Central Rockies Variant

Of the

Forest Vegetation Simulator

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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 vegetation. The FVS model was originally called Prognosis (Stage, 1973) and was developed for use in the Inland Empire area of Idaho and Montana. New “variants” of the FVS model are created by imbedding new tree growth, mortality, and volume equations for a particular geographic area in the FVS framework. Geographic variants of FVS have been developed for most of the forested lands in the western, upper mid-west, northeast, and some areas of the southeast United States. FVS can simulate a wide variety of forest types, stand structures, and pure or mixed species stands.

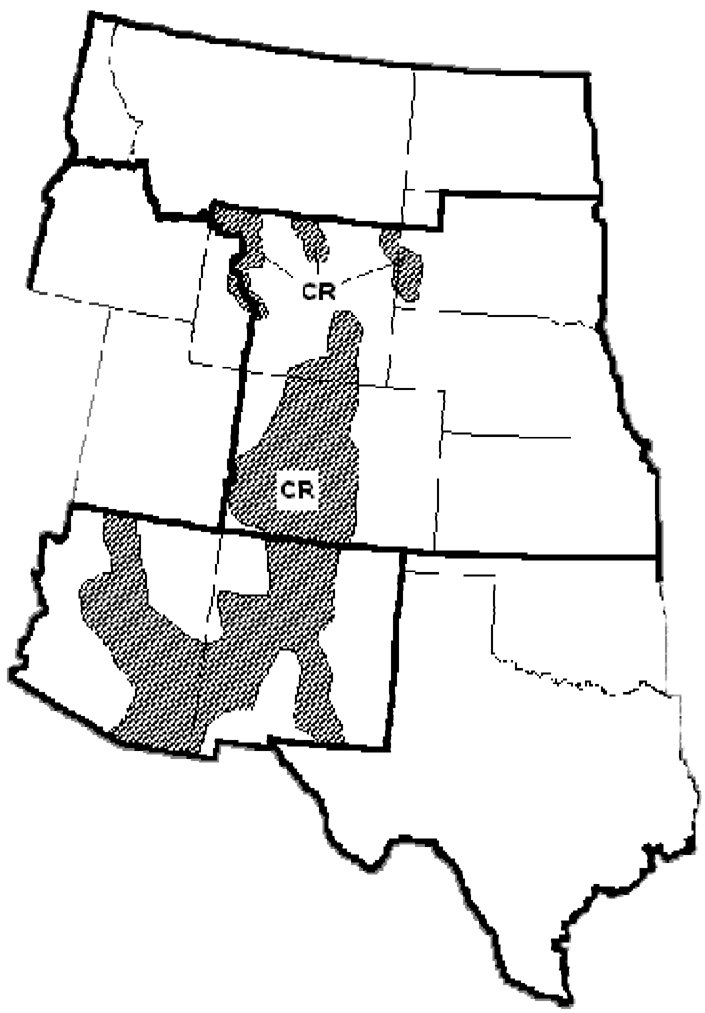
The Central Rockies (CR) variant of FVS was originally developed in 1990. It was based on the growth equations and relationships from the GENGYM model (Edminster, Mowrer, Mathiasen, et. al. 1991). Although GENGYM is a diameter class model, and FVS is an individual tree model, results produced with FVS 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.

2.0 GEOGRAPHIC RANGE

The CR variant covers all the National Forests in Regions 2 and 3. It extends from the northern border of Wyoming, down through Colorado, and into Arizona and New Mexico. However, given the changes that have taken place in this major upgrade, the model could be applied to the forests in Utah and southern Idaho as well. A map indicating the approximate geographic area covered by this variant is shown in Figure 1.

Figure 1. Approximate geographic area covered by the Central Rockies variant of the Forest Vegetation Simulator.



3.0 CONTROL VARIABLES

Users should specify certain variables used by the Central Rockies variant to control the simulation. These are entered in parameter fields on various FVS keywords.

3.1 MODEL TYPE

The CR variant contains the 5 model types, shown in Table 1. Model type is entered as a number, ranging from 1 to 5, in Field 1 of the MODTYPE keyword. If the MODTYPE keyword is missing, or contains an incorrect value, then the default model type is determined from the forest code. The default model type by Forest code is shown in Table 2.

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 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 last column of Table 1 is used to identify the model type, and is also used in labeling some FVS output files.

Table 1. Model types used in the Central Rockies FVS variant:

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

3.2 FOREST CODE AND DEFAULT MODEL TYPE

Forest code is entered as a number in Field 1 of the STDINFO keyword. Any forest code can be used with any model type code. If the forest code is missing or incorrect, a default forest code is used. 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 211 (Routt National Forest). A complete list of forest codes recognized in the CR variant is shown in Table 2. Forest code is used in some growth equations as an index for location effects, and to trigger the correct volume equations for that forest.

Table 2. Forest codes used in the Central Rockies FVS variant, and their associated default model types.

Forest Code	National Forest	Default Model Type
202	Bighorn	Lodgepole Pine
203	Black Hills	Black Hills Ponderosa Pine
204	Grand Mesa, Uncompahgre, Gunnison	Spruce-fir
206	Medicine Bow	Lodgepole Pine
207	Nebraska	Black Hills Ponderosa Pine
209	Rio Grande	Spruce-fir
210	Arapaho, Roosevelt	Lodgepole Pine
211	Routt	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

3.3 SPECIES CODES

The CR variant of FVS recognizes 24 species codes. These correspond to the 24 species currently output from the RMSTAND inventory program used by Forest Service Regions 2, 3, and 4 to process inventory data. Of these 24, 20 represent specific species and 4 represent the groups: “cottonwoods”, “oaks”, “other softwoods” and “other hardwoods”. Either the species alpha code or its’ Forest Inventory and Analysis (FIA) code can be used in the FVS input data. Either the species FVS number or its’ alpha code can be used to specify a species on the FVS keywords. A complete list of species codes recognized by the CR variant is shown in Table 3.

Table 3. Species codes used in the Central Rockies FVS variant.

FVS Number	Alpha Code	FIA Code	Common Name	Scientific Name
1	AF	019	Subalpine fir	Abies lasiocarpa var. lasiocarpa
2	CB	018	Corkbark fir	Abies lasiocarpa var. arizonica
3	DF	202	Douglas-fir	Pseudotsuga menziesii
4	GF	017	Grand fir	Abies grandis
5	WF	015	White fir	Abies concolor
6	MH	264	Mountain hemlock	Tsuga mertensiana
7	RC	242	Western redcedar	Thuja plicata
8	WL	073	Western larch	Larix occidentalis
9	BC	102	Bristlecone pine	Pinus aristata
10	LM	113	Limber pine	Pinus flexilis var. flexilis
11	LP	108	Lodgepole pine	Pinus contorta
12	PI	106	Pinyon pine	Pinus edulis
13	PP	122	Ponderosa pine	Pinus ponderosa
14	WB	101	Whitebark pine	Pinus albicaulis
15	WP	114	Southwestern white pine	Pinus strobiformis
16	JU	066	Rocky Mountain juniper	Juniperus scopulorum
17	BS	096	Blue spruce	Picea pungens
18	ES	093	Engelmann spruce	Picea engelmannii
19	WS	094	White spruce	Picea glauca
20	AS	746	Quaking aspen	Populus tremuloides
21	CO	740	Cottonwoods	Populus sp.
22	OA	800	Oaks	Quercus sp.
23	OS	001	Other softwoods	
24	OH	004	Other hardwoods	

3.4 SITE INDEX REFERENCES AND DEFAULTS

The FVS CR variant uses site index as a growth predictor variable. Site index values are supplied to the model using the SITECODE keyword. 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. In any event, the user should make sure the site index value being used by the model accurately portrays the productivity in the stand being projected. 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 4 should be used if possible. Default values for site species and site index, by model type, are shown in Table 5.

Table 4. Recommended site index references for use with the CR variant of FVS.

Model Type	Reference Species	Ref Age	Age Type	Reference
SW Mixed Conifers	Douglas-fir	100	Breast Height	Edminster, Mathiasen, Olsen 1991
SW Ponderosa Pine	Ponderosa pine	100	Breast Height	Minor 1964
BHills Ponderosa Pine	Ponderosa pine	100	Total	Meyer 1961
Spruce-fir	Engelmann spruce / Subalpine fir	100	Breast Height	Alexander 1967
Lodgepole Pine	Lodgepole pine	100	Total	Alexander, Tackle, Dahms 1967

Table 5. Default values for site species and site index, by model type, for the CR variant of FVS.

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

3.5 STAND DENSITY INDEX DEFAULTS

Stand Density Index (SDI) is an important variable in the mortality routine. Users can enter species-specific SDI values using the SDIMAX keyword. The SDI value is a measure of stocking and can be interpreted as the number of trees-per-acre that an area can support if all the trees were 10" in diameter. As an alternative, users can enter a basal area maximum using the BAMAX keyword, and the model will then compute a SDI maximum from the specified basal area maximum. However, this alternative is NOT recommended because a single SDI value will be applied to all species. This is not biologically correct and it also eliminates some sophistication of the mortality model (see MORTALITY section). Default SDI values for the CR variant are shown in Table 6.

Table 6. Default values for stand density index for the CR variant of FVS.

FVS Number	Alpha Code	Common Name	SDI Maximum
1	AF	Subalpine fir	735
2	CB	Corkbark fir	735
3	DF	Douglas-fir	560
4	GF	Grand fir	735
5	WF	White fir	735
6	MH	Mountain hemlock	735
7	RC	Western redcedar	770
8	WL	Western larch	650
9	BC	Bristlecone pine	470
10	LM	Limber pine	470
11	LP	Lodgepole pine	675
12	PI	Pinyon pine	415
13	PP	Ponderosa pine	529
14	WB	Whitebark pine	470
15	WP	Western white pine	645
16	JU	Western juniper	415
17	BS	Blue spruce	735
18	ES	Engelmann spruce	735
19	WS	White spruce	735
20	AS	Quaking aspen	725
21	CO	Cottonwoods	470
22	OA	Oaks	470
23	OS	Other softwoods	470
24	OH	Other hardwoods	470

3.6 PLANT ASSOCIATIONS

Plant association codes are only used in the fire and fuels extension to this variant (see section 7.0), they are not used in any of the growth relationships. Users do not need to enter plant association codes if the fire and fuels extension is not being used.

Plant association codes are entered in field 2 of the STDINFO keyword. Plant association codes are used to select the appropriate default fuel model. Codes recognized in this variant are the NRIS Common Stand Exam codes (USDA Forest Service 2000), pre-pended with a one-digit Region number. Valid codes are shown in Appendices A and B. Region 2 codes originate from Johnson (1987), and Region 3 codes from USDA Forest Service (1997).

4.0 GROWTH MODEL RELATIONSHIPS

For discussion purposes, model relationships can be broken into groups by their function. There are those that estimate values missing in the input data; those that estimate growth on trees smaller than some threshold diameter; those that estimate growth on trees larger than some threshold diameter; those used for mortality; and those used for crown ratio change.

4.1 HEIGHT – DIAMETER RELATIONSHIPS

Height-diameter relationships are used for two purposes in the model: (1) to estimate heights missing in the input data, and (2) to estimate diameter growth on trees smaller than some threshold diameter. In the CR variant, height-diameter relationships are a logistic functional form, as shown in equation {1} (Wykoff, et.al 1982). The equation was fit to data of the same species used to develop other FVS variants. Default equation coefficients are shown in Table 7.

{1} $HT = 4.5 + e^{a + b/(DBH+1)}$

where HT is the total tree height in feet
DBH is the tree diameter at breast height
a, b are species specific coefficients show in Table 7

When heights are given in the input data for 3 or more trees of a given species, the value of "a" in equation {1} for that species is recalculated from the input data and replaces the default value shown in Table 7. In the event that the calculated value is less than zero, the default is used..

Table 7. Default coefficients for the CR variant height-diameter relationship

FVS Number	Alpha Code	Common Name	"a" Coefficient	"b" Coefficient
1	AF	Subalpine fir	4.4717	-6.7387
2	CB	Corkbark fir	4.4717	-6.7387
3	DF	Douglas-fir	4.5879	-8.9277
4	GF	Grand fir	5.0271	-11.2168
5	WF	White fir	4.3008	-6.8139
6	MH	Mountain hemlock	4.8740	-10.4050
7	RC	Western redcedar	5.1631	-9.2566
8	WL	Western larch	5.1631	-9.2566
9	BC	Bristlecone pine	4.1920	-5.1651
10	LM	Limber pine	4.1920	-5.1651
11	LP	Lodgepole pine	4.3767	-6.1281
12	PI	Pinyon pine	4.1920	-5.1651
13	PP	Ponderosa pine	4.6024	-11.4693
14	WB	Whitebark pine	4.1920	-5.1651
15	WP	Western white pine	5.1999	-9.2672
16	JU	Western juniper	4.1920	-5.1651
17	BS	Blue spruce	4.5293	-7.7725
18	ES	Engelmann spruce	4.5293	-7.7725
19	WS	White spruce	4.5293	-7.7725
20	AS	Quaking aspen	4.4421	-6.5405
21	CO	Cottonwoods	4.4421	-6.5405
22	OA	Oaks	4.1920	-5.1651
23	OS	Other softwoods	4.2597	-9.3949
24	OH	Other hardwoods	4.4421	-6.5405

For the Black Hills Ponderosa Pine model type, the default height-diameter relationships for all species is shown in the following equations:

{2} $HT = 32.108633 * (SI^{0.276926}) * [(1-e^{-0.057766*DBH})^{1.0026686}] + 4.5$ for DBH > 0.5”

{3} $HT = DBH * [12.41173 + 0.04633*SI - 0.000158*SI^2]$ for DBH ≤ 0.5”

where HT is the total tree height in feet
DBH is the tree diameter at breast height
SI is the site index for the species

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 STAGNATION EFFECT

A stagnation effect on growth and mortality is built into the Central Rockies variant. The stagnation effect, equation {4}, is a number between 0.5 and 1.0 which indicates a proportion reduction in growth and mortality due to a stand becoming stagnated. The full stagnation effect is applied to large tree diameter growth and half the stagnation effect is applied to large tree height growth. The default condition in the variant is to not consider stagnation effects on growth. However, users can activate this feature by putting a 1 in field 7 of the SDIMAX keyword.

{4} DSTAG = 3.33333 * (1 – RELSDI) for $0.7 < RELSDI \le 0.85$

DSTAG = 1.0 for $RELSDI \le 0.7$
DSTAG = 0.5 for $RELSDI > 0.85$

where RELSDI = current stand density index / maximum stand density index

4.3 BARK RATIO RELATIONSHIPS

Bark ratio estimates are used to convert between diameter outside bark and diameter inside bark in various parts of the model. Equation forms used in the Central Rockies variant are shown below, and coefficients for these equations are shown in Table 8.

Equation forms:
{1} $BRATIO = b_1 + b_2 * [1/DBH]$
{2} $BRATIO = b_1$

BRATIO = bark ratio (bounded to be $0.80 \le BRATIO \le 0.99$)
DBH = tree diameter at breast height (bounded to be $DBH \ge 1.0$ for this calculation)

Table 8. Coefficients for the bark ratio equations in the Central Rockies FVS variant.

FVS Number = Alpha Code; Model Type	Equation Form	b_1	b_2	Equation Source
1 = AF	2	0.890	0.	PP from Wykoff, et. al. 1982
2 = CB	2	0.890	0.	PP from Wykoff, et. al. 1982
3 = DF	2	0.867	0.	Wykoff, et. al. 1982
4 = GF	2	0.890	0.	PP from Wykoff, et. al. 1982
5 = WF	2	0.890	0.	PP from Wykoff, et. al. 1982
6 = MH	2	0.9497	0.	Wykoff, et. al. 1982
7 = RC	2	0.9497	0.	Wykoff, et. al. 1982
8 = WL	1	0.87407	-0.185	Schmidt, et. al. 1976
9 = BC	1	0.9625	-0.1141	Uses LP equation
10 = LM	1	0.9625	-0.1141	Uses LP equation
11 = LP	1	0.9625	-0.1141	Myers 1964
12 = PI; SM, SP	1	0.8967	-0.4448	PP from Dolph PSW-368
12 = PI; all other	1*	0.9002	-0.3089	Uses PP equation
13 = PP; SM, SP	1	0.8967	-0.4448	PP from Dolph PSW-368
13 = PP; all other	1*	0.9002	-0.3089	Myers & Van Deusen 1958
14 = WB	1	0.9625	-0.1141	Uses LP equation
15 = WP	2	0.9643	0.	Wykoff, et. al. 1982
16 = JU; SM, SP	1	0.8967	-0.4448	PP from Dolph PSW-368
16 = JU; all other	1*	0.9002	-0.3089	Uses PP equation
17 = BS	1	0.9502	-0.2528	Uses ES equation
18 = ES	1	0.9502	-0.2528	Myers & Alexander 1972
19 = WS	1	0.9502	-0.2528	Uses ES equation
20 = AS	2	0.950	0.	Utah FVS variant
21 = CO	1	0.892	-0.086	Edminster, et. al. 1977
22 = OA	1	0.93789	-0.24096	Clark, et. al. 1991
23 = OS; SM, SP	1	0.8967	-0.4448	PP from Dolph PSW-368
23 = OS; all other	1*	0.9002	-0.3089	Uses PP equation
24 = OH	1	0.892	-0.086	Uses CO equation

* DBH limited to $1.0 \le DBH \le 19.0$ inches in this calculation

4.4 CROWN COMPETION FACTOR AND CROWN WIDTH

The Central Rockies variant uses crown competition factor (CCF) as a predictor variable in some growth relationships, and crown width for each tree is reported on the tree list output table and used for percent cover calculations in the model. Crown competition factor for an individual tree is calculated using equation {5}, the coefficients shown in Table 9, and the appropriate equation index from Table 10. Crown competition factor, on a per-acre basis, is computed by multiplying the individual tree CCF values by the tree's per-acre representation, and summing these products over all trees in the stand. Crown width is calculated using equation {6}.

{5} $CCFT = 0.001$ for $DBH \le 0.1$

$CCFT = a * DBH^{b}$ for $0.1 < DBH < 10.0$

$CCFT = c + d * DBH + e * DBH^2$ for $DBH \ge 10.0$

where CCFT = crown competition factor for an individual tree
DBH = diameter at breast height
and coefficients are shown in Table 9

{6} Crown Width = square root [CCFT / 0.001803]

Table 9. Coefficients for the crown competition factor equations used in the Central Rockies Variant

Equation Index	a	b	c	d	e
1	0.009187	1.76	0.01925	0.0167	0.00365
2	0.017299	1.5571	0.11	0.0333	0.00259
3	0.015248	1.7333	0.04	0.0270	0.00405
4	0.011109	1.7250	0.03	0.0215	0.00363
5	0.008915	1.78	0.03	0.0238	0.00490
6	0.007875	1.7360	0.03	0.0173	0.00259
7	0.011402	1.7560	0.03	0.0216	0.00405
8	0.007813	1.7680	0.03	0.0180	0.00281

Table 10. Index to crown competition factor equations used in the Central Rockies Variant

FVS Number = Alpha Code	SM model type Equation Index	SP model type Equation Index	BH model type Equation Index	SF model type Equation Index	LP model type Equation Index
1 = AF	7	3	1	7	7
2 = CB	7	3	1	7	7
3 = DF	2	2	2	2	2
4 = GF	7	3	1	7	7
5 = WF	3	3	1	7	7
6 = MH	1	1	1	1	1
7 = RC	1	1	1	1	1
8 = WL	1	1	1	1	1
9 = BC	1	1	1	1	1
10 = LM	1	1	1	1	1
11 = LP	1	1	1	1	1
12 = PI	1	7	1	1	1
13 = PP	8	8	8	1	8
14 = WB	1	1	1	1	1
15 = WP	1	1	1	1	1
16 = JU	1	1	1	1	1
17 = BS	1	1	6	6	6
18 = ES	6	1	6	6	6
19 = WS	6	1	6	6	6
20 = AS	5	5	5	5	5
21 = CO	4	4	1	4	4
22 = OA	4	6	4	4	4
23 = OS	1	1	1	1	1
24 = OH	4	4	4	4	4

4.5 SMALL TREE GROWTH RELATIONSHIPS

Trees are considered "small" trees for FVS modeling purposes when they are smaller than some threshold diameter. This threshold diameter is a function of the lower diameter limit in the data used to fit the model, and how well the model formulation used to estimate growth on "large" trees fits trees in the lower end of the diameter range. In the Central Rockies variant, the threshold diameter for each species is shown in Table 11.

Table 11. Threshold diameters for switching between small tree growth equations and large tree growth equations in the Central Rockies FVS variant, and the range of diameters (minimum and maximum) over which small tree height growth estimates are weighted with large tree estimates to assure a smooth transition between the two model formulations.

FVS Number	Alpha Code	Common Name	Threshold dbh	Minimum DBH	Maximum DBH
1	AF	Subalpine fir	1.0	0.5	2.0
2	CB	Corkbark fir	1.0	0.5	2.0
3	DF	Douglas-fir	1.0	0.5	2.0
4	GF	Grand fir	3.0	2.0	5.0
5	WF	White fir	1.0	0.5	2.0
6	MH	Mountain hemlock	3.0	2.0	4.0
7	RC	Western redcedar	3.0	2.0	5.0
8	WL	Western larch	3.0	2.0	5.0
9	BC	Bristlecone pine	99.0*	99.0*	N/a
10	LM	Limber pine	2.0	0.5	4.0
11	LP	Lodgepole pine	1.0	0.5	2.0
12	PI	Pinyon pine	99.0*	99.0*	N/a
13	PP	Ponderosa pine	1.0	0.5	2.0
14	WB	Whitebark pine	1.0	0.5	2.0
15	WP	Western white pine	1.0	0.5	2.0
16	JU	Western juniper	99.0*	99.0*	N/a
17	BS	Blue spruce	1.0	0.5	2.0
18	ES	Engelmann spruce	1.0	0.5	2.0
19	WS	White spruce	1.0	0.5	2.0
20	AS	Quaking aspen	1.0	0.5	2.0
21	CO	Cottonwoods	1.0	0.5	2.0
22	OA	Oaks	99.0*	99.0*	N/a
23	OS	Other softwoods	1.0	0.5	2.0
24	OH	Other hardwoods	1.0	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.

The small tree model is height-growth driven. That is to say, height growth is estimated first, then diameter growth is estimated from height growth, and finally crown ratio change is estimated. These components are discussed in the following sections.

4.5.1 Small Tree Height Growth

Data was not available to fit small tree height growth models for the Central Rockies variant for species other than aspen. As a result, for all species except aspen, the CR variant uses a blend of theoretical models for CR, and small tree height growth modifier equations from the Utah FVS 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 as follows:

{7} RELSI = (SI – SITELO) / (SITEHI – SITELO)

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

where RELSI = relative site index
SI = site index
SITELO = lower end of the site range for this species (see Table 12)
SITEHI = upper end of the site range for this species (see Table 12)
POTHTG = potential height growth
C = constant (1.10 for red cedar and western larch; 1.0 for all other species)

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.

Table 12. Site index range used for the calculating small tree height growth in the Central Rockies FVS variant

FVS Number	Alpha Code	Common Name	SITELO	SITEHI
1	AF	Subalpine fir	40	105
2	CB	Corkbark fir	30	100
3	DF	Douglas-fir	40	120
4	GF	Grand fir	30	130
5	WF	White fir	40	105
6	MH	Mountain hemlock	40	70
7	RC	Western redcedar	20	125
8	WL	Western larch	40	120
9	BC	Bristlecone pine	20	60
10	LM	Limber pine	10	60
11	LP	Lodgepole pine	30	95
12	PI	Pinyon pine	6	40
13	PP	Ponderosa pine	30	100
14	WB	Whitebark pine	20	60
15	WP	Western white pine	30	130
16	JU	Western juniper	6	30
17	BS	Blue spruce	30	110
18	ES	Engelmann spruce	40	120
19	WS	White spruce	30	85
20	AS	Quaking aspen	20	100
21	CO	Cottonwoods	30	120
22	OA	Oaks	6	40
23	OS	Other softwoods	30	95
24	OH	Other hardwoods	20	100

Once potential height growth is estimated, the height growth modifiers are calculated. The density related modifier is based on stand crown competition factor and average height of the 40 largest diameter trees, equation {9}.

{9} $$PCTRED = 1.11436 - 0.011493*X + 0.43012E\text{-}04 * X^2 - 0.72221E\text{-}07 * X^3 + 0.5607E\text{-}10 * X^4 - 0.1641E\text{-}13 * X^5$$

where $X = AVHT * (CCF/100.)$ with an upper bound of X=300.

and PCTRED = reduction proportion in height growth due to stand density
AVHT = average height of the 40 largest diameter trees in the stand
CCF = stand crown competition factor

PCTRED is bounded on the upper side at 1.0, and on the lower side at 0.01. The vigor multiplier is based on a trees live crown ratio, equation {10}.

{10} $VIGOR = (150 * CR^3 * e^{(-6 * CR)}) + 0.3$

where VIGOR = reduction proportion in height growth due to tree vigor
CR = a trees' live crown ratio (compacted) expressed as a proportion

VIGOR is bounded on the upper side at 1. The vigor modifier is reduced, equation {11}, for pinyon pine, juniper, oaks, and bristlecone pine.

{11} VIGOR = 1 – [(1-VIGOR) / 3] for pinyon, juniper, oaks, and bristlecone pine

Small tree height growth for an individual tree other than aspen is then estimated as the potential height growth adjusted by these two modifiers, equation {12}. A small random error is added to this estimate, and the estimate is then adjusted to account for cycle length and any user defined small-tree height growth adjustments.

{12} Height growth = POTHTG * PCTRED * VIGOR

Height growth for small aspen is obtained from a height-age curve (Shepperd 1995). Shepperd's original curve seemed to overestimate height growth and is reduced by 25 percent in this variant, equation {13}.

{13} $Height = (26.9825 * Age^{1.1752}) * 0.75$

where Height is total tree height in centimeters and Age is the total tree age

A height is estimated from the trees' current age, and then it's 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 {13} for age.

Height growth estimates from the small tree model are weighted, using equation {14}, with height growth estimates from the large tree model to assure a smooth transition between the two models.

{14} Predicted height growth = (small tree height growth)*(1 –weight) + (large tree height growth)*weight

where weight = (diameter – minimum DBH) / (maximum DBH – minimum DBH)
weight = 0 if diameter is less than the minimum DBH shown in Table 11
weight = 1 if diameter is greater than the maximum DBH shown in Table 11

4.5.2 Small Tree Diameter Growth

The height-diameter functions discussed in the Height – Diameter Relationships section are used to estimate small tree diameter growth for all species except ponderosa pine, bristlecone pine, pinyon pine, juniper, and oaks. The functions are algebraically solved to estimate diameter as a function of height. Height at the start of the projection cycle is known, and height at the end of the cycle is obtained by adding the height growth (as described in section 4.5.1) to the starting height. A predicted diameter at the start of the projection cycle is estimated from the height at the start of the projection cycle, and a predicted diameter at the end of the projection cycle is estimated from the height at the end of the projection cycle. Small tree diameter growth is calculated as the difference between predicted diameter at the start of the projection period and the predicted diameter at the end of the projection period, adjusted for bark ratio.

Ponderosa pine uses equation {14a} in the same manner as just described for the other species.

{14a} Diameter at breast height = (height – 4.17085) / 3.03659

Bristlecone pine, pinyon pine, juniper, and oaks use equation {14b} as previously described.

{14b} Diameter at breast height = (height – 4.5) * 10 / (SI – 4.5)

where SI is the site index for the individual species

4.5.3 Crown Ratio Change

See section 4.6.3 in the Large Tree Growth Relationships section 4.6.

4.6 LARGE TREE GROWTH RELATIONSHIPS

The large tree model in FVS is diameter-growth driven. That is to say, diameter growth is estimated first, then height growth is estimated from diameter growth and other variables, and finally crown ratio change is estimated. 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, pinyon pine, western juniper and oaks. This equation did not perform satisfactorily for these species and is not used for these species in this variant. However, this equation is used in both GENGYM and this variant for estimating diameter growth on trees classified as "other softwoods".

4.6.1 Large Tree Diameter Growth

Of the 24 species in this variant, 14 use the GENGYM diameter growth equations. Equations from GENGYM predict a tree's future diameter based on stand and tree variables. The equation form is shown in {15} with coefficients shown in Table 13.

{15} $DF = a_0 + a_1 * DBH + a_2 * BA + a_3 * SI + a_4 * [LN(DBH)]^2 + a_5 * BGTTBA + a_6 * LN(BATEM) + a_7 * DBH^2$

where
DF = end of cycle diameter at breast height
DBH = current tree diameter at breast height (DBH $\geq$ 1.0 for this computation)
BA = total stand basal area
SI = site index
BGTTBA = basal area above this tree's diameter class / total stand basal area
BATEM = total stand basal area
LN = natural logarithm

BGTTBA and BATEM are subject to the following restrictions:
Southwestern Mixed Conifers model type:
BATEM $\geq$ 1.0
If BATEM is less than 65, then BGTTBA is set to 0.
Southwestern Ponderosa Pine model type:

BATEM $\geq$ 21.

Black Hills Ponderosa Pine and Spruce-Fir model types:

BATEM $\geq$ 5.

Lodgepole pine model type:

BATEM $\geq$ 14.

Table 13. Coefficients for calculating large tree diameter growth in the Central Rockies FVS variant, for species using the GENGYM equations.

FVS Number = Alpha Code: Model Type	a_0	DBH a_1	BA a_2	SI a_3	LN(DBH)^2 a_4	BGTTBA a_5	LN(BATEM) a_6	DBH^2 a_7
1 = AF: SM,SP	0.50283	0.93999	-0.0016822	0.00791	0.16235			
1 = AF: all other	2.19459	0.94659		0.00615	0.11326	-0.20410	-0.35970	
2 = CB: SM,SP	0.50283	0.93999	-0.0016822	0.00791	0.16235			
2 = CB: all other	2.19459	0.94659		0.00615	0.11326	-0.20410	-0.35970	
3 = DF: all	0.58234	0.94542	-0.0025092	0.00705	0.15738	-0.14044		
4 = GF: **								
5 = WF: all	0.46172	1.04089	-0.0019984	0.00659		-0.09197		-0.0011355
6 = MH: **								
7 = RC: **								
8 = WL: **								
9 = BC: ***								
10 = LM: **								
11 = LP: all	1.32652	0.96279		0.00590	0.06298	-0.17138	-0.21827	
12 = PI: ***								
13 = PP: SM*	0.26265	0.94001	-0.0016405	0.00601	0.16328			
13 = PP: SP	4.10552	0.88872		0.01378	0.23834	-0.52784	-0.83531	
13 = PP: BH*	2.50428	0.94573		0.01354	0.05940	-0.46350	-0.45765	
13 = PP: LP,SF	2.50428	0.94573		0.01354	0.05940	-0.46350	-0.45765	
14 = WB: **								
15 = WP: all	0.89451	0.95435	-0.0012183	0.00159	0.09987	-0.20815		
16 = JU: ***								
17 = BS: all	0.50941	1.02697	-0.0035783	0.01022				-0.0009882
18 = ES: SM,SP	0.67074	1.03068	-0.0020055	0.00633				-0.0010875
18 = ES: all other	2.28652	0.94475		0.01295	0.10778	-0.48056	-0.41632	
19 = WS: all	2.94734	0.88423		0.01207	0.25363		-0.64449	
20 = AS: SM,SP	0.24506	1.01291	-0.0008466	0.00631				
20 = AS: all other	1.55986	1.01825		0.00672		-0.00073	-0.29342	
21 = CO: SM,SP	0.24506	1.01291	-0.0008466	0.00631				
21 = CO: all other	1.55986	1.01825		0.00672		-0.00073	-0.29342	
22 = OA: ***								
23 = OS: all	0.25897	1.03129	-0.0002025	0.00177				
24 = OH: SM,SP	0.24506	1.01291	-0.0008466	0.00631				
24 = OH: all other	1.55986	1.01825		0.00672		-0.00073	-0.29342	

Coefficients shown as blanks are equal to zero.

*see discussion below

**uses equations from another variant; described below

***uses the equations described for the small tree model for all sized trees

In the Southwestern Mixed Conifer (SM) model type, the estimated future diameter for ponderosa pine is a blend {16} 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.

{16} DF = (1.0 – FACTOR) * SMDF + FACTOR * SPDF

where DF = end of cycle diameter (blended)
FACTOR = adjustment factor which is the maximum of ADJB and ADJR, shown below
SMDF = estimated future diameter using the SM model type equation
SPDF = estimated future diameter using the SP model type equation

and

ADJB = 0.0	for stand basal area $\geq$ 100
= 2.5 - 0.025 * stand basal area	for 60 < stand basal area < 100
= 1.0	for stand basal area $\leq$ 60

ppratio = ponderosa pine basal area / stand basal area

ADJR = 0.0	for ppratio $\leq$ 0.3
= -1.5 + 5.0 * ppratio	for 0.3 < ppratio < 0.5
= 1.0	for 0.5 $\leq$ ppratio

Similarly, in the Black Hills Ponderosa pine (BH) model type, the estimated future diameter for ponderosa 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; (2) whether the tree exists in an overtopped condition; and (3) whether the estimated future diameter using the BH equation is greater than the estimated future diameter using the SP equation. A stand is considered uneven-aged if the range in age between the 5th percentile tree and the 95th percentile tree exceeds 40 years. 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). If all three of these conditions are met, the estimated future diameter is a blend {17} of the estimate using the equation shown for the BH model type and an estimate from the equation shown for the Southwestern Ponderosa Pine (SP) model type.

{17} DF = SPDF	for baratio $\geq$ 0.5
DF = (2.5 – 5.0 * baratio) * BHDF + (-1.5 + 5.0 * baratio) * SPDF	for 0.3 < baratio < 0.5

where DF = estimated future diameter (blended)
SPDF = estimated future diameter using the SP model type equation
BHDF = estimated future diameter using the BH model type equation
baratio = basal area in dbh classes larger than this trees dbh class / 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 {18}, adjusting this value to account for a stagnation effect {19}, and then converting the result to a DDS basis using equation {20}.

{18} DIAGR = (Estimated Future Diameter – Current Diameter) * Bark Ratio

{19} DIAGR = DIAGR * Stagnation Multiplier	for species other than Black Hills ponderosa pine
= DIAGR * Stagnation Multiplier * 0.8	for ponderosa pine in the Black Hills model type

{20} DDS = LN [(DIAGR * {(2.0 * Current Diameter * Bark Ratio) + DIAGR})]

Six species use large tree diameter growth relationships from other variants, which predict DDS directly. The grand fir equation is from the Central Idaho variant. Equations for mountain hemlock, western red cedar, and western larch are from the North Idaho 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 variant. The whitebark pine equation is from the Eastern Montana 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 {21} with species-specific coefficients shown in Table 14.

$$\{21\}\ DDS = a_0 + a_1 * SIN(ASPECT) * SLOPE + a_2 * COS(ASPECT) * SLOPE + a_3 * SLOPE + a_4 * SLOPE^2 + a_5 * LN(DBH) + a_6 * DBH^2 + a_7 * BAL + a_8 * CR + a_9 * CR^2 + a_{10} * LN(BA) + a_{11} * PCCF + a_{12} * BAL/LN(DBH+1) + a_{13} * PBAL/LN(DBH+1) + a_{14} * LN(RELDEN) + a_{15} * RELDEN + a_{16} * SI$$

where:
SIN = trigonometric sine function
COS = trigonometric cosine function
LN = natural logarithm
ASPECT = stand aspect
SLOPE = stand slope in percent
DBH = tree diameter at breast height
BAL = total stand basal area in trees larger than this tree
CR = crown ratio expressed as a proportion
BA = total stand basal area
PCCF = crown competition factor for the sampling point where the tree is located
RELDEN = crown competition factor for the stand
PBAL = basal area on the sampling point in trees larger than this tree
SI = site index

Table 14. Coefficients for calculating large tree diameter growth in the Central Rockies FVS variant, for species using DDS equations from other variants

Coefficient	Grand Fir	Mtn hemlock	W Red Cedar	W Larch	Limber Pine	Whitebark Pine
a_0	0.88728	0.19489	1.26832	1.39215	1.911884	-0.5933
a_1	0.009335	0.13363	0.05534	0.03430	-0.01752	-0.01606
a_2	-0.004469	0.17935	-0.06625	-0.21337	-0.609774	0.00270
a_3	-0.033374	0.07628	0.11931	0.33523	-2.05706	-0.20011
a_4	-0.418343			-0.70216	2.113263	
a_5	1.286963	0.89778	0.58705	0.54140	0.213947	0.80110
a_6	-0.0004408	-0.000484		-0.000310	-0.0006538	
a_7			0.0074596	0.0043637	-0.00358634	0.00064
a_8	1.175105	1.28403	1.29360	1.03478	1.523464	1.02878
a_9	0.219013			0.07509		-0.45448
a_{10}	-0.217923					
a_{11}	-0.000512					
a_{12}		-0.006611	-0.0228375	-0.0203256		-0.00328
a_{13}	-0.000578					
a_{14}						-0.25717
a_{15}		-0.0010744	-0.0015356	-0.0005438	-0.00199592	
a_{16}					0.001766	

*Coefficients shown as blanks are equal to zero.
.

Once DDS is estimated using equation {21}, it must be transformed into a real scale diameter growth using equation {22}, adjusted for the stagnation effect {23}, and then converted back to DDS scale {20} for further processing.

{22} DIAGR = SQRT { EXP(DDS) + [(DBH*Bark Ratio)^2] } – DBH * Bark Ratio

{23} DIAGR = DIAGR * Stagnation Multiplier

For bristlecone pine, pinyon pine, juniper, and oaks, the equations described in the small tree model section are used for trees of all sizes.

4.6.2 Large Tree Height Growth

Height growth equations used in the Central Rockies variant for large trees have the same origins as the diameter growth equations used for large trees. In other words, equations for 14 of the species come from the GENGYM model, equations for 6 species come from other variants, and 4 species use the equations described in the small tree model section.

The equations from GENGYM predict height growth from the site index curves listed in Table 4 for even-aged stands, and height growth from a regression equation for uneven-aged stands. These estimates get blended when certain conditions are met.

4.6.2.1 EVEN-AGED STANDS HEIGHT GROWTH ESTIMATE

First a height is estimated from the site curve using the beginning of cycle DBH and estimated tree age. Next, a second height is estimated from the site curves using the end of cycle DBH and the estimated age plus 10 years. The 10-year even-aged height growth estimate is then the difference between these two estimates.

4.6.2.1.1 SW Mixed Conifers Model Type

The even-aged height growth estimation sequence is a four-step process. First an age is determined, second heights from the guide curve and the lower 95 percent confidence interval are estimated, third these estimates are combined, and fourth 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 first set to the tree's 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).

Second, total tree height on the appropriate guide curve (HG) is determined using equation {24}.

{24} $HG = 4.5 + 109.559129 * (1 – 0.975884 * e^{-0.014377*AGETEM})^{1.289266}$

The estimated height of the lower bound of the 95 percent confidence interval (HL) is determined using equation {25}.

{25} $HL = 72.512644 * (1 – 0.876961 * e^{-0.020066*AGETEM})^{2.016632}$

Third, the estimates are combined using equation {26}.

{26} HT = -[(HG-HL) * ((82.488 – Site Index) / 26.279)] + HG

where HT = the even-aged height estimate, given the tree's age

If site index is 80, or greater, and the tree's age is less than AGETEM as determined above, HT is further modified using equation {27}.

{27} $HT = 4.5 + [(HT - 4.5) / AGETEM] * \text{tree age}$

If site index is greater than or equal to 80 and AGETEM is less than 20, then the estimate of HT, using equations {26} and {27}, is replaced by an estimate of HT using equation {28}.

{28} $HT = 4.5 + [(0.02348 * \text{Site Index}) - 0.93429] * AGETEM$

And finally, the estimated HT is multiplied by an adjustment factor {29} to account for a tree's position in the canopy.

{29} $HT = HT * FACTOR$

where FACTOR = (1 – basal area above the trees' diameter class / total stand basal area)
and FACTOR is constrained to be in the interval (0.768 – 1.0)

4.6.2.1.2 SW 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, and fourth 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 first set to the tree's 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 (120 – Site Index).

Second, total tree height on the appropriate guide curve (HG) is determined using equation {30}.

{30} $HG = 4.5 + 106.493954 * (1 - 0.938775 * e^{-0.016066*AGETEM})^{1.550720}$

The estimated height of the lower bound of the 95 percent confidence interval (HL) is determined using equation {31}.

{31} $HL = 78.078735 * (1 - 0.843715 * e^{-0.020412*AGETEM})^{2.280435}$

Third, the estimates are combined using equation {32}.

{32} $HT = -[(HG-HL) * ((81.5585 - \text{Site Index}) / 21.7149)] + HG$

where HT = even-aged height estimate given the tree's age

If site index is 80, or greater, and the tree's age is less than AGETEM as determined above, HT is further modified using equation {27}.

If site index is greater than or equal to 80 and AGETEM is less than 20, then the estimate of HT using equations {32} and {27} is replaced by an estimate of HT using equation {33}.

{33} $HT = 4.5 + [(0.02463 * \text{Site Index}) - 1.1025] * AGETEM$

And finally, the estimate HT is multiplied by an adjustment factor {29} to account for a trees position in the canopy.

4.6.2.1.3 Black Hills Ponderosa Pine Model Type

Even-aged height is estimated using Meyer's (1961) ponderosa pine site curves. If the trees' height is above the height at which the site curve flattens off {34}, or the tree is over 165 years old, 10-year height growth is set to 0.1 foot.

{34} Height at which site curve flattens off = (Site Index + 0.3846) * 1.2999886

Otherwise, height is calculated using equation {35}.

{35} $HT = (\text{Site Index} + 0.3846) * (-0.5234 + 1.8234 * e^{-(1.0989 - 0.006105 * \text{tree age})\ 2.35})$

A height is estimated for the tree's current age and the current age + 10 years. Height growth is then the difference between these two estimates {36}, and is modified using equation {37}.

{36} HTG = HT10 – HTNOW

where HTNOW is equation {35} evaluated with the current tree age
HT10 is equation {35} evaluated with the current tree age + 10 years

{37} HTG = HTG * FACTOR

where FACTOR = (1 – basal area above the trees' diameter class / total stand basal area)
and FACTOR is constrained to be in the interval (0.793 – 1.0)

So the estimate in the Black Hills model type is actually a height growth estimate, rather than a height estimate. This is a minor, but necessary, point relating to the discussion below on combining estimates.

4.6.2.1.4 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 {38} with AGETEM being the tree age or 30, whichever value is greater.

{38} $HT = 4.5 + (2.75780 * \text{Site Index}^{0.83312}) * [1 - e^{(-0.015701 * \text{tree age})}]^{(22.71944 * \text{Site Index}^{-0.63557})}$

If the tree age is less than 30 years, then the height estimate is modified using equation {39}.

{39} HT = 4.5 + [(HT – 4.5) / AGETEM] * tree age

And finally, the height estimate is modified for the trees' crown position using equation {40}.

{40} HT = HT * FACTOR

where FACTOR = (1 – basal area above the trees' diameter class / total stand basal area)
and FACTOR is constrained to be in the interval (0.728 – 1.0)

4.5.2.1.5 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 {41} with AGETEM being the tree age constrained to the interval (30 – 200 years).

{41} $HT = 9.89331 - 0.19177 * AGETEM + 0.00124 * AGETEM^2 - 0.00082 * CCFTEM * SI + 0.01387 * AGETEM * SI - 0.0000455 * AGETEM^2 * SI$

where SI = Site Index

CCFTEM = (stand crown competition factor – 125)   constrained to be $\geq$ 0

If the tree age is less than 30 years, the estimate of HT is further modified using equation {42}.

{42} HT = (HT / AGETEM) * tree age

And finally, the height estimate is modified using equation {43} to account for the trees' crown position.

{43} HT = HT * FACTOR

where FACTOR = (1 – basal area above the trees' diameter class / total stand basal area)
and   FACTOR is constrained to be in the interval (0.742 – 1.0)

4.6.2.2 UNEVEN-AGED STANDS HEIGHT GROWTH ESTIMATE

Equations from GENGYM predict a tree's future height based on stand and tree variables. The equation form is shown in {44} with coefficients shown in Table 15.

{44} $HTU = 4.5 + a_1 * Si^{a2} * [1 - \exp(a_3 * DBH)]^{(a_4 * BATEM^{a_5})}$ for AF & CB in model types 1, 2; DF; WF; OS; PP; WP; BS; WS; ES in model types 1,2; AS, CO & OH in model types 1,2

$HTU = 4.5 + (a_1 + a_2 * SI) * [1 - \exp(a_3 * DBH)]^{(a_4 * BATEM^{a_5})}$ for AF & CB in model types 3, 4, 5; LP; WB; ES in model types 3,4,5; AS, CO & OH in model types 3,4,5

where HTU = end of cycle total height uneven-aged estimate
DBH = current tree diameter at breast height
SI = site index
BATEM = total stand basal area
and $a_1 - a_5$ are coefficients shown in Table 15

BATEM is subject to the following restrictions:
- Southwestern Mixed Conifers model type:
  - BATEM $\geq$ 1.0
- Southwestern Ponderosa Pine model type:
  - BATEM $\geq$ 21.
- Black Hills Ponderosa Pine and Spruce-Fir model types:
  - BATEM $\geq$ 5.
- Lodgepole pine model type:
  - BATEM $\geq$ 14.

Table 15. Coefficients for calculating large tree height uneven-aged estimate in the Central Rockies FVS variant, for species using the GENGYM equations.

FVS Number = Alpha Code: Model Type	a_1	a_2	a_3	a_4	a_5
1 = AF: SM,SP	4.514294	0.755380	-0.080869	1.409884	0.003919
1 = AF: all other	15.5	1.1	-0.097152	4.698567	-0.252630
2 = CB: SM,SP	4.514294	0.755380	-0.080869	1.409884	0.003919
2 = CB: all other	15.5	1.1	-0.097152	4.698567	-0.252630
3 = DF: all	13.096420	0.480509	-0.077408	1.237589	-0.063297
4 = GF: **					
5 = WF: all	13.822088	0.462393	-0.075766	1.312638	-0.040708
6 = MH: **					
7 = RC: **					
8 = WL: **					
9 = BC: ***					
10 = LM: **					
11 = LP: all	8.5	1.1	-0.085004	1.709643	-0.163186
12 = PI: ***					
13 = PP: SM	24.244690	0.343864	-0.069180	1.251384	-0.272018
13 = PP: SP	40.78321	0.332614	-0.021471	0.922811	-0.133923
13 = PP: BH,LP,SF	32.108633	0.276926	-0.057766	0.984340	-0.169876
14 = WB: all	8.5	1.1	-0.085004	1.709643	-0.163186
15 = WP: all	18.967185	0.379790	-0.071482	1.159608	-0.099449
16 = JU: ***					
17 = BS: all	54.180173	0.177962	-0.089253	1.533535	-0.028852
18 = ES: SM,SP	10.616238	0.549461	-0.087283	1.488355	-0.027226
18 = ES: all other	15.5	1.1	-0.110383	6.262899	-0.286055
19 = WS: all	54.180173	0.177962	-0.089253	1.533535	-0.028852
20 = AS: SM,SP	14.187987	0.416525	-0.126806	1.310744	-0.245126
20 = AS: all other	-2.04	1.4534	-0.058112	1.894400	-0.192979
21 = CO: SM,SP	14.187987	0.416525	-0.126806	1.310744	-0.245126
21 = CO: all other	-2.04	1.4534	-0.058112	1.894400	-0.192979
22 = OA: ***					
23 = OS: all	42.269377	0.	-0.165687	1.184734	0.
24 = OH: SM,SP	14.187987	0.416525	-0.126806	1.310744	-0.245126
24 = OH: all other	-2.04	1.4534	-0.058112	1.894400	-0.192979

Coefficients shown as blanks are equal to zero.
**uses equations from another variant; described below
***uses the equations described for the small tree model for all sized trees

Five species use large tree height growth relationships from other variants, to estimate uneven-aged height growth. These relationships predict height growth directly. The grand fir equation is from the Central Idaho variant. Equations for mountain hemlock, western red cedar, and western larch are from the North Idaho variant for elevation 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 variant. The equation form for four of these species is shown in {45} with species specific coefficients shown in Table 16.

{45} $HTG = EXP[CON + a_4 * LN(DG)] + 0.4809$

$$CON = a_0 + a_1 * HT^2 + a_2 * LN(DBH) + a_3 * LN(HT)$$

where: HT = total tree height
LN = natural logarithm
DBH = tree diameter at breast height
DG = diameter growth for the tree

Table 16. Coefficients for calculating large tree height growth in the Central Rockies FVS variant, for species using equations from other variants for uneven-aged height growth estimate

Coefficient	Grand Fir	Mtn hemlock	W Red Cedar	W Larch
a_0	1.38455	1.09510	1.21694	1.96089
a_1	-0.00013358	-0.0000446	-0.00003631	-0.00002607
a_2	-0.09775	-0.09775	-0.1219	-0.3899
a_3	0.23315	0.23315	0.23315	0.23315
a_4	0.62144	0.34003	0.37042	0.75756

.
Once uneven-aged height growth is estimated using equation {45}, it is adjusted for site index using equation {46} and the coefficients shown in Table 17.

{46} HTG = HTG * [a + b * SI]

where SI = site index, and site index is bounded to the range shown in Table 17 and the adjustment factor [a + b * SI] is bounded to be 1.0 or greater for Western Red Cedar

Table 17. Coefficients for adjusting the large tree uneven-aged height growth estimate in the Central Rockies FVS variant for site index.

Coefficient	Grand Fir (SI $\leq$ 80)	Grand Fir (SI > 80)	Mtn hemlock	W Red Cedar	Western Larch	Limber Pine (SI < 40)	Limber Pine (SI $\geq$ 40)
a	0.1	-0.7	0.36	0.0875	0.23337	0.2	-0.1
b	0.0125	0.0225	0.012	0.01375	0.008333	0.015	0.0225
SI lower bound	40	40	40	40	40	20	20
SI upper bound	120	120	70	110	120	60	60

The equation for limber pine predicts future height and is more complex. If the beginning of cycle diameter or end of cycle diameter are 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 the following set of equations is used:

Y1 = (DBH – 0.1) / 45
Y2 = (HT – 4.5) / 90
FBY1 = LN[Y1/(1 - Y1)]
FBY2 = LN[Y2/(1 - Y2)]
Z = [0.30546 + 0.94823 * FBY2 – 0.70453 * (1.64770 + 1.35015 * FBY1)] * 1.40910

$$PSI = 2.46480 * [(D10 - 0.1) / (45.1 - D10)]^{1.00316} * [e^{(0.74842 * Z)}]$$
H10 = [(PSI / (1 + PSI)) * 90] + 4.5

HTG = H10 – HT if H10 > HT
= 0.1 otherwise

where DBH = beginning of cycle diameter
HT = beginning of cycle height
D10 = end of cycle diameter
H10 = end of cycle height

Height growth is then adjusted for site index using equation {46} and the coefficients shown in Table 17.

4.6.2.3 COMBINING THE ESTIMATES INTO THE FINAL HEIGHT GROWTH ESTIMATE

As stated at the beginning of this section, the GENGYM equations predict height rather than height growth. In addition, there is an even-aged height estimate and an uneven-aged height estimate corresponding to the beginning of the growth cycle conditions and the end of the growth cycle conditions. These need to be combined to form the final height growth estimate.

The first step in this process, for model types other than the Black Hills, is to take the difference of the estimates to form the two height growth estimates {47} and {48}.

{47} HTGE = HTE10 – HTEnow

{48} HTGU = HTU10 – HTUnow

where HTGE is the even-aged height growth estimate
HTGU is the uneven-aged height growth estimate
HTEnow is the even-aged height estimate using beginning of cycle tree age
HTE10 is the even-aged height estimate using beginning of cycle tree age + 10 years
HTUnow is the uneven-aged height estimate using beginning of cycle values
HTU10 is the uneven-aged height estimate using end of cycle values (10 year cycle)

For the Black Hills model type, HTGE was already determined {36} and {37} and HTGU is estimated using {48}.

The second step in the process is to adjust the even-aged estimate for the Lodgepole Pine model type for young trees. This is necessary so the even-aged estimates match the site curve at age 30. If the tree age is less than 30, then even-aged height growth is estimated using equation {49}.

{49} HTGE = [(5.25621 + 0.37515 * SI – 0.00082 * CCF * SI) * (AGE/31)] – HT

where SI = site index
CCF = crown competition factor for the inventory point on which the tree is located
AGE = current tree age
HT = beginning of cycle tree height

The third step is to multiply the even-aged estimate by a species specific adjustment factor so the trees will go through the site height. This is done for all model types using equation {50} and the factors shown in Table 18.

{50} HTGE = HTGE * FACTOR

Table 18. Even-aged height growth adjustment factors for the Central Rockies FVS variant.

FVS Number = Alpha Code	SM model type FACTOR	SP model type FACTOR	BH model type FACTOR	SF model type FACTOR	LP model type FACTOR
1 = AF	1.25	1.25	1.13	1.15	1.25
2 = CB	1.25	1.25	1.13	1.15	1.25
3 = DF	1.18	1.18	1.10	1.18	1.25
4 = GF	1.00	1.00	1.10	1.00	1.10
5 = WF	1.20	1.20	1.13	1.15	1.25
6 = MH	1.00	1.00	1.10	1.00	1.10
7 = RC	1.00	1.00	1.10	1.00	1.10
8 = WL	1.00	1.00	1.10	1.00	1.10
9 = BC	1.00	1.00	1.00	1.00	1.00
10 = LM	1.00	1.00	1.07	1.00	1.07
11 = LP	1.20	1.15	1.13	1.10	1.30
12 = PI	1.00	1.00	1.00	1.00	1.00
13 = PP	1.20	1.20	1.10	1.15	1.25
14 = WB	1.20	1.15	1.10	1.05	1.20
15 = WP	1.20	1.20	1.10	1.15	1.20
16 = JU	1.00	1.00	1.00	1.00	1.00
17 = BS	1.20	1.20	1.15	1.10	1.20
18 = ES	1.20	1.20	1.15	1.10	1.20
19 = WS	1.20	1.20	1.15	1.10	1.20
20 = AS	1.00	1.00	1.00	1.00	1.00
21 = CO	1.15	1.15	1.05	1.05	1.18
22 = OA	1.00	1.00	1.00	1.00	1.00
23 = OS	1.15	1.15	1.05	1.05	1.15
24 = OH	1.15	1.15	1.15	1.05	1.20

The fourth step is to combine the even-aged and uneven-aged estimates if certain conditions are met. The even-aged height growth estimate is used: 1) if the stand is even-aged (range in tree ages is less than or equal to 40 years), 2) if the stand is uneven-aged and the total stand basal area is less than 70 square feet (open grown condition), or 3) if the stand is uneven-aged and the tree's percentile in the basal area distribution is 40 or greater (overstory tree). The uneven-aged estimate is used if the stand is uneven-aged and the tree's percentile in the basal area distribution is 10 or less (overtopped tree). For trees in an uneven-aged stand and their percentile in the basal area distribution is between 10 and 40, the even-aged and uneven-aged estimates are weighted using equation {51}.

{51} HTG = XWT * HTGE + (1 – XWT) * HTGU

where XWT = [(PCT-10) * 3.33333] / 100

and PCT is the tree's percentile in the basal area distribution
HTG is the final height growth estimate
HTGE is the even-aged height growth estimate
HTGU is the uneven-aged height growth estimate

And finally, for aspen, the height growth estimate is adjusted for site index using equation {46} with a = 0.6253, b = 0.00583, and the site index bounds being 30 and 90.

4.6.2.4 FINAL ADJUSTMENTS

Whether the height growth estimate was derived via a direct estimate using equations from another variant, or via the GENGYM method, some final adjustments need to be made. First a small random increment is added to the height growth to allow for some variability between individual trees. Second, a check is made to ensure that the height growth is not negative. Third, the height growth is adjusted to match the cycle length and account for any user-supplied height growth modifiers. And finally, if the stagnation effect has been activated, then its effects are accounted for using equation {52}.

{52} HTG = HTG * (DSTAG + 1) / 2

For bristlecone pine, pinyon pine, juniper, and oaks, this section does not apply. The equations described in the small tree model section are used for trees of all sizes for these species.

4.6.3 Large Tree Crown Ratio Change

All species except mountain hemlock, western red cedar, and western larch use equations from GENGYM which predict crown length as a function of tree and stand attributes {53}, with coefficients shown in Table 19. Crown length is then converted to crown ratio by dividing crown length by total tree height.

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

where CL = predicted crown length
HT = total tree height
DBH = diameter at breast height
BA = total stand basal area
BAU = total stand basal area above the diameter class for the given tree
$a_0 – a_4$ are coefficients shown in Table 19

Table 19. Coefficients to predict crown length for the Central Rockies FVS variant.

FVS Number = Alpha Code: Model Type	a_0	a_1	a_2	a_3	a_4
1 = AF; SW, SP	0.50706	0.73070			
1 = AF; all others	0.36135	0.57085			
2 = CB; SW,SP	0.50706	0.73070			
2 = CB; all others	0.36135	0.57085			
3 = DF; all	6.47479	0.50703	0.54482	-0.03326	
4 = GF; all	6.22959	0.67587		-0.03098	
5 = WF; all	6.22959	0.67587		-0.03098	
6 = MH; all	See equation {54}				
7 = RC; all	See equation {55}				
8 = WL; all	See equation {56}				
9 = BC; all	-0.59373	0.67703			
10 = LM; all	-0.59373	0.67703			
11 = LP; all	5.00215	0.06334	0.88236		-0.03821
12 = PI; all	-0.59373	0.67703			
13 = PP; SW	5.63367	0.56252		-0.06411	
13 = PP; SP	4.35671	0.32549	0.84714	-0.03802	
13 = PP; all others	3.49178	0.17421	0.80767	-0.03272	
14 = WB; all	-0.59373	0.67703			
15 = WP; all	3.03832	0.65587		-0.01792	

16 = JU; all	-0.59373	0.67703		
17 = BS; all	3.61635	0.61547	0.93639	-0.02360
18 = ES; SW, SP	1.05857	0.68442		
18 = ES; all other	3.22244	0.44315	0.44755	
19 = WS; all	0.15768	0.74697		
20 = AS; all	5.17281	0.32552		-0.01675
21 = CO; all	5.17281	0.32552		-0.01675
22 = OA; all	-0.59373	0.67703		
23 = OS; all	-0.59373	0.67703		
24 = OH; all	5.17281	0.32552		-0.01675

Coefficients shown as blanks are equal to zero

The remaining three species use equations from other variants that predict crown ratio directly. The equation for mountain hemlock is given in {54} with coefficients shown in Table 19. This equation is from the North Idaho variant for the Bitterroot National Forest with habitat type set to 710.

{54} $CR = 0.3450 – 0.00264 * BA + 0.00000512 * CCF^2 - 0.25138 * LN(HT) + 0.05140 * LN(PCT)$

where CR = predicted crown ratio
BA = total stand basal area
CCF = total stand crown competition factor
HT = total tree height at the beginning of the cycle
PCT = the trees percentile in the basal area distribution
LN = natural logarithm

The equation for western red cedar is shown in equation {55} with coefficients shown in Table 19. This equation is from the North Idaho variant with habitat type set to 550.

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

where DBH = tree diameter at breast height at the end of the cycle
and all other variables are as defined above

The equation for western larch is shown in equation {56} with coefficients shown in Table 19. This equation is also from the North Idaho variant for the Bitterroot National Forest with habitat type set to 260.

{56} $CR = 0.03441 – 0.00204 * BAT + 0.30066 * LN(DBH) – 0.59302 * LN(HT)$

Once crown ratio is predicted, it is bounded to a change of no more than ten percent per cycle, and to no more than the potential change in crown ratio if all the height growth contributed to the crown change during the cycle.

4.7 MORTALITY MODEL

The mortality model used in the Central Rockies variant is based on Stand Density Index (SDI), and techniques developed by Dixon (1986). The mortality model imbedded in the GENGYM model was used in earlier versions of this variant, but it did not perform as well as desired. The new mortality model should provide users with the flexibility they want in manipulating mortality, as well as the model sensitivity they need to simulate stand conditions that change through time.

Two types of mortality are present: (1) background mortality, and (2) density related mortality. Density related mortality accounts for mortality in stands that are dense enough for competition to be the causal agent. All other mortality is attributable to background mortality. Background mortality gives way to density related mortality based on the relationship between current and maximum stand SDI. In the Central Rockies variant, density related mortality begins when the stand SDI is above 55 percent of maximum SDI, and stand density peaks at 85 percent of maximum SDI (Smith 1984, Long 1984). Users can change these values using fields 5 and 6 of the SDIMAX keyword. Background mortality is used when current stand SDI is below 55 percent of maximum SDI. The 55 percent value is referred to as the lower limit of density related mortality, and the 85 percent value is the upper limit.

Users can set maximum SDI values for any, or all, species with the SDIMAX keyword, or the default values shown in Table 6 will be used. The stand SDI maximum is a weighted average {57} of the individual species SDI maximums. The weights are based on the basal area each individual species represents in the stand. The weighted maximum SDI is calculated each growth cycle, and mortality is determined based on the stands' position relative to the maximum SDI. Over time, maximum SDI changes as the species mix in the stand changes.

$$\{57\}\ \text{Maximum SDI} = \frac{S1SDI*S1BA + S2SDI*S2BA + \ldots + SnSDI*SnBA}{\text{TOTAL STAND BA}}$$

where S1SDI = maximum SDI for the first species in the stand
S1BA = total basal area of species 1 in the stand
S2SDI = maximum SDI for the second species in the stand
S2BA = total basal area of species 2 in the stand
SnSDI = maximum SDI for the nth species in the stand
SnBA = total basal area of the nth species in the stand

Current stand SDI is calculated using equation {58} (Long and Daniel 1990).

$$\{58\}\ \text{Stand SDI} = \Sigma[TPA_i * (DBH_i/10)^{1.605}]$$

where TPA_i = trees-per-acre represented by the i^{th} tree record
DBH_i = diameter at breast height of the i^{th} tree record
and the summation is over all trees in the stand

A restriction on DBH was added in FVS to achieve mathematical consistency with a similar estimate based on stand values. For trees with a diameter less than 1.0 inch, a diameter of 1.0 inch is used in the calculation.

If the stand SDI at the time of inventory is above the upper limit of density related mortality plus 5 percent (e.g. 90% if using the default value of 85% for the upper limit), then the maximum SDI is automatically reset. The new maximum is set so the stand SDI at the time of inventory corresponds to the upper limit of density related mortality. If the stand SDI at the time of inventory is greater than the upper limit of density related mortality, but within 5 percent, then the stand stocking will be reduced to the upper limit the first projection cycle.

The relationship between stand SDI at the time of inventory and the maximum SDI determines the trajectory a stand will take throughout the projection. Certain management actions, such as a thinning, may change this trajectory. This trajectory can be thought of as a relationship between trees-per-acre on the y-axis and quadratic mean diameter on the x-axis. For density related mortality, this trajectory determines how many trees will die in the projection cycle. For background mortality, the number of trees dying is determined by the background mortality rate.

The background mortality rates in the Central Rockies variant were not available. Those fit for the Southern Oregon / Northeast California (SO) variant are used. Species in the Central Rockies variant use coefficients from the most similar species in the SO variant for which coefficients were estimated. The background rate, equation {59}, is an annual mortality rate that is adjusted to the projection cycle length using a compound interest formula {60}. Coefficients for species in the CR variant are shown in Table 20.

{59} $RI = (1 / [1 + e^{(a + b*DBH)}]) / 2$

where RI = annual background mortality rate
DBH = tree diameter at breast height

{60} $RIP = 1 – [1- RI]^{YRS}$

where RIP = background mortality rate for the current projection cycle
YRS = number of years in the current projection cycle

Table 20. Coefficients for the background mortality equation in the Central Rockies variant

a	b	Central Rockies Species
6.5112	-0.0052485	WL, WP
7.2985	-0.0129121	DF
5.1677	-0.0077681	AF, CB, GF, WF, RC, BC, LM, PI, WB, JU, OS
9.6943	-0.0127328	MH, BS, ES, WS
5.9617	-0.0340128	LP, AS, CO, OA, OH
5.5877	-0.005348	PP

Once the number of mortality trees has been determined, the mortality needs to be dispersed across the individual tree records. Mortality in FVS is achieved by adjusting the number of trees-per-acre a record represents. Tree records are processed, each receiving a calculated mortality, until the total number of mortality trees has been achieved. All tree records will receive some mortality in a projection.

Mortality rates for individual tree records in the Central Rockies variant, equation {61}, are partially dependent on shade tolerance of individual species. The more intolerant species have higher mortality rates than the tolerant species. Shade tolerance ratings for species in the CR variant are shown in Table 21, where 0.1 corresponds to a species being very tolerant, 0.3 tolerant, 0.5 moderately tolerant, 0.7 intolerant, and 0.9 very intolerant. The rate is also dependent on a tree's social position as measured by its' rank in the basal area distribution. Tree's with a lower rank (e.g. understory tree) receive heavier mortality than those with a higher rank (e.g. overstory tree). And finally, the rate is dependent on a tree's vigor as measured by crown ratio. Trees with a lower crown ratio receive higher mortality than trees with a higher crown ratio. The mortality model makes multiple passes through the tree records multiplying a record's trees-per-acre value times the mortality rate (MR), accumulating the results, and reducing the trees-per-acre representation until the desired mortality level has been reached.

{61} $MR = [0.84525 – 0.01074 * PCT + 0.0000002 * PCT^3] * [(100 – CR)/100] * SHADE * 0.01$

where MR = individual tree mortality rate
PCT = a tree's percentile rank in the basal area distribution
CR = a tree's crown ratio
SHADE = a tree's shade tolerance rating (shown in Table 21)
(and the value of the function in the first bracket is bounded between 0.01 and 1.0)

Table 21. Shade tolerance ratings used in the mortality function for the Central Rockies FVS variant.

FVS Number = Alpha Code	SHADE
1 = AF	0.1
2 = CB	0.1
3 = DF	0.5
4 = GF	0.3
5 = WF	0.3
6 = MH	0.3
7 = RC	0.1
8 = WL	0.9
9 = BC	0.9
10 = LM	0.9
11 = LP	0.7
12 = PI	0.7
13 = PP	0.7
14 = WB	0.9
15 = WP	0.5
16 = JU	0.7
17 = BS	0.5
18 = ES	0.3
19 = WS	0.3
20 = AS	0.9
21 = CO	0.9
22 = OA	0.7
23 = OS	0.7
24 = OH	0.9

5.0 VOLUME ESTIMATION

The Central Rockies variant contains a choice of three volume estimation methods. These are (1) volume equations contained in the National Volume Estimator Library; (2) southwestern volume equations; and (3) user defined volume equations. The National Volume Estimator Library contains equations from a variety of sources and is generally regarded as the "standard" for use in the Forest Service. Southwestern volume equations are from Chojnacky and Ott (1986) for Pinyon and Juniper, Chojnacky (1988) for oaks, and Hann and Bare (1978) for the remaining species.

For Region 2 forests, the default is the National Volume Estimator Library equations. If a user on a Region 2 forest chooses to use the southwestern equations, then equation coefficients for the Cibola National Forest are used.

For Region 3 forests, the default is the southwestern equations because the National Volume Estimator Library equations for Region 3 currently only returns merchantable cubic and board foot volumes and not total cubic foot volume.

Volume adjustments such as adjusting the merchantable top diameters, minimum diameter for merchantability, and defect adjustments can be made using the VOLUME, BFVOLUME, BFFDLN, BFDEFECT, MCFDLN, and MCDEFECT keywords. Individual tree defect percentages can also be entered directly in the tree data.

5.1 NATIONAL VOLUME ESTIMATOR LIBRARY EQUATIONS

Equation numbers for the National Volume Estimator Library equations are given in Table 22. For Region 2, if the equation number is blank, volumes are not calculated for that species. There are exceptions to the equation numbers shown in Table 22. Some of these exceptions are based on model type, and some are based on National Forest codes.

Exceptions to the equation numbers presented in Table 22 are as follows:

(1) The Southwest Ponderosa Pine model type uses Region 3 equation number 304 for subalpine fir, corkbark fir, and grand fir.
(2) The Black Hills model type uses Region 2 equation number 200CZ2W746 for cottonwood.
(3) The Spruce-fir model type uses Region 3 equation number 306 for white fir.
(4) The Lodgepole pine model type uses Region 3 equations 306 for white fir and 307 for lodgepole pine.

(5) The Black Hills National Forest uses Region 2 equation number 203FW2W122 for ponderosa pine.
(6) The San Juan National Forest uses Region 2 equation number 213FW2W122 for ponderosa pine.
(7) The Big Horn and Shoshone National Forests use Region 2 equation number 202FW2W108 for lodgepole pine.
(8) The Carson and Sante Fe National Forests use Region 3 equation numbers 303 for Douglas-fir and 305 for white fir in the Southwest Mixed Conifer model type, and the Black Hills model type.
(9) The Carson and Sante Fe National Forests use Region 3 equation numbers 303 for Douglas-fir and Grand fir, and 305 for white fir, subalpine fir, and corkbark fir in the Southwest Ponderosa Pine model type.
(10) The Carson National Forest uses equation 303 for Douglas-fir in the Spruce-fir model type.

Table 22. National Volume Estimator Library equation numbers for the Central Rockies FVS variant.

FVS Number = Alpha Code	Region 2 Equation Number	Region 3 Equation Number
1 = AF	200CZ2W019	306
2 = CB	200CZ2W019	306
3 = DF	200CZ2W202	302
4 = GF	200CZ2W019	306
5 = WF	200CZ2W015	304
6 = MH	407FW2W093	307
7 = RC	407FW2W093	306
8 = WL	407FW2W093	306
9 = BC	200CZ2W122	307
10 = LM	200CZ2W122	307
11 = LP	200FW2W108**	307
12 = PI		310
13 = PP	200CZ2W122*	301
14 = WB	200CZ2W122	307
15 = WP	200CZ2W122	307
16 = JU		309
17 = BS	407FW2W093	306
18 = ES	407FW2W093	306
19 = WS	407FW2W093	306
20 = AS	200CZ2W746	308
21 = CO		311
22 = OA		312
23 = OS		309
24 = OH		311

5.2 SOUTHWESTERN VOLUME EQUATIONS

Total cubic foot volume for Pinyon and Juniper are calculated using equations from Chojnacky and Ott (1986), and total cubic foot volume for oak is calculated using equations from Chojnacky (1988). In the FVS output report, merchantable cubic foot volume is set equal to total cubic foot volume for these species, since these species are primarily used for firewood. Board foot volumes for these species are not computed. The equation form is shown in {62} with coefficients shown in Table 23.

{62} $V = a_0 + a_1 * X + a_2 * X^2$ for $X \leq 5$

$V = b_0 + b_1 * X – b_2 / X$ for $X > 5$

where V = total cubic foot volume
$X = DBH^2 * HT$
DBH = tree diameter at breast height
HT = total tree height
$a_0 – a_2$ are coefficients shown in Table 23
$b_0 – b_2$ are coefficients shown in Table 23

Table 23. Coefficients for pinyon, juniper, and oak volumes in the southwestern equation set for the Central Rockies variant

Species	a_0	a_1	a_2	b_0	b_1	b_2
Pinyon	-0.07	2.51	0.098	7.29	2.51	24.53
Juniper	-0.05	2.48	0.057	4.24	2.48	14.29
Oak	-0.068	2.4048	0.1383	6.571	2.4048	17.704

Volumes for cottonwood and the miscellaneous categories "other softwoods" and "other hardwoods" are not computed.

Volumes for all other species are computed using equations from Hann and Bare (1978). Table 24 shows the equation index by species and National Forest, and Table 25 shows which Hann and Bare (1978) equation this corresponds to. For example, for species BC, the index value is 1 for all Region 3 forests. This indicates the Hann and Bare (1978) white pine equation is used to calculate volumes for this species.

Table 24. Southwestern volume equation index by Forest for the Central Rockies FVS variant.

FVS Number = Alpha Code			F	O	R	E	S	T				all
	301	302	303	304	305	306	307	308	309	310	312	R2
1 = AF	2	2	2	2	2	2	2	2	2	2	2	2
2 = CB	2	2	2	2	2	2	2	2	2	2	2	2
3 = DF	6	7	7	7	7	7	7	6	7	7	7	7
4 = GF	2	2	2	2	2	2	2	2	2	2	2	2
5 = WF	9	10	10	10	10	10	10	9	10	10	10	10
6 = MH	9	10	10	10	10	10	10	9	10	10	10	10
7 = RC	9	10	10	10	10	10	10	9	10	10	10	10
8 = WL	9	10	10	10	10	10	10	9	10	10	10	10
9 = BC	1	1	1	1	1	1	1	1	1	1	1	1
10 = LM	1	1	1	1	1	1	1	1	1	1	1	1
11 = LP	6	7	7	7	7	7	7	6	7	7	7	7
12 = PI												
13 = PP	4	5	4	4	4	4	4	4	4	5	4	4
14 = WB	1	1	1	1	1	1	1	1	1	1	1	1
15 = WP	1	1	1	1	1	1	1	1	1	1	1	1
16 = JU												
17 = BS	2	2	2	2	2	2	2	2	2	2	2	2
18 = ES	2	2	2	2	2	2	2	2	2	2	2	2
19 = WS	2	2	2	2	2	2	2	2	2	2	2	2
20 = AS	8	8	8	8	8	8	8	8	8	8	8	8
21 = CO												
22 = OA												
23 = OS												
24 = OH												

*Volume is not computed for species where the index is blank

Table 25. Hann and Bare (1978) equations used in the Central Rockies Variant

Index	Description
1	White Pine
2	Engelmann Spruce / Corkbark Fir
3	Yellow Pine
4	Ponderosa Pine - - Coconino, Tonto, Lincoln National Forests
5	Ponderosa Pine - - Santa Fe, Carson National Forests
6	Douglas-fir - - Lincoln, Tonto National Forests
7	Douglas-fir - - Santa Fe, Carson National Forests
8	Aspen
9	White Fir - - Lincoln National Forest
10	White Fir - - Santa Fe, Carson National Forests

Total cubic foot volumes are computed using equation {63} and coefficients shown in Table 26. Merchantable cubic foot volume is calculated using equations {64} and {65} and coefficients shown in Table 26.

{63} $TV = a_0 + a_1 * DBH^2 * HT$

where TV = total cubic foot volume
DBH = tree diameter at breast height
HT = total tree height
and a_0 and a_1 are shown in Table 26

{64} $TOP = b_1 + [b_2 * TOPD^3 * HT] / [DBH^{b0}] + b_3 * DBH^2$

where TOP = total volume above the merchantable top
TOPD = merchantable top diameter inside bark for cubic foot volume
DBH = tree diameter at breast height
HT = total tree height
and b_0-b_3 are shown in Table 26

{65} VM = TV – TOP

where VM = total merchantable cubic foot volume

Table 26. Hann and Bare (1978) total cubic foot and merchantable cubic foot volume coefficients

Index	a_0	a_1	b_0	b_1	b_2	b_3
1	0.16089	0.0020325	1.5	-0.21301	0.0049121	0.0060606
2	0.22547	0.0021697	1.5	-0.26648	0.0061290	0.0074311
3	0.23720	0.0022112	1.0	0.01855	0.0007882	0.0050551
4	0.08107	0.0019835	1.5	-0.12535	0.0036042	0.0054063
5	0.04831	0.0020497	1.5	-0.13397	0.0065017	0.0049022
6	0.43837	0.0017564	1.0	-0.08315	0.0012190	0.0054174
7	0.34113	0.0019180	1.5	-0.18763	0.0067187	0.0053645
8	0.03270	0.0023112	1.5	-0.23643	0.0058021	0.0060804
9	0.21090	0.0018400	1.0	-0.18270	0.0012482	0.0062448
10	0.15778	0.0020091	1.5	-0.18756	0.0063265	0.0060413

Merchantable Scribner board foot volumes are computed using equations {63}, {64}, {66}, {67} and {68} and coefficients shown in Tables 26, 27, and 28. First, equation {64} is evaluated with BFTOPD replacing TOPD, where BFTOPD is the merchantable top diameter inside bark for board foot volume. Next, equations {66} through {68} are executed in order.

{66} $VMR = TV - TOP$

where TV is the total cubic foot volume {63} and TOP is the value of {64} with BFTOPD replacing TOPD

{67} $VI = VMR * [f_0 - (f_1 / DBH) - (f_2 / DBH^2) - (f_3 / DBH^3)]$

where VI = international board foot volume
DBH = tree diameter at breast height
and $f_0 - f_3$ are shown in Table 27

{68} $VS = VI * [e_0 - (e_1 / DBH) - (e_2 / DBH^{1.177748}) - (e_3 / DBH^2)]$

where VS = Scribner board foot volume
DBH = tree diameter at breast height
VI = international board foot volume from equation {67}
and $e_0 - e_3$ are shown in Table 28

Table 27. Hann and Bare (1978) International board foot volume coefficients

Index	f_0	f_1	f_2	f_3
1	6.69197	7.52011	216.34837	0.
2	5.98736	9.84792	-300.81281	2855.34246
3	7.10051	7.97922	229.55650	0.
4	6.84752	7.69491	221.37723	0.
5	7.58122	8.51941	245.09754	0.
6	6.58735	0.89272	243.51491	0.
7	6.59717	0.89405	243.87797	0.
8	6.68808	-1.27685	-4.50480	1423.98524
9	6.24688	7.01994	201.95873	0.
10	5.73645	1.72093	74.57379	0.

Table 28. Hann and Bare (1978) Scribner board foot volume coefficients

Index	e_0	e_1	e_2	e_3
1	1.00609	2.38466	0.	0.
2	0.87845	0.	0.	15.99846
3	0.98210	0.92603	0.	14.49444
4	0.96579	0.40579	0.	16.93678
5	0.99399	1.46349	0.	12.40585
6	1.00090	0.	4.10007	0.
7	0.87026	0.	0.	19.49594
8	0.88789	0.	0.	17.19374
9	1.0	1.88814	0.	8.85145
10	1.01725	1.87057	0.	8.51445

5.3 USER DEFINED VOLUME EQUATIONS

A user's own volume equations can be used in FVS if they fit the functional form shown in equation {69}. Equation coefficients are entered into FVS using the CFVOLEQU and/or BFVOLEQU keywords. Users must also use the VOLUME and/or BFVOLUME keywords, and enter a volume calculation method of 7 in field 7 to tell FVS that user defined equations should be used in the calculation of volumes.

{69} $V = a_0 + a_1 * DBH + a_2 * DBH * HT + a_3 * DBH^2 * HT + a_4 * DBH^{a5} * HT^{a6}$

where V = volume
DBH = tree diameter at breast height
HT = total tree height
$a_0 – a_6$ = user defined coefficients

6.0 REGENERATION ESTABLISHMENT

The FVS regeneration / establishment model is used to simulate stand establishment from bare ground, or to bring seedlings into a simulation with existing trees. Table 29 shows the bud width, minimum seedling heights, and maximum seedling heights by species for the Central Rockies variant.

Table 29. Bud widths and minimum seedling height for species in the Central Rockies FVS variant.

FVS Number = Alpha Code	Bud Width (inches)	Minimum Seedling Height (ft)	Maximum Seedling Height (ft)
1 = AF	0.3	0.5	7
2 = CB	0.3	0.5	7
3 = DF	0.3	1.0	10
4 = GF	0.3	0.5	7
5 = WF	0.3	0.5	7
6 = MH	0.3	0.5	10
7 = RC	0.3	0.5	9
8 = WL	0.3	1.0	10
9 = BC	0.4	0.5	9
10 = LM	0.4	0.5	9
11 = LP	0.4	1.0	10
12 = PI	0.4	0.5	6
13 = PP	0.5	1.0	10
14 = WB	0.4	1.0	9
15 = WP	0.4	1.0	9
16 = JU	0.3	0.5	6
17 = BS	0.3	0.5	7
18 = ES	0.3	0.5	7
19 = WS	0.3	0.5	7
20 = AS	0.2	3.0	16
21 = CO	0.3	3.0	16
22 = OA	0.3	0.5	10
23 = OS	0.2	1.0	9
24 = OH	0.2	0.5	12

The Central Rockies variant has three species that automatically produce stump sprouts when cut. These are aspen, cottonwood, and oak. Users wanting to turn the automatic sprouting off can do so with the NOSPROUT keyword. Establishment of all other species must be user specified with the PLANT or NATURAL keywords.

Two sets of equations are used to grow regenerating trees in height from the time they are established until the end of the cycle in which they are established. The first set estimates tree height five years after seedlings are established, or at the end of the cycle if the cycle boundary is within five years of the establishment date. The second set grows the trees from the point five years after establishment to the end of the cycle.

The first set of equations is still under development, and for now a height of 1.0 foot is assumed for all species. However, users can override this value by specifying an average seedling height in field 6 of the PLANT or NATURAL keywords. The height specified in field 6 is not subject to the minimum height restrictions shown in Table 29 and seedlings as small as 0.1 foot can be established.

The second set of equations, which grow the trees in height from the point five years after establishment to the end of the cycle, are the equations described in the section 4.5.1. After seedling height is estimated, diameter growth is estimated using equations described in section 4.5.2.

Regenerating trees become visible in FVS at the end of the growth cycle. FVS automatically generates tree records corresponding to regenerating trees. These tree records can be found in the tree list output file with tree identification numbers beginning with the letters “ES”.

7.0 FIRE AND FUELS EXTENSION

The fire and fuels extension to FVS (Beukema et.al. 1998) integrates FVS with elements from existing models of fire behavior and fire effects. It also simulates silvicultural impacts on fuel pools, and tracks snags from the time the tree dies until it falls over and decays. Various types of fuels are represented, including ladder and canopy fuels, and surface fuels. Fire behavior and fire effects on the stand are modeled.

The fire and fuels extension does not simulate fire spread or the probability of fire. However, given that a fire does occur, the model will predict the potential fire intensity, resulting mortality, and various other fire-related effects. Model outputs include displays of fuel loading, stand structure, snags, and potential fire behavior over time. The fire and fuels extension, coupled with capabilities of FVS, provides a basis for comparing proposed fuel treatments.

The snag and woody debris portion of the model is useful without invoking any fire simulations. The predicted quantity and dynamics of standing and downed dead wood are of interest to wildlife biologists and forest managers. A detailed description of the fire and fuels extension can be found in Beukema et.al. (1998).

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9.0 APPENDICES

APPENDIX A: REGION 2 PLANT ASSOCIATION CODES FOR THE CENTRAL ROCKIES VARIANT

200101	White fir-Douglas-fir/Rocky Mountain maple
2001010	White fir-Douglas-fir/Rocky Mountain maple/Rocky Mountain Maple
2001011	White fir-Douglas-fir/Rocky Mountain maple/Oregon-grape
2001012	White fir-Douglas-fir/Rocky Mountain maple/ocean spray
2001013	White fir-Douglas-fir/Rocky Mountain maple/thinleaf alder
200102	White fir-Douglas-fir/sparse undergrowth
200103	White fir-Douglas-fir/forest fleabane
200104	White fir-Douglas-fir/Arizona fescue
2001040	White fir-Douglas-fir/Arizona fescue/Arizona fescue
2001041	White fir-Douglas-fir/Arizona fescue/Parry oatgrass
200105	White fir-Douglas-fir/Gambel oak
2001050	White fir-Douglas-fir/Gambel oak/Gambel oak
2001052	White fir-Douglas-fir/Gambel oak/Arizona fescue
2001053	White fir-Douglas-fir/Gambel oak/fragrant bedstraw
2001054	White fir-Douglas-fir/Gambel oak/mountain lover
200109	White fir-Douglas-fir/bearberry
200110	White fir-Douglas-fir/Rocky Mountain whortleberry
200111	White fir-Douglas-fir/Saskatoon serviceberry
200112	White fir-Douglas-fir/greenleaf manzanita
200113	White fir-Douglas-fir/ocean spray
200114	White fir-Douglas-fir/mountain snowberry
200115	White fir-limber pine/Arizona fescue
200116	White fir-Douglas-fir/common juniper
200117	White fir-Douglas-fir/Oregon-grape
200118	White fir-Douglas-fir/mallow ninebark
200201	Subalpine fir/elk sedge
200203	Subalpine fir/mountain lover
200301	Subalpine fir-Engelmann spruce/red baneberry
200302	Subalpine fir-Engelmann spruce/heartleaf arnica

2003020	Subalpine fir-Engelmann spruce/heartleaf arnica/heartleaf arnica
2003021	Subalpine fir-Engelmann spruce/heartleaf arnica/weedy milkvetch
2003022	Subalpine fir-Engelmann spruce/heartleaf arnica/russet buffaloberry
2003023	Subalpine fir-Engelmann spruce/heartleaf arnica/Engelmann spruce
200303	Subalpine fir-Engelmann spruce/broadleaf arnica
200304	Subalpine fir-Engelmann spruce/Oregon-grape
200305	Subalpine fir-Engelmann spruce/bluejoint reedgrass
200306	Subalpine fir-Engelmann spruce/mountain bluebells
200307	Subalpine fir-Engelmann spruce/elk sedge
200308	Subalpine fir-Engelmann spruce/forest fleabane
200309	Subalpine fir-Engelmann spruce/common juniper
200310	Subalpine fir-Engelmann spruce/American twinflower
2003100	Subalpine fir-Engelmann spruce/American twinflower/American twinflower
2003101	Subalpine fir-Engelmann spruce/American twinflower/broom huckleberry
200311	Subalpine fir-Engelmann spruce/moss species
200313	Subalpine fir-Engelmann spruce/mountain lover
2003130	Subalpine fir-Engelmann spruce/mountain lover/mountain lover
2003131	Subalpine fir-Engelmann spruce/mountain lover/Douglas-fir
2003132	Subalpine fir-Engelmann spruce/mountain lover/mountain gooseberry
200315	Subalpine fir-Engelmann spruce/Wheeler bluegrass
200316	Subalpine fir-Engelmann spruce/arrowleaf groundsel
200318	Subalpine fir-Engelmann spruce/western meadow-rue
200319	Subalpine fir-Engelmann spruce/globe huckleberry
2003190	Subalpine fir-Engelmann spruce/globe huckleberry/globe huckleberry
2003191	Subalpine fir-Engelmann spruce/globe huckleberry/broom huckleberry
200320	Subalpine fir-Engelmann spruce/Rocky Mountain whortleberry
2003200	Subalpine fir-Engelmann spruce/Rocky Mountain whortleberry/ Rocky Mountain whortleberry
2003201	Subalpine fir-Engelmann spruce/Rocky Mountain whortleberry/ Jacob'sladder
200321	Subalpine fir-Engelmann spruce/broom huckleberry
2003210	Subalpine fir-Engelmann spruce/broom huckleberry/broom huckleberry
2003211	Subalpine fir-Engelmann spruce/broom huckleberry/whitebarkpine
2003212	Subalpine fir-Engelmann spruce/broom huckleberry/Jacob's ladder
2003213	Subalpine fir-Engelmann spruce/broom huckleberry/elk sedge
2003216	Subalpine fir-Engelmann spruce/broom huckleberry/russet buffaloberry
2003217	Subalpine fir-Engelmann spruce/broom huckleberry/heartleafarnica

200322	Subalpine fir-Engelmann spruce/currant species
2003220	Subalpine fir-Engelmann spruce/currant species/currant species
2003221	Subalpine fir-Engelmann spruce/currant species/Fendler meadow-rue
200323	Subalpine fir-Engelmann spruce/grayleaf willow
200324	Subalpine fir-Engelmann spruce/western thimbleberry
2003240	Subalpine fir-Engelmann spruce/western thimbleberry/ western thimbleberry
2003241	Subalpine fir-Engelmann spruce/western thimbleberry/broom huckleberry
200325	Subalpine fir-Engelmann spruce/shiny-leaf spirea
200326	Subalpine fir-Engelmann spruce/Ross sedge
200327	Subalpine fir-Engelmann spruce/Rocky Mountain maple
200328	Subalpine fir-Engelmann spruce/pinegrass
2003280	Subalpine fir-Engelmann spruce/pinegrass/pinegrass
2003281	Subalpine fir-Engelmann spruce/pinegrass/mountain lover
200329	Subalpine fir-Engelmann spruce/dwarf bilberry
200330	Subalpine fir-Engelmann spruce/mallow ninebark
200401	Engelmann spruce/heartleaf arnica
200402	Engelmann spruce/elkslip marsh-marigold
200403	Engelmann spruce/soft leaved sedge
200405	Engelmann spruce-blue spruce/fragrant bedstraw
200406	Engelmann spruce/moss species
200407	Engelmann spruce/common juniper
200408	Engelmann spruce/American twinflower
200409	Engelmann spruce/mallow ninebark
200413	Engelmann spruce/whiproot clover
200414	Engelmann spruce/broom huckleberry
2004140	Engelmann spruce/broom huckleberry/broom huckleberry
2004141	Engelmann spruce/broom huckleberry/American bistort
2004142	Engelmann spruce/broom huckleberry/silvery lupine
2004145	Engelmann spruce/broom huckleberry/Jacob's ladder
200415	Engelmann spruce/Rocky Mountain whortleberry
2004150	Engelmann spruce/Rocky Mountain whortleberry/ Rocky Mountain whortleberry
2004151	Engelmann spruce/Rocky Mounatin whortleberry/Jacob's ladder
200416	Engelmann spruce/Thurber fescue
200417	Engelmann spruce-Douglas-fir/common juniper
200418	Engelmann spruce/dwarf bilberry

200501	White spruce/sedge
200502	White spruce/common juniper
200503	White spruce/American twinflower
2005030	White spruce/American twinflower/American twinflower
2005031	White spruce/American twinflower/broom huckleberry
2005032	White spruce/American twinflower/shiny-leaf spirea
200601	Blue spruce/Saskatoon serviceberry-redosier
2006010	Blue spruce/Saskatoon serviceberry-redosier/Saskatoon serviceberry
2006011	Blue spruce/Saskatoon serviceberry-redosier/redosier
200602	Blue spruce/heartleaf arnica
200603	Blue spruce/bluegrass species
200604	Blue spruce-Douglas-fir/American twinflower
2006040	Blue spruce-Douglas-fir/American twinflower/American twinflower
2006043	Blue spruce-Douglas-fir/American twinflower/common juniper
200605	Blue spruce/thinleaf alder
200606	Blue spruce-Douglas-fir/silvertop sedge
200607	Blue spruce-Douglas-fir/forest fleabane
200608	Blue spruce-Douglas-fir/bearberry
200609	Blue spruce-Douglas-fir/Arizona fescue
2006090	Blue spruce-Douglas-fir/Arizona fescue/Arizona fescue
2006091	Blue spruce-Douglas-fir/Arizona fescue/Parry oatgrass
200610	Blue spruce-Douglas-fir/Oregon-grape
200611	Blue spruce-Engelmann spruce/field horsetail
200612	Blue spruce-Douglas-fir/common juniper
2006120	Blue spruce-Douglas-fir/common juniper/common juniper
2006121	Blue spruce-Douglas-fir/common juniper/elk sedge
200701	Whitebark pine/elk sedge
2007010	Whitebark pine/elk sedge/elk sedge
2007011	Whitebark pine/elk sedge/lodgepole pine
200702	Whitebark pine/Ross sedge
2007020	Whitebark pine/Ross sedge/Ross sedge
2007021	Whitebark pine/Ross sedge/lodgepole pine
200703	Whitebark pine-limber pine/varileaf cinquefoil
200704	Whitebark pine/Idaho fescue
200705	Whitebark pine/common juniper
2007050	Whitebark pine/common juniper/common juniper
2007051	Whitebark pine/common juniper/buffaloberry

200706	Whitebark pine/broom huckleberry
200801	Bristlecone pine/Thurber fescue
200802	Bristlecone pine/Arizona fescue
200803	Bristlecone pine/whiproot clover
200804	Bristlecone pine/mountain gooseberry
200805	Bristlecone pine/common juniper
200901	Lodgepole pine/bearberry
200903	Lodgepole pine/elk sedge
2009030	Lodgepole pine/elk sedge/elk sedge
2009031	Lodgepole pine/elk sedge/mountain lover
200905	Lodgepole pine/common juniper
200907	Lodgepole pine/Wheeler bluegrass
200908	Lodgepole pine/russet buffaloberry
2009080	Lodgepole pine/russet buffaloberry/russet buffaloberry
2009081	Lodgepole pine/russet buffaloberry/mountain lover
200909	Lodgepole pine/Rocky Mountain whortleberry
200910	Lodgepole pine/broom huckleberry
200911	Lodgepole pine/Ross sedge
200912	Lodgepole pine/dwarf bilberry
201001	Limber pine/bluebunch wheatgrass
201002	Limber pine/purple pinegrass
201003	Limber pine/Idaho fescue
201004	Limber pine/spike-fescue
2010040	Limber pine/spike-fescue/spike-fescue
2010041	Limber pine/spike-fescue/American pasque-flower
2010042	Limber pine/spike-fescue/prairie junegrass
201005	Limber pine/common juniper
201006	Limber pine/whiproot clover
201007	Limber pine/curlleaf mountain-mahogany
201008	Limber pine/creeping juniper
201009	Limber pine/Thurber fescue
201010	Limber pine/common chokecherry
201101	Ponderosa pine-juniper species/bluebunch wheatgrass
201102	Ponderosa pine/little bluestem-western wheatgrass
201103	Ponderosa pine-juniper species/blue grama
201104	Ponderosa pine/sideoats grama
201105	Ponderosa pine/elk sedge

2011050	Ponderosa pine/elk sedge/elk sedge
2011051	Ponderosa pine/elk sedge/silvery lupine
2011052	Ponderosa pine/elk sedge/yellow stonecrop
201106	Ponderosa pine/Ross sedge
201107	Ponderosa pine/true mountain-mahogany
201108	Ponderosa pine/timber oatgrass
201109	Ponderosa pine/Arizona fescue
2011090	Ponderosa pine/Arizona fescue/Arizona fescue
2011091	Ponderosa pine/Arizona fescue/Parry oatgrass
2011092	Ponderosa pine/Arizona fescue/blue grama
201110	Ponderosa pine/Idaho fescue
2011100	Ponderosa pine/Idaho fescue/Idaho fescue
2011101	Ponderosa pine/Idaho fescue/greenleaf manzanita
201111	Ponderosa pine/spike-fescue
201112	Ponderosa pine/common juniper
201113	Ponderosa pine/common juniper-common snowberry
201115	Ponderosa pine-juniper species/true mountain-mahogany
201117	Ponderosa pine-Douglas-fir/mountain muhly
2011170	Ponderosa pine-Douglas-fir/mountian muhly/mountain muhly
2011171	Ponderosa pine-Douglas-fir/mountain muhly/Fendler ceanothus
2011172	Ponderosa pine-Douglas-fir/mountain muhly/thickspike wheatgrass
201118	Ponderosa pine/pinyon-Gambel oak
201119	Ponderosa pine/mountain ninebark
201120	Ponderosa pine/antelope bitterbrush
201121	Ponderosa pine/Gambel oak
2011210	Ponderosa pine/Gambel oak/Gambel oak
2011211	Ponderosa pine/Gambel oak/Arizona fescue
2011214	Ponderosa pine/Gambel oak/mountain snowberry
2011215	Ponderosa pine/Gambel oak/inland box-elder
201122	Ponderosa pine/common chokecherry
2011220	Ponderosa pine/common chokecherry/common chokecherry
2011221	Ponderosa pine/common chokecherry/silvertop sedge
2011222	Ponderosa pine/common chokecherry/Saskatoon serviceberry
2011224	Ponderosa pine/common chokecherry/Oregon-grape
2011225	Ponderosa pine/common chokecherry/bur oak
2011226	Ponderosa pine/common chokecherry/big bluestem
201123	Ponderosa pine/shiny spirea

201124	Ponderosa pine/common snowberry
2011240	Ponderosa pine/common snowberry/common snowberry
2011242	Ponderosa pine/common snowberry/roughleaf ricegrass
2011243	Ponderosa pine/common snowberry/Oregon-grape
201125	Ponderosa pine/bluebunch wheatgrass
2011250	Ponderosa pine/bluebunch wheatgrass/bluebunch wheatgrass
2011251	Ponderosa pine/bluebunch wheatgrass/big sagebrush
201126	Ponderosa pine/sun sedge
201127	Ponderosa pine/blue grama
2011270	Ponderosa pine/blue grama/blue grama
2011272	Ponderosa pine/blue grama/sand bluestem
2011273	Ponderosa pine/blue grama/big sagebrush
2011274	Ponderosa pine/Blue grama/pinyon
201128	Ponderosa pine/little bluestem
2011280	Ponderosa pine/little bluestem/little bluestem
2011281	Ponderosa pine/little bluestem/wavyleaf oak
201129	Ponderosa pine/greenleaf manzanita
2011290	Ponderosa pine/greenleaf manzanita/greenleaf manzanita
2011291	Ponderosa pine/greenleaf manzanita/true mountain-mahogany
201131	Ponderosa pine/black sagebrush
201132	Ponderosa pine/curlleaf mountain-mahogany
201140	Ponderosa pine/bearberry
201150	Ponderosa pine-juniper species/western snowberry
201151	Ponderosa pine/bur oak
201201	Douglas-fir/Rocky Mountain maple
2012010	Douglas-fir/Rocky Mountain maple/Rocky Mountain maple
2012011	Douglas-fir/Rocky Mountain maple/mountain lover
2012012	Douglas-fir/Rocky Moutain maple/mountain snowberry
201202	Douglas-fir/heartleaf arnica
2012020	Douglas-fir/heartleaf arnica/heartleaf arnica
2012021	Douglas-fir/heartleaf arnica/weedy milkvetch
201203	Douglas-fir/Oregon-grape
2012030	Douglas-fir/Oregon-grape/Oregon-grape
2012032	Douglas-fir/Oregon-grape/common juniper
201204	Douglas-fir/Ross sedge
201205	Douglas-fir/pinegrass
2012050	Douglas-fir/pinegrass/pinegrass

2012052	Douglas-fir/pinegrass/Idaho fescue
2012053	Douglas-fir/pinegrass/ponderosa pine
201206	Douglas-fir/elk sedge
201207	Douglas-fir/true mountain-mahogany
201208	Douglas-fir/Idaho fescue
201209	Douglas-fir/waxflower
201210	Douglas-fir/common juniper
201211	Douglas-fir/mountain lover
201212	Douglas-fir/mallow ninebark
201213	Douglas-fir/mountain ninebark
201214	Douglas-fir/Gambel oak
2012140	Douglas-fir/Gambel oak/Gambel oak
2012141	Douglas-fir/Gambel oak/Arizona fescue
201215	Douglas-fir/shiny-leaf spirea
2012150	Douglas-fir/shiny-leaf spirea/shiny-leaf spirea
2012151	Douglas-fir/shiny-leaf spirea/pinegrass
2012153	Douglas-fir/shiny-leaf spirea/ponderosa pine
201216	Douglas-fir/common snowberry
201217	Douglas-fir/mountain snowberry
2012170	Douglas-fir/mountain snowberry/mountain snowberry
2012171	Douglas-fir/mountain snowberry/Oregon-grape
2012172	Douglas-fir/mountain snowberry/elk sedge
2012173	Douglas-fir/mountain snowberry/spike-fescue
2012174	Douglas-fir/mountain snowberry/bluebunch wheatgrass
201218	Douglas-fir/globe huckleberry
201219	Douglas-fir/bearberry-common juniper
201220	Douglas-fir/greenleaf manzanita
201221	Douglas-fir/antelope bitterbrush
201222	Douglas-fir/Saskatoon serviceberry
201223	Douglas-fir/curlleaf mountain-mahogany
201233	Douglas-fir/Arizona fescue
201241	Douglas-fir/ocean spray
201702	Green ash/common chokecherry
210202	Ironwood/succulent hawthorn
210203	Ironwood-bur oak/sparse understory
210301	Narrowleaf cottonwood/Saskatoon serviceberry
2103010	Narrowleaf cottonwood/Saskatoon serviceberry/Saskatoon serviceberry

2103011	Narrowleaf cottonwood/Saskatoon serviceberry/inland box-elder
210302	Narrowleaf cottonwood/sandbar willow-river birch
210303	Narrowleaf cottonwood/river birch-currant species
210304	Narrowleaf cottonwood/mountain ninebark-common chokecherry
210305	Narrowleaf cottonwood-Engelmann spruce/bush honeysuckle
210306	Narrowleaf cottonwood/thinleaf alder-redosier
210401	Plains cottonwood/western snowberry-giant wildrye
2104010	Plains cottonwood/western snowberry-giant wildrye/western snowberry
2104011	Plains cottonwood/western snowberry-giant wildrye/redosier
210402	Plains cottonwood-narrowleaf cottonwood/willow species
210403	Plains cottonwood/willow species
210404	Plains cottonwood/American black currant
210405	Plains cottonwood/western snowberry-sandbar willow
210501	Quaking aspen/elk sedge
210502	Quaking aspen/beaked hazel
2105020	Quaking aspen/beaked hazel/beaked hazel
2105021	Quaking aspen/beaked hazel/bracken
2105022	Quaking aspen/beaked hazel/wild sarsaparilla
210503	Quaking aspen/Thurber fescue
210504	Quaking aspen/common cow-parsnip
210505	Quaking aspen/aspen peavine
210507	Quaking aspen/silvery lupine
210508	Quaking aspen/common juniper
210510	Quaking aspen/bracken
210511	Quaking aspen/mountain snowberry
210512	Quaking aspen/Fendler meadow-rue
2105120	Quaking aspen/Fendler meadow-rue/Fendler meadow-rue
2105121	Quaking aspen/Fendler meadow-rue/golden banner
2105123	Quaking aspen/Fendler meadow-rue/stinging nettle
210513	Quaking aspen/false-hellebore
210514	Quaking aspen/big sagebrush
210515	Quaking aspen/Saskatoon serviceberry
2105150	Quaking aspen/Saskatoon serviceberry/Saskatoon serviceberry
2105151	Quaking aspen/Saskatoon serviceberry/Rocky Mountain maple
2105152	Quaking aspen/Saskatoon serviceberry/Gambel oak
2105153	Quaking aspen/Saskatoon serviceberry/Engelmann aster
2105154	Quaking aspen/Saskatoon serviceberry/balsam poplar

210516	Quaking aspen/sticky-laurel
210517	Quaking aspen/pinegrass
210518	Quaking aspen/lovage species
210519	Quaking aspen/common chokecherry
2105190	Quaking aspen/common chokecherry/common chokecherry
2105191	Quaking aspen/common chokecherry/common snowberry
210520	Quaking aspen/Oregon-grape
210521	Quaking aspen/bearberry
210522	Quaking aspen/Arizona fescue
210523	Quaking aspen/black elderberry
210601	Bur oak/western snowberry
2106010	Bur oak/western snowberry/western snowberry
2106011	Bur oak/western snowberry/quaking aspen
210603	Bur oak/hazelnut species
210701	Green ash/western snowberry
2107010	Green ash/western snowberry/western snowberry
2107011	Green ash/western snowberry/prairie sandreed
2107020	Green ash/common chokecherry/common chokecherry
2107021	Green ash/common chokecherry/Sprengel's sedge
210801	Paper birch/beaked hazel
210901	Balsam poplar/redosier
212051	Douglas-fir/pinegrass/mountain lover
220101	Oneseed juniper/sideoats grama
220102	Oneseed juniper/blue grama
220103	Oneseed juniper/western wheatgrass
220201	Pinyon-Utah juniper/beardless bluebunch wheatgrass
220202	Utah juniper/big sagebrush
220203	Utah juniper/true mountain-mahogany-squaw-apple
2202030	Utah juniper/true mountain-mahogany-squaw-apple/ true mountain-mahogany
2202031	Utah juniper/true mountain-mahogany-squaw-apple/ Wyoming big sagebrush
220204	Utah juniper/Indian ricegrass
220205	Utah juniper/yellow-wood
220206	Utah juniper/Salina wildrye
220301	Rocky Mountain juniper/western wheatgrass
220302	Rocky Mountain juniper/big sagebrush

220303	Rocky Mountain juniper/bluebunch wheatgrass
220304	Rocky Mountain juniper/true mountain-mahogany
220306	Rocky Mountain juniper/antelope bitterbrush
220307	Rocky Mountain juniper/little ricegrass
220401	Pinyon-Utah juniper/big sagebrush
2204010	Pinyon-Utah juniper/big sagebrush/big sagebrush
2204011	Pinyon-Utah juniper/big sagebrush/blue grama
220402	Pinyon/blue grama
220403	Pinyon-Utah juniper/Utah serviceberry-true mountain-mahogany
2204030	Pinyon-Utah juniper/Utah serviceberry-true mountain-mahogany/ Utah serviceberry
2204031	Pinyon-Utah juniper/Utah serviceberry-true mountain-mahogany/ greenleaf manzanita
220404	Pinyon/Gambel oak
220405	Pinyon-Utah juniper/antelope bitterbrush
220406	Pinyon-Utah juniper/muttongrass
220407	Pinyon-oneseed juniper/true mountain-mahogany
220408	Pinyon-oneseed juniper/Nelson's needlegrass
220409	Pinyon-Utah juniper/true mountain-mahogany
2204090	Pinyon-Utah juniper/true mountain-mahogany/true mountain-mahogany
2204091	Pinyon-Utah juniper/true mountain-mahogany/Gambel oak
220410	Pinyon/black sagebrush

APPENDIX B: REGION 3 PLANT ASSOCIATION CODES FOR THE CENTRAL ROCKIES VARIANT

3001010	White fir/Rocky Mountain maple
3001011	Oregongrape phase
3001012	Rockspirea phase
3001013	Riparian phase
3001020	White fir/Oregongrape
3001021	New Mexico Locust phase
3001022	Common juniper phase
3001030	White fir/sprucefir fleabane
3001040	White fir/Arizona fescue
3001041	Muttongrass phase
3001042	Gambel oak phase
3001050	White fir/Gambel oak
3001051	Screwleaf muhly phase
3001052	Arizona fescue phase
3001053	Pine muhly phase
3001054	Rockspirea phase
3001060	White fir/Screwleaf muhly
3001070	White fir/Arizona peavine
3001080	White fir/Bigtooth maple
3001081	Rockspirea phase
3001090	White fir/Kinnikinnik
3001100	White fir/Whortleberry
3001110	White fir/New Mexico locust
3001111	Dryspike sedge phase
3001120	White fir/Beardless wildrye
3001130	White fir/Arizona walnut
3001140	White fir/whortleleaf snowberry ponderosa pine series
3001141	Limber pine phase
3001150	White fir/dryspike sedge
3001160	White fir/burnet ragwort
3003	Abies bifolia (corkbark fir)
3003060	Corkbark fir/mountain bluebells
3003080	Corkbark fir/sprucefir fleabane

3003090	Subalpine fir/common juniper
3003110	Corkbark fir/Moss
3003111	Engelmann spruce phase
3003112	Douglas-fir phase
3003200	Corkbark fir/Whortleberry
3003201	Twinflower phase
3003202	Thimbleberry phase
3003203	Cliffbrush phase
3003231	Rocky Mountain maple Phase
3003240	Corkbark fir/Thimbleberry
3003300	Corkbark fir/Burnet ragwort
3003301	Douglas-fir phase
3003310	Corkbark fir/Arizona peavine
3003320	Corbark fir/cliffbush
3003350	Corkbark fir/scree
3003370	Corkbark fir/dryspike sedge
3004060	Engelmann spruce/Moss typic phase
3004061	Typical phase
3004062	Interior Douglas-fir phase
300415	Engelmann spruce/Whortleberry-skunkweed polemonium
3004151	Engelmann spruce phase
3004152	Corkbark fir phase
3004300	Engelmann spruce/Rocky Mountain maple
3004310	Engelmann spruce/Sprucefir fleabane
3004320	Engelmann spruce/beardless wildrye
3004330	Engelmann spruce/Ross avens
3004340	Engelmann spruce/gooseberry currant
300435	Engelmann spruce/bittercress ragwort
3004350	Corkbark phase
3004351	White fir phase
3004360	Engelmann spruce/Whortleberry
3006010	Blue spruce/Redosier dogwood
300604	Blue spruce/Twinflower
3006060	Blue spruce/Dryspike sedge
3006070	Blue spruce/Sprucefir fleabane
3006071	Ponderosa pine phase
3006080	Blue spruce/Kinnikinnik

3006090	Blue spruce/Arizona fescue
3006130	Blue spruce/bittercress ragwort
3011	Picea pungens (blue spruce)
3011030	Ponderosa pine/blue grama
3011031	Little bluestem phase
3011032	Sand bluestem phase
3011033	Big sagebrush phase
3011034	Gray oak phase
3011035	Gambel oak phase
3011090	Ponderosa pine/Arizona fescue phase
3011091	Parry danthonia phase
3011092	Blue grama phase
3011093	Gambel oak phase
3011130	White fir/scree
3011210	Ponderosa pine/Gambel oak
3011211	Arizona fescue phase
3011212	Longtongue muhly phase
3011213	Twoneedle pinyon phase
3011214	Mountain muhly phase
3011215	Blue grama phase
3011216	New Mexico locust phase
3011220	Ponderosa pine/Silverleaf oak
3011320	Ponderosa pine/Stansbury cliffrose
3011330	Ponderosa pine/mountain muhly
3011340	Ponderosa pine/screwleaf muhly
3011341	Gambel oak phase
3011350	Ponderosa pine/Indian ricegrass
3011360	Ponderosa pine/Gray oak /mountain muhly phase
3011361	Longtongue muhly phase
3011370	Ponderosa pine/wavyleaf oak
3011380	Ponderosa pine/black sagebrush
3011390	Ponderosa pine/screwleaf muhly -Arizona fescue
3011391	Blue grama phase
3011392	Gambel oak phase
3011400	Ponderosa pine/kinnikinnik
3011410	Ponderosa pine/Arizona white oak
3011411	Blue grama phase

3011420	Ponderosa pine/pointleaf manzanita c. t.
3011430	Ponderosa pine/netleaf oak
3011440	Ponderosa pine/Emory oak
3011460	Ponderosa pine/scree
3011470	Ponderosa pine/Arizona walnut
3011500	Ponderosa pine/rockland
301203	Douglas-fir/Oregongrape
301213	Douglas-fir/mountain ninebark
3012140	Douglas-fir/Gambel oak
3012141	Arizona fescue phase
3012142	Screwleaf muhly phase
3012143	Rockspirea phase
301231	Douglas-fir/kinnikinnik
3012320	Douglas-fir/fringed brome
3012330	Douglas-fir/Arizona fescue
3012331	Bristlecone pine phase
3012332	Limber pine phase
3012333	Aspen phase
3012340	Douglas-fir/Mountain muhly / pinyon pine phase
3012341	Limber pine phase
3012350	Douglas-fir/screwleaf muhly
3012360	Douglas-fir/Silverleaf oak ponderosa pine phase
3012361	Chihuahua pine phase
3012362	Netleaf oak phase
3012380	Douglas-fir/scree
301239	Douglas-fir/bigtooth maple
301241	Douglas-fir/rockspirea
301242	Douglas-fir/wavyleak oak
3012430	Douglas-fir/Arizona white oak
303101	Arizona cypress/silverleaf oak
303102	Arizona cypress/shrub live oak
3032010	Apache pine/longtongue muhly
3032030	Apache pine/silverleaf oak
3033010	Chihuahua pine/pinyon ricegrass
3033020	Chihuahua pine/Arizona white oak
3033030	Chihuahua pine/Silverleaf oak
3103	Populus angustifolia (narrowleaf cotonwood)

3104	Populus deltoides spp. wislizeni (Rio Grande cotonwood)
3123	Alnus tenuifolia (thinleaf alder)
3130	Platanus wrightii (Arizona sycamore)
3201010	Oneseed juniper/sideoats grama
3201011	Beargrass phase
3201020	Oneseed juniper/blue grama
3201040	Oneseed juniper/big sagebrush
3201331	Oneseed juniper/Rabbitbrush-Apacheplume
3201332	Big sagebrush phase
3201333	Gray oak phase
3201340	Oneseed juniper/sand bluestem
3201350	Oneseed juniper/Bigelow sagebrush
320140	Oneseed juniper/winterfat
3201400	Oneseed juniper/wavyleaf oak
3201410	Oneseed juniper/sacahuista-lecheguilla
3201420	Oneseed juniper/lecheguilla
3201430	Pinchot juniper/creosotebush
3202020	Utah juniper/big sagebrush
3202320	Utah juniper/blue grama
3202321	Cliffrose phase
3202330	Utah juniper/tobosagrass mesquite phase
3202331	Arizona pinyon phase
3202500	Utah Juniper-oneseed juniper/sparse c.t.
3204010	Twoneedle pinyon pine/big sagebrush Utah juniper phase
3204011	Oneseed juniper phase
3204012	Rocky Mountain juniper phase
3204021	Twoneedle pinyon pine/blue gama Utah juniper phase
3204022	Oneseed juniper phase
3204023	Alligator juniper phase
3204024	Hillslope phase
3204031	Twoneedle pinyon pine/treu mountain mahogany wavyleaf oak phase
3204032	Gray oak phase
3204033	Gambel oak phase
320404	Twoneedle pinyon pine/Gambel oak
3204050	Twoneedle pinyon pine/antelope bitterbrush
320406	Twoneedle pinyon pine/Muttongrass
320410	Twoneedle pinyon pine/pine muhly

320411	Twoneedle pinyon pine/New Mexico muhly
3204300	Twoneedle pinyon pine/sand bluestem
320431	Twoneedle pinyon pine/Arizona fescue
3204320	Twoneedle pinyon pine/Stansbury cliffrose
3204321	Big sagebrush phase
3204330	Twoneedle pinyon pine/Rabbitbrush-Apacheplume
3204350	Twoneedle pinyon pine/rockland
3204360	Twoneedle pinyon pine/wavyleaf oak
3204370	Twoneedle pinyon pine/Dore needlegrass
3204400	Twoneedle pinyon pine/manzanita
320441	Twoneedle pinyon pine/blackbrush
3204500	Twoneedle pinyon pine/sparse c. t.
3230030	Redberry juniper/crucifixion thorn
3230040	Redberry juniper/shrub live oak shrub live oak phase
3230041	Mesquite phase
3230042	Blue grama phase
3231010	Alligator juniper/pointleal manzanita
3231020	Alligator juniper/blue grama
3231021	Mesquite phase
3231030	Alligator juniper/desert ceanothus
3231040	Alligator juniper/skunkbush sumac
3231050	Alligator juniper/Bullgrass
3232020	Border pinyon/Mexican orange
3232030	Border pinyon/bullgrass
323204	Border pinyon/pinyon ricegrass
3232050	Border pinyon/Toumey oak
3232060	Border pinyon/silverleaf oak
3232070	Border pinyon/evergreen sumac
3232330	Border pine/Rabbitbrush-Apacheplume
3233010	Arizona pinyon pine/manzanita
3233020	Arizona pinyon pine/blue gama alligator juniper phase
3233021	Utah juniper phase
3233022	Cliffrose phase
3233030	Arizona pinyon pine/crucifixion thorn
3233040	Arizona pinyon/shrub live oak vegetation
3233041	Typic phase
3233042	Cliffrose phase

3233050	Arizona pinyon pine/banana yucca
3233330	Arizona pinyon/Rabbitbrush-Apacheplume
3238040	Bristlecone pine/Gooseberry current
3238300	Bristlecone pine/Arizona fescue
3238310	Bristlecone pine/Thurber fescue
3240300	Limber pine/Kinnikinnik
325000	Scarp Woodland
3335	Salix bebbiana (Bebb willow)
3610010	Mexican blue oak/mixed grama
3610020	Mexican blue oak/common sotol
3620010	Emory oak/pointleaf manzanita
3620020	Emory oak/sideoats grama
3620021	Sacahuista phase
3620030	Emory oak/common sotol
3620040	Emory oak/Arizona walnut
3630010	Gray oak/sideoats grama
3630020	Gray oak/true mountain mahogany
3630030	Arizona white oak/bullgrass
3630040	Arizona white oak/skunkbush sumac
3630041	Alligator juniper phase
3630042	Oneseed juniper phase
3630043	Pinyon ricegrass phase
3630050	Arizona white oak/pinyon ricegrass
3650010	Silverleaf oak/longtongue muhly