juniper/little ricegrass
361	20401	Pinyon-Utah juniper/big sagebrush
362	204010	Pinyon-Utah juniper/big sagebrush/big sagebrush
363	204011	Pinyon-Utah juniper/big sagebrush/blue grama
364	20402	Pinyon/blue grama
365	20403	Pinyon-Utah juniper/Utah serviceberry-true mountain-mahogany
366	204030	Pinyon-Utah juniper/Utah serviceberry-true mountain-mahogany/Utah serviceberry
367	204031	Pinyon-Utah juniper/Utah serviceberry-true mountain-mahogany/greenleaf manzanite
368	20404	Pinyon/Gambel oak
369	20405	Pinyon-Utah juniper/antelope bitterbrush
370	20406	Pinyon-Utah juniper/muttongrass
371	20407	Pinyon-oneseed juniper/true mountain-mahogany
372	20408	Pinyon-oneseed juniper/Nelson's needlegrass
373	20409	Pinyon-Utah juniper/true mountain-mahogany
374	204090	Pinyon-Utah juniper/true mountain-mahogany/true mountain-mahogany
375	204091	Pinyon-Utah juniper/true mountain-mahogany/Gambel oak
376	20410	Pinyon/black sagebrush

11.2 Appendix B: Plant Association Codes for Region 3 Forests

Table 11.2.1 Plant association codes recognized in the CR variant in region 3 forests.

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
377	001010	White fir/Rocky Mountain maple
378	001011	Oregongrape phase
379	001012	Rockspirea phase
380	001013	Riparian phase
381	001020	White fir/Oregongrape
382	001021	New Mexico Locust phase
383	001022	Common juniper phase
384	001030	White fir/sprucefir fleabane
385	001040	White fir/Arizona fescue
386	001041	Muttongrass phase
387	001042	Gambel oak phase
388	001050	White fir/Gambel oak
389	001051	Screwleaf muhly phase
390	001052	Arizona fescue phase
391	001053	Pine muhly phase
392	001054	Rockspirea phase
393	001060	White fir/Screwleaf muhly
394	001070	White fir/Arizona peavine
395	001080	White fir/Bigtooth maple
396	001081	Rockspirea phase
397	001090	White fir/Kinnikinnik
398	001100	White fir/Whortleberry
399	001110	White fir/New Mexico locust
400	001111	Dryspike sedge phase
401	001120	White fir/Beardless wildrye
402	001130	White fir/Arizona walnut
403	001140	White fir/whortleleaf snowberry ponderosa pine series
404	001141	Limber pine phase
405	001150	White fir/dryspike sedge
406	001160	White fir/burnet ragwort
407	003	Abies bifolia (corkbark fir)
408	003060	Corkbark fir/mountain bluebells
409	003080	Corkbark fir/sprucefir fleabane
410	003090	Subalpine fir/common juniper
411	003110	Corkbark fir/Moss
412	003111	Engelmann spruce phase
413	003112	Douglas-fir phase
414	003200	Corkbark fir/Whortleberry
415	003201	Twinflower phase

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
416	003202	Thimbleberry phase
417	003203	Cliffbrush phase
418	003231	Rocky Mountain maple Phase
419	003240	Corkbark fir/Thimbleberry
420	003300	Corkbark fir/Burnet ragwort
421	003301	Douglas-fir phase
422	003310	Corkbark fir/Arizona peavine
423	003320	Corbark fir/cliffbush
424	003350	Corkbark fir/scree
425	003370	Corkbark fir/dryspike sedge
426	004060	Engelmann spruce/Moss typic phase
427	004061	Typical phase
428	004062	Interior Douglas-fir phase
429	00415	Engelmann spruce/Whortleberry-skunkweed polemonium
430	004151	Engelmann spruce phase
431	004152	Corkbark fir phase
432	004300	Engelmann spruce/Rocky Mountain maple
433	004310	Engelmann spruce/Sprucefir fleabane
434	004320	Engelmann spruce/beardless wildrye
435	004330	Engelmann spruce/Ross avens
436	004340	Engelmann spruce/gooseberry currant
437	00435	Engelmann spruce/bittercress ragwort
438	004350	Corkbark phase
439	004351	White fir phase
440	004360	Engelmann spruce/Whortleberry
441	006010	Blue spruce/Redosier dogwood
442	00604	Blue spruce/Twinflower
443	006060	Blue spruce/Dryspike sedge
444	006070	Blue spruce/Sprucefir fleabane
445	006071	Ponderosa pine phase
446	006080	Blue spruce/Kinnikinnik
447	006090	Blue spruce/Arizona fescue
448	006130	Blue spruce/bittercress ragwort
449	011	Picea pungens (blue spruce)
450	011030	Ponderosa pine/blue grama
451	011031	Little bluestem phase
452	011032	Sand bluestem phase
453	011033	Big sagebrush phase
454	011034	Gray oak phase

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
455	011035	Gambel oak phase
456	011090	Ponderosa pine/Arizona fescue phase
457	011091	Parry danthonia phase
458	011092	Blue grama phase
459	011093	Gambel oak phase
460	011130	White fir/scree
461	011210	Ponderosa pine/Gambel oak
462	011211	Arizona fescue phase
463	011212	Longtongue muhly phase
464	011213	Twoneedle pinyon phase
465	011214	Mountain muhly phase
466	011215	Blue grama phase
467	011216	New Mexico locust phase
468	011220	Ponderosa pine/Silverleaf oak
469	011320	Ponderosa pine/Stansbury cliffrose
470	011330	Ponderosa pine/mountain muhly
471	011340	Ponderosa pine/screwleaf muhly
472	011341	Gambel oak phase
473	011350	Ponderosa pine/Indian ricegrass
474	011360	Ponderosa pine/Gray oak /mountain muhly phase
475	011361	Longtongue muhly phase
476	011370	Ponderosa pine/wavyleaf oak
477	011380	Ponderosa pine/black sagebrush
478	011390	Ponderosa pine/screwleaf muhly -Arizona fescue
479	011391	Blue grama phase
480	011392	Gambel oak phase
481	011400	Ponderosa pine/kinnikinnik
482	011410	Ponderosa pine/Arizona white oak
483	011411	Blue grama phase
484	011420	Ponderosa pine/pointleaf manzanita c. t.
485	011430	Ponderosa pine/netleaf oak
486	011440	Ponderosa pine/Emory oak
487	011460	Ponderosa pine/scree
488	011470	Ponderosa pine/Arizona walnut
489	011500	Ponderosa pine/rockland
490	01203	Douglas-fir/Oregongrape
491	01213	Douglas-fir/mountain ninebark
492	012140	Douglas-fir/Gambel oak
493	012141	Arizona fescue phase

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
494	012142	Screwleaf muhly phase
495	012143	Rockspirea phase
496	01231	Douglas-fir/kinnikinnik
497	012320	Douglas-fir/fringed brome
498	012330	Douglas-fir/Arizona fescue
499	012331	Bristlecone pine phase
500	012332	Limber pine phase
501	012333	Aspen phase
502	012340	Douglas-fir/Mountain muhly / twoneedle pinyon phase
503	012341	Limber pine phase
504	012350	Douglas-fir/screwleaf muhly
505	012360	Douglas-fir/Silverleaf oak ponderosa pine phase
506	012361	Chihuahuan pine phase
507	012362	Netleaf oak phase
508	012380	Douglas-fir/scree
509	01239	Douglas-fir/bigtooth maple
510	01241	Douglas-fir/rockspirea
511	01242	Douglas-fir/wavyleak oak
512	012430	Douglas-fir/Arizona white oak
513	03101	Arizona cypress/silverleaf oak
514	03102	Arizona cypress/shrub live oak
515	032010	Apache pine/longtongue muhly
516	032030	Apache pine/silverleaf oak
517	033010	Chihuahuan pine/pinyon ricegrass
518	033020	Chihuahuan pine/Arizona white oak
519	033030	Chihuahuan pine/Silverleaf oak
520	103	Populus angustifolia (narrowleaf cotonwood)
521	104	Populus deltoides spp. wislizeni (Rio Grande cotonwood)
522	123	Alnus tenuifolia (thinleaf alder)
523	130	Platanus wrightii (Arizona sycamore)
524	201010	Oneseed juniper/sideoats grama
525	201011	Beargrass phase
526	201020	Oneseed juniper/blue grama
527	201040	Oneseed juniper/big sagebrush
528	201331	Oneseed juniper/Rabbitbrush-Apacheplume
529	201332	Big sagebrush phase
530	201333	Gray oak phase
531	201340	Oneseed juniper/sand bluestem
532	201350	Oneseed juniper/Bigelow sagebrush

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
533	20140	Oneseed juniper/winterfat
534	201400	Oneseed juniper/wavyleaf oak
535	201410	Oneseed juniper/sacahuista-lecheguilla
536	201420	Oneseed juniper/lecheguilla
537	201430	Pinchot juniper/creosotebush
538	202020	Utah juniper/big sagebrush
539	202320	Utah juniper/blue grama
540	202321	Cliffrose phase
541	202330	Utah juniper/tobosagrass mesquite phase
542	202331	Arizona pinyon phase
543	202500	Utah Juniper-oneseed juniper/sparse c.t.
544	204010	Twoneedle pinyon/big sagebrush Utah juniper phase
545	204011	Oneseed juniper phase
546	204012	Rocky Mountain juniper phase
547	204021	Twoneedle pinyon/blue gama Utah juniper phase
548	204022	Oneseed juniper phase
549	204023	Alligator juniper phase
550	204024	Hillslope phase
551	204031	Twoneedle pinyon/treu mountain mahogany wavyleaf oak phase
552	204032	Gray oak phase
553	204033	Gambel oak phase
554	20404	Twoneedle pinyon/Gambel oak
555	204050	Twoneedle pinyon/antelope bitterbrush
556	20406	Twoneedle pinyon/Muttongrass
557	20410	Twoneedle pinyon/pine muhly
558	20411	Twoneedle pinyon/New Mexico muhly
559	204300	Twoneedle pinyon/sand bluestem
560	20431	Twoneedle pinyon/Arizona fescue
561	204320	Twoneedle pinyon/Stansbury cliffrose
562	204321	Big sagebrush phase
563	204330	Twoneedle pinyon/Rabbitbrush-Apacheplume
564	204350	Twoneedle pinyon/rockland
565	204360	Twoneedle pinyon/wavyleaf oak
566	204370	Twoneedle pinyon/Dore needlegrass
567	204400	Twoneedle pinyon/manzanita
568	20441	Twoneedle pinyon/blackbrush
569	204500	Twoneedle pinyon/sparse c. t.
570	230030	Redberry juniper/crucifixion thorn

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
571	230040	Redberry juniper/shrub live oak shrub live oak phase
572	230041	Mesquite phase
573	230042	Blue grama phase
574	231010	Alligator juniper/pointleal manzanita
575	231020	Alligator juniper/blue grama
576	231021	Mesquite phase
577	231030	Alligator juniper/desert ceanothus
578	231040	Alligator juniper/skunkbush sumac
579	231050	Alligator juniper/Bullgrass
580	232020	Border pinyon/Mexican orange
581	232030	Border pinyon/bullgrass
582	23204	Border pinyon/pinyon ricegrass
583	232050	Border pinyon/Toumey oak
584	232060	Border pinyon/silverleaf oak
585	232070	Border pinyon/evergreen sumac
586	232330	Border pine/Rabbitbrush-Apacheplume
587	233010	Arizona twoneedle pinyon/manzanita
588	233020	Arizona twoneedle pinyon/blue gama alligator juniper phase
589	233021	Utah juniper phase
590	233022	Cliffrose phase
591	233030	Arizona twoneedle pinyon/crucifixion thorn
592	233040	Arizona pinyon/shrub live oak vegetation
593	233041	Typic phase
594	233042	Cliffrose phase
595	233050	Arizona twoneedle pinyon/banana yucca
596	233330	Arizona pinyon/Rabbitbrush-Apacheplume
597	238040	Bristlecone pine/Gooseberry current
598	238300	Bristlecone pine/Arizona fescue
599	238310	Bristlecone pine/Thurber fescue
600	240300	Limber pine/Kinnikinnik
601	25000	Scarp Woodland
602	335	Salix bebbiana (Bebb willow)
603	610010	Mexican blue oak/mixed grama
604	610020	Mexican blue oak/common sotol
605	620010	Emory oak/pointleaf manzanita
606	620020	Emory oak/sideoats grama
607	620021	Sacahuista phase
608	620030	Emory oak/common sotol

PA FVS Sequence Number	Plant Association Codes	Plant Association Type Name
609	620040	Emory oak/Arizona walnut
610	630010	Gray oak/sideoats grama
611	630020	Gray oak/true mountain mahogany
612	630030	Arizona white oak/bullgrass
613	630040	Arizona white oak/skunkbush sumac
614	630041	Alligator juniper phase
615	630042	Oneseed juniper phase
616	630043	Pinyon ricegrass phase
617	630050	Arizona white oak/pinyon ricegrass
618	650010	Silverleaf oak/longtongue muhly

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