Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Blue Mountains (BM) Variant Overview of the Forest Vegetation Simulator

April 2023

Ponderosa pine stand, Umatilla National Forest
(David Powell, FS-R6)

Blue Mountains (BM) Variant Overview of the Forest Vegetation Simulator

Authors and Contributors:

The FVS staff has maintained model documentation for this variant in the form of a variant overview since its release in 1986. The original author was Ralph Johnson. In 2008, the previous document was replaced with this updated variant overview. Gary Dixon, Christopher Dixon, Robert Havis, Chad Keyser, Stephanie Rebain, Erin Smith-Mateja, and Don Vandendriesche were involved with this major update. Chad Keyser cross-checked information contained in this variant overview with the FVS source code. In 2009, Gary Dixon expanded the species list and made significant updates to this variant overview.

FVS Staff. 2008 (revised April 3, 2023). Blue Mountains (BM) Variant Overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 60p.

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Quick Guide to Default Settings

Parameter or Attribute	**Default Setting**	
Number of Projection Cycles	1 (10 if using FVS GUI)	
Projection Cycle Length	10 years	
Location Code (National Forest)	616 – Wallowa-Whitman	
Plant Association Code	79 (CWG113 ABGR/CARU-BLUE)	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation	45 (4500 feet)	
Latitude / Longitude	Latitude	Longitude
All location codes	45	118
Site Species	Plant Association Code specific	
Site Index	Plant Association Code specific	
Maximum Stand Density Index	Plant Association Code specific	
Maximum Basal Area	Based on maximum stand density index	
Volume Equations	National Volume Estimator Library	
Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot
Merchantable Board Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Large Trees (variable radius plot)	40 BAF	
Small Trees (fixed radius plot)	1/300th Acre	
Breakpoint DBH	5.0 inches	

1.0 Introduction

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

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

The Blue Mountains (BM) variant was developed in 1986. It covers the northeast quarter of Oregon, roughly bounded on the west by U.S. Highway 97 from Bend to Biggs and on the south by U.S. Highway 20 from Bend to Ontario, and includes a small portion of southeast Washington, roughly surrounded by U.S. Highway 12 from Walla Walla to Lewiston, Idaho. Data used in the BM variant came from forest inventories gathered by the Forest Service, and tree nutrition studies. Equations for western white pine came from those developed for the South Central Oregon and Northeastern California (SO) variant; equations used for mountain hemlock are from the North Idaho (NI) variant.

Since the variant’s development in 1986, many of the functions have been adjusted and improved as more data has become available, and as model technology has advanced. In 2009 this variant was expanded from its 10 original species to 18 species. Surrogate equations from other variants were used for these additional 8 species. Equations for western juniper, limber pine, and quaking aspen came from the Utah variant; whitebark pine from the Tetons variant; and Pacific yew, Alaska cedar, black cottonwood, and other hardwood from the West Cascades variant. In addition, the other softwood category was modified to use the same equations as ponderosa pine.

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

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

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

2.0 Geographic Range

The BM variant was fit to data representing forest types in northeastern Oregon and southeastern Washington. Data used in initial model development came from forest inventories on the Malheur, Ochoco, Umatilla, and Wallowa-Whitman National Forests and tree nutrition studies. Distribution of data samples for species fit from this data are shown in Appendix A.

The BM variant covers forest types in northeastern Oregon and the southeastern corner of Washington. The suggested geographic range of use for the BM variant is shown in figure 2.0.1.

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

3.0 Control Variables

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

3.1 Location Codes

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

If the location code is missing or incorrect in the BM variant, a default forest code of 616 (Wallowa – Whitman) will be used. Location codes recognized in the BM variant are shown in table 3.1.1.

Table 3.1.1 Location codes used in the BM variant.

Location Code	Location
604	Malheur National Forest
607	Ochoco National Forest
614	Umatilla National Forest
616	Wallowa – Whitman National Forest
619	Whitman National Forest (mapped to 616)
8117	Umatilla Reservation (mapped to 614)

3.2 Species Codes

The BM variant recognizes 16 species, plus two other composite species categories. You may use FVS species codes, Forest Inventory and Analysis (FIA) species codes, or USDA Natural Resources Conservation Service PLANTS symbols to represent these species in FVS input data. Any valid western species code identifying species not recognized by the variant will be mapped to a similar species in the variant. The species mapping crosswalk is available on the FVS website variant documentation webpage. Any non-valid species code will default to the "other hardwood" category.

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

Table 3.2.1 Species codes recognized by the BM variant.

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name[1]	Common Name[1]
1	WP	119	PIMO3	*Pinus monticola*	western white pine
2	WL	073	LAOC	*Larix occidentalis*	western larch
3	DF	202	PSME	*Pseudotsuga menziesii*	Douglas-fir
4	GF	017	ABGR	*Abies grandis*	grand fir
5	MH	264	TSME	*Tsuga mertensiana*	mountain hemlock
6	WJ	064	JUOC	*Juniperus occidentalis*	western juniper
7	LP	108	PICO	*Pinus contorta*	lodgepole pine
8	ES	093	PIEN	*Picea engelmannii*	Engelmann spruce
9	AF	019	ABLA	*Abies lasiocarpa*	subalpine fir
10	PP	122	PIPO	*Pinus ponderosa*	ponderosa pine
11	WB	101	PIAL	*Pinus albicaulis*	whitebark pine
12	LM	113	PIFL2	*Pinus flexilis*	limber pine
13	PY	231	TABR2	*Taxus brevifolia*	Pacific yew
14	YC	042	CANO9	*Callitropsis nootkatensis*	Alaska cedar
15	AS	746	POTR5	*Populus tremuloides*	quaking aspen
16	CW	747	POBAT	*Populus balsamifera* ssp. *trichocarpa*	black cottonwood
17	OS	299	2TN		other softwood[2]
18	OH	998	2TB		other hardwood[2]

[1]Set based on the USDA Forest Service NRM TAXA lists and the USDA Plants database.
[2]Other categories use FIA codes and NRM TAXA codes that best match the other category.

3.3 Habitat Type, Plant Association, and Ecological Unit Codes

Plant association codes recognized in the BM variant are shown in Appendix B. If an incorrect plant association code is entered or no code is entered FVS will use the default plant association code, which is 79 (CWG113 ABGR/CARU-BLUE). Plant association codes are used to set default site information such as site species, site indices, and maximum stand density indices as well as modeling snag dynamics in FFE-FVS. The site species, site index and maximum stand density indices can be reset via FVS keywords. Users may enter the plant association code or the plant association FVS sequence number on the STDINFO keyword, when entering stand information from a database, or when using the SETSITE keyword without the PARMS option. If using the PARMS option with the SETSITE keyword, users must use the FVS sequence number for the plant association.

3.4 Site Index

Site index is used in some of the growth equations for the BM variant. Users should always use the same site curves that FVS uses, which are shown in table 3.4.1. If site index is available, a single site index for the whole stand can be entered, a site index for each individual species in the stand can be entered, or a combination of these can be entered.

Table 3.4.1 Site index reference curves for species in the BM variant.

Species Code	Reference	BHA or TTA1	Base Age
WP	Brickell, J.E. (1970)	TTA	50
WL	Cochran, P.H. (1985)	BHA	50
DF	Cochran, P.H. (1979a)	BHA	50
GF	Cochran, P.H. (1979b)	BHA	50
MH	Means unpublished (1986)[2]	BHA	100
LP	Dahms, Walter (1964)	TTA	50
ES	Alexander (1967)	BHA	100
AF	Demars, D.J. et. al. (1970)	BHA	100
PP, OS	Barrett, J.W. (1978)	BHA	100
WJ, WB, LM	Alexander, Tackle, and Dahms (1967)	TTA	100
PY, YC, CW, OH	Curtis, R.O., et. al. (1974)	BHA	100
AS	Edminster, Mowrer, and Shepperd (1985)	BHA	80

[1] Equation is based on total tree age (TTA) or breast height age (BHA)

[2] The source equation is in metric units; site index values for MH are assumed to be in meters.

If site index is missing or incorrect, the default site species and site index are determined by plant association codes found in Appendix B. If the plant association code is missing or incorrect, the site species is set to grand fir with a default site index set to 63.

Site indices for species not assigned a site index are determined based on the site index of the site species (height at base age) with an adjustment for the reference age differences between the site species and the target species.

3.5 Maximum Density

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

The default maximum SDI is set based on a user-specified, or default, plant association code or a user specified basal area maximum. If a user specified basal area maximum is present, the maximum SDI for all species is computed using equation {3.5.1}; otherwise, the SDI maximum for a species is assigned from the SDI maximum for that species associated with the plant association code shown in Appendix B. If a species SDI maximum is unknown for a given plant association code, then it is assigned the SDI maximum for the site species associated with the plant association code. SDI maximums were set based on growth basal area (GBA) analysis developed by Hall (1983), an analysis of Current Vegetation Survey (CVS) plots in USFS Region 6 by Crookston (2008) or an analysis performed by Powell (2009). Some SDI maximums associated with plant associations are unreasonably large, so SDI maximums are capped at 850. Maximum stand density index at the stand level is a weighted average, by basal area, of the individual species SDI maximums.

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

where:

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

4.0 Growth Relationships

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

4.1 Height-Diameter Relationships

Height-diameter relationships in FVS are primarily used to estimate tree heights missing in the input data, and occasionally to estimate diameter growth on trees smaller than a given threshold diameter. In the BM variant, FVS will dub in heights by one of two methods. By default, for all species except western juniper, whitebark pine, limber pine, and quaking aspen, the BM variant will use the Curtis-Arney functional form as shown in equation {4.1.1} (Curtis 1967, Arney 1985). For western juniper, whitebark pine, limber pine, and quaking aspen a logistic height-diameter equation {4.1.2} (Wykoff, et.al 1982) is used.

If the input data contains at least three measured heights for a species, then FVS can calibrated the logistic height-diameter equation to the input data. This calibration is done automatically for western juniper, whitebark pine, limber pine and quaking aspen. However, it must be invoked using the NOHTDREG keyword for all other species. Coefficients for equation {4.1.1} are given in table 4.1.1 sorted by species and location code. Coefficients for equation {4.1.3} are given in table 4.1.2.

{4.1.1} Curtis-Arney functional form

$DBH \geq 3.0”: HT = 4.5 + P_2 * \exp[-P_3 * DBH ^ P_4]$

$DBH < 3.0”: HT = [(4.5 + P_2 * \exp[-P_3 * 3.0 ^ P_4] – 4.51) * (DBH – 0.3) / 2.7] + 4.51$

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

where:

HT	is tree height
DBH	is tree diameter at breast height
B_1 - B_2	are species-specific coefficients shown in table 4.1.2
P_1 - P_4	are species-specific coefficients shown in table 4.1.1

Table 4.1.1 Coefficients for Curtis-Arney equation {4.1.1} in the BM variant.

Species Code	Location Code	P_2	P_3	P_4
WP	604 - Malheur	140.8498	4.9436	-0.6048
	607 - Ochoco	140.8498	4.9436	-0.6048
	614 - Umatilla	140.8498	4.9436	-0.6048
	616 - Wallowa-Whitman	140.8498	4.9436	-0.6048
WL	604 - Malheur	188.1500	5.6420	-0.7348
	607 - Ochoco	255.4638	5.5577	-0.6054
	614 - Umatilla	186.6625	5.3006	-0.7604

Species Code	Location Code	P_2	P_3	P_4
	616 - Wallowa-Whitman	326.9389	4.6684	-0.4657
DF	604 - Malheur	476.1213	5.0963	-0.3461
	607 - Ochoco	318.7441	5.6666	-0.4666
	614 - Umatilla	219.4816	5.3103	-0.5643
	616 - Wallowa-Whitman	260.1577	5.2245	-0.5013
GF	604 - Malheur	846.4856	6.1757	-0.3210
	607 - Ochoco	686.4831	6.5393	-0.3740
	614 - Umatilla	297.7143	5.9520	-0.5290
	616 - Wallowa-Whitman	360.9231	5.7382	-0.4544
MH	604 - Malheur	150.5836	5.5158	-0.6435
	607 - Ochoco	150.5836	5.5158	-0.6435
	614 - Umatilla	150.5836	5.5158	-0.6435
	616 - Wallowa-Whitman	150.5836	5.5158	-0.6435
LP	604 - Malheur	1901.4963	5.9791	-0.2300
	607 - Ochoco	228.0877	4.2939	-0.4277
	614 - Umatilla	89.0137	7.7404	-1.3530
	616 - Wallowa-Whitman	117.1495	4.8451	-0.8613
ES	604 - Malheur	211.5595	7.310	-0.7176
	607 - Ochoco	738.6208	5.5866	-0.3193
	614 - Umatilla	221.5298	6.1879	-0.6629
	616 - Wallowa-Whitman	219.4529	6.1539	-0.6558
AF	604 - Malheur	437.3897	5.6600	-0.3975
	607 - Ochoco	128.7188	6.9094	-0.9039
	614 - Umatilla	164.6321	6.9476	-0.7650
	616 - Wallowa-Whitman	128.7188	6.9094	-0.9039
PP	604 - Malheur	1818.1733	6.8482	-0.2535
	607 - Ochoco	1526.6312	6.9207	-0.2774
	614 - Umatilla	313.4270	6.4808	-0.5194
	616 - Wallowa-Whitman	649.6683	6.1279	-0.3511
PY	604 - Malheur	77.2207	3.5181	-0.5894
	607 - Ochoco	77.2207	3.5181	-0.5894
	614 - Umatilla	77.2207	3.5181	-0.5894
	616 - Wallowa-Whitman	77.2207	3.5181	-0.5894
YC	604 - Malheur	97.7769	8.8202	-1.0534
	607 - Ochoco	97.7769	8.8202	-1.0534
	614 - Umatilla	97.7769	8.8202	-1.0534
	616 - Wallowa-Whitman	97.7769	8.8202	-1.0534
CW	604 - Malheur	178.6441	4.5852	-0.6746
	607 - Ochoco	178.6441	4.5852	-0.6746
	614 - Umatilla	178.6441	4.5852	-0.6746

Species Code	Location Code	P_2	P_3	P_4
	616 - Wallowa-Whitman	178.6441	4.5852	-0.6746
OS	604 - Malheur	1818.1733	6.8482	-0.2535
	607 - Ochoco	1526.6312	6.9207	-0.2774
	614 - Umatilla	313.4270	6.4808	-0.5194
	616 - Wallowa-Whitman	649.6683	6.1279	-0.3511
OH	604 - Malheur	1709.7229	5.8887	-0.2286
	607 - Ochoco	1709.7229	5.8887	-0.2286
	614 - Umatilla	1709.7229	5.8887	-0.2286
	616 - Wallowa-Whitman	1709.7229	5.8887	-0.2286

Table 4.1.2 Coefficients for the logistic Wykoff equation {4.1.2} in the BM variant.

Species Code	Default B_1	B_2
WP	5.035	-10.674
WL	5.043	-9.123
DF	4.929	-10.744
GF	4.874	-10.405
MH	4.874	-10.405
WJ	3.200	-5.000
LP	4.954	-9.177
ES	5.035	-10.674
AF	4.875	-9.568
PP	4.993	-12.430
WB	4.1920	-5.1651
LM	4.1920	-5.1651
PY	5.1880	-13.8010
YC	5.143	-13.497
AS	4.4421	-6.5405
CW	5.1520	-13.5760
OS	4.993	-12.430
OH	5.1520	-13.5760

4.2 Bark Ratio Relationships

Bark ratio estimates are used to convert between diameter outside bark and diameter inside bark in various parts of the model. The equation used for western white pine, western larch, Douglas-fir, grand fir, mountain hemlock, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, Pacific yew, Alaska cedar, other softwood, and other hardwood is shown in equation {4.2.1} and coefficients (b_1 and b_2) for this equation by species are shown in table 4.2.1.

{4.2.1} $DIB = b_1 * DBH^{\wedge}b_2$ where $BRATIO = DIB / DBH$

where:

BRATIO	is species-specific bark ratio. Bounded to 0 ≤ *BRATIO* ≤ 0.999 for WP, WL, DF, GF, MH, LP, ES, AF, PP, OS and bounded to 0.80≤ *BRATIO* ≤ 0.99 for PY, YC, OH
DBH	is tree diameter at breast height
DIB	is tree diameter inside bark at breast height
b_1 - b_2	are species-specific coefficients shown in table 4.2.1

The equation used for western juniper and limber pine is shown in {4.2.2} with coefficients (b_1 and b_2) shown in table 4.2.1.

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

where:

BRATIO	is species-specific bark ratio (bounded to 0.80≤ *BRATIO* ≤ 0.99)
DBH	is tree diameter at breast height. Bounded to 1.0≤ *DBH* ≤ 19.0) for WJ and bounded to 1.0≤ *DBH* for LM
b_1 - b_2	are species-specific coefficients shown in table 4.2.1

The equation used for whitebark pine and quaking aspen is shown in {4.2.3} with coefficient (b_1) shown in table 4.2.1.

{4.2.3} $BRATIO = b_1$

where:

BRATIO	is species-specific bark ratio (bounded to 0.80≤ *BRATIO* ≤ 0.99)
b_1	is the species-specific coefficient shown in table 4.2.1

Black cottonwood uses equation {4.2.4} with coefficients (b_1 and b_2) shown in table 4.2.1.

{4.2.4} $DIB = b_1 + b_2*DBH$ $\qquad$ $BRATIO = DIB / DBH$

where:

BRATIO	is species-specific bark ratio (bounded to 0.80≤ *BRATIO* ≤ 0.99)
DBH	is tree diameter at breast height
DIB	is tree diameter inside bark at breast height
b_1 - b_2	are species-specific coefficients shown in table 4.2.1

Table 4.2.1 Coefficients for the bark ratio equation {4.2.1} in the BM variant.

Species Code	b_1	b_2
WP	0.859045	1.0
WL	0.859045	1.0
DF	0.903563	0.989388
GF	0.904973	1.0
MH	0.903563	0.989388
WJ	0.9002	-0.3089
LP	0.9	1.0

Species Code	b_1	b_2
ES	0.9	1.0
AF	0.904973	1.0
PP	0.809427	1.016866
WB	0.969	0.0
LM	0.9625	-0.1141
PY	0.933290	1.0
YC	0.837291	1.0
AS	0.950	0.0
CW	0.075256	0.949670
OS	0.809427	1.016866
OH	0.9000	1.0

4.3 Crown Ratio Relationships

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

4.3.1 Crown Ratio Dubbing

In the BM variant, crown ratios missing in the input data are predicted using different equations depending on tree species and size. For all species, live trees less than 1.0" in diameter and dead trees of all sizes use equation {4.3.1.1} and one of the equations listed below, {4.3.1.2} - {4.3.1.3}, to compute crown ratio. Species group assignment and equation number used by species is found in table 4.3.1.1. Equation coefficients are found in table 4.3.1.2.

{4.3.1.1} $X = R_1 + R_2 * DBH + R_3 * HT + R_4 * BA + R_5 * PCCF + R_6 * AVH/HT + R_7 * AVH + R_8 * BA * PCCF + R_9 * MAI$

{4.3.1.2} $CR = 1 / (1 + \exp(X + N(0,SD)))$ where absolute value of $(X + N(0,SD)) < 86$

{4.3.1.3} $CR = (((X + N(0,SD)) - 1) * 10 + 1) / 100$

where:

CR is crown ratio expressed as a proportion (bounded to $0.05 \leq CR \leq 0.95$)
DBH is tree diameter at breast height
HT is tree height
BA is total stand basal area
PCCF is crown competition factor on the inventory point where the tree is established
HT_{Avg} is average height of the 40 largest diameter trees in the stand
MAI is stand mean annual increment
N(0,SD) is a random increment from a normal distribution with a mean of 0 and a standard deviation of SD
$R_1 – R_9$ are species-specific coefficients shown in table 4.3.1.1

Table 4.3.1.1 Species group and equation assignment by species in the BM variant.

Species Code	Species Group	Equation Number	Species Code	Species Group	Equation Number
WP	1	{4.3.1.1}	PP	3	{4.3.1.1}
WL	1	{4.3.1.1}	WB	3	{4.3.1.1}
DF	2	{4.3.1.1}	LM	3	{4.3.1.1}
GF	2	{4.3.1.1}	PY	5	{4.3.1.2}
MH	2	{4.3.1.1}	YC	6	{4.3.1.2}
WJ	4	{4.3.1.1}	AS	2	{4.3.1.1}
LP	3	{4.3.1.1}	CW	7	{4.3.1.2}
ES	2	{4.3.1.1}	OS	3	{4.3.1.1}
AF	2	{4.3.1.1}	OH	7	{4.3.1.2}

Table 4.3.1.2 Coefficients for the crown ratio equation {4.3.1.1} in the BM variant.

Coefficient	Species Group						
	1	2	3	4	5	6	7
R_1	-1.66949	-0.426688	-1.66949	-2.19723	6.489813	7.558538	5.0
R_2	-0.209765	-0.093105	-0.209765	0	0	0	0
R_3	0	0.022409	0	0	-0.029815	-0.015637	0
R_4	0.003359	0.002633	0.003359	0	-0.009276	-0.009064	0
R_5	0.011032	0	0.011032	0	0	0	0
R_6	0	-0.045532	0	0	0	0	0
R_7	0.017727	0	0.017727	0	0	0	0
R_8	-0.000053	0.000022	-0.000053	0	0	0	0
R_9	0.014098	-0.013115	0.014098	0	0	0	0
SD	0.5	0.6957**	*	0.2	2.0426	1.9658	0.5

* SD = 0.6124 for LP; 0.4942 for PP and OS; 0.5 for WB and LM

** SD = 0.9310 for AS

A Weibull-based crown model developed by Dixon (1985) as described in Dixon (2002) is used to predict crown ratio for all live trees 1.0” in diameter or larger. To estimate crown ratio using this methodology, the average stand crown ratio is estimated from stand density index using equation {4.3.1.4}. Weibull parameters are then estimated from the average stand crown ratio using equations in equation set {4.3.1.5}. Individual tree crown ratio is then set from the Weibull distribution, equation {4.3.1.6} based on a tree's relative position in the diameter distribution and multiplied by a scale factor, shown in equation {4.3.1.7}, which accounts for stand density. Crowns estimated from the Weibull distribution are bounded to be between the 5 and 95 percentile points of the specified Weibull distribution. Equation coefficients for each species are shown in table 4.3.1.3.

{4.3.1.4} $ACR = d_0 + d_1 * RELSDI * 100.0$ where: $RELSDI = SDI_{stand} / SDI_{max}$

{4.3.1.5} Weibull parameters A, B, and C are estimated from average crown ratio

$A = a_0$
$B = b_0 + b_1 * ACR \quad (B \geq 3)$
$C = c_0 + c_1 * ACR \quad (C \geq 2)$

{4.3.1.6} $Y = 1\text{-exp}(-((X-A)/B)^\wedge C)$

{4.3.1.7} $SCALE = 1 – 0.00167 * (CCF – 100)$

where:

ACR	is predicted average stand crown ratio for the species
SDI_{stand}	is stand density index of the stand
SDI_{max}	is maximum stand density index
A, *B*, *C*	are parameters of the Weibull crown ratio distribution
X	is a tree's crown ratio expressed as a percent / 10
Y	is a trees rank in the diameter distribution (1 = smallest; ITRN = largest) divided by the total number of trees (ITRN) multiplied by *SCALE*
SCALE	is a density dependent scaling factor (bounded to $0.3 \leq SCALE \leq 1.0$)
CCF	is stand crown competition factor

a_0, b_{0-1}, c_{0-1}, and d_{0-1} are species-specific coefficients shown in table 4.3.1.3

Table 4.3.1.3 Coefficients for the Weibull parameter equations {4.3.1.4} and {4.3.1.5} in the BM variant.

Species Code	Model Coefficients						
	a_0	b_0	b_1	c_0	c_1	d_0	d_1
WP	0	0.74338	0.97850	-3.98461	1.34802	6.94062	-0.01927
WL	0	-0.00114	1.11300	3.40943	0	5.30390	-0.02049
DF	0	0.35559	1.04220	-0.68418	0.80153	6.69836	-0.02594
GF	0	0.46010	1.02563	-1.74681	0.98317	7.07172	-0.03044
MH	0	0.46010	1.02563	-1.74681	0.98317	7.07172	-0.03044
WJ	0	0.07609	1.10184	3.01	0	7.23800	0
LP	0	-0.04970	1.14250	2.49474	0	4.82367	-0.02373
ES	0	0.74338	0.97850	-3.98461	1.34802	6.94062	-0.01927
AF	0	0.40743	1.02954	4.06366	0	7.97175	-0.03545
PP	0	0.22542	1.06011	0.58615	0.64158	6.23850	-0.03064

Species Code	Model Coefficients						
	a_0	b_0	b_1	c_0	c_1	d_0	d_1
WB	1	-0.82631	1.06217	3.31429	0	6.19911	-0.02216
LM	1	-0.82631	1.06217	3.31429	0	6.19911	-0.02216
PY	0	0.196054	1.073909	0.345647	0.620145	5.417431	-0.011608
YC	1	-0.811424	1.056190	-3.831124	1.401938	5.200550	-0.014890
AS	0	-0.08414	1.14765	2.77500	0	4.01678	-0.01516
CW	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
OS	0	0.22542	1.06011	0.58615	0.64158	6.23850	-0.03064
OH	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042

4.3.2 Crown Ratio Change

Crown ratio change is estimated after growth, mortality and regeneration are estimated during a projection cycle. Crown ratio change is the difference between the crown ratio at the beginning of the cycle and the predicted crown ratio at the end of the cycle. Crown ratio predicted at the end of the projection cycle is estimated for live tree records using the Weibull distribution, equations {4.3.1.4}-{4.3.1.7}, for all species. Crown change is checked to make sure it doesn't exceed the change possible if all height growth produces new crown. Crown change is further bounded to 1% per year for the length of the cycle to avoid drastic changes in crown ratio. Equations {4.3.1.1}-{4.3.1.3} are not used when estimating crown ratio change.

4.3.3 Crown Ratio for Newly Established Trees

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

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

where:

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

4.4 Crown Width Relationships

The BM variant calculates the maximum crown width for each individual tree, based on individual tree and stand attributes. Crown width for each tree is reported in the tree list output table and used for percent canopy cover (*PCC*) calculations in the model.

Crown width is calculated using equations {4.4.1} – {4.4.6}, and coefficients for these equations are shown in table 4.4.1. The minimum diameter and bounds for certain data values are given in table 4.4.2. Equation numbers in Table 4.4.1 are given with the first three digits representing the FIA species code, and the last two digits representing the equation source.

{4.4.1} Bechtold (2004); Equation 01

$DBH \geq MinD: CW = a_1 + (a_2 * DBH) + (a_3 * DBH\text{^}2)$
$DBH < MinD: CW = [a_1 + (a_2 * MinD) * (a_3 * MinD\text{^}2)] * (DBH / MinD)$

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

$HT < 5.0: CW = [0.8 * HT * \text{MAX}(0.5, CR * 0.01)] * [1 - (HT - 5) * 0.1] * a_1 * DBH\text{^}a_2 * HT\text{^}a_3 * CL\text{^}a_4 * (HT\text{-}5) * 0.1$
$5.0 \leq HT < 15.0: CW = 0.8 * HT * \text{MAX}(0.5, CR * 0.01)$
$HT \geq 15.0: CW = a_1 * (DBH\text{^}a_2) * (HT\text{^}a_3) * (CL\text{^}a_4)$

{4.4.3} Crookston (2003); Equation 03 (western larch and grand fir)

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

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

{4.4.4 Crookston (2005); Equation 04

$DBH \geq MinD: CW = a_1 * DBH\text{^}a_2$
$DBH < MinD: CW = [a_1 * MinD\text{^}a_2] * (DBH / MinD)$

{4.4.5} Crookston (2005); Equation 05

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

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

{4.4.6} Donnelly (1996); Equation 06

$DBH \geq MinD\ CW = a_1 * DBH\text{^}a_2$
$DBH < MinD\ CW = [a_1 * MinD\text{^}a_2] * (DBH / MinD)$

where:

BF	is a species-specific coefficient based on forest code (*BF* = 1.0 in the AK variant)
CW	is tree maximum crown width
CL	is tree crown length
DBH	is tree diameter at breast height
HT	is tree height
BA	is total stand basal area
EL	is stand elevation in hundreds of feet
MinD	is the minimum diameter
$a_1 - a_6$	are species-specific coefficients shown in table 4.4.1

Table 4.4.1 Coefficients for crown width equations {4.4.1}-{4.4.6} in the BM variant.

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
WP	11905	5.3822	0.57896	-0.19579	0.14875	0	-0.00685

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
WL	07303	1.02478	0.99889	0.19422	0.59423	-0.09078	-0.02341
DF	20205	6.0227	0.54361	-0.20669	0.20395	-0.00644	-0.00378
GF	01703	1.0303	1.14079	0.20904	0.38787	0	0
MH	26403	6.90396	0.55645	-0.28509	0.20430	0	0
WJ	06405	5.1486	0.73636	-0.46927	0.39114	-0.05429	0
LP	10805	6.6941	0.81980	-0.36992	0.17722	-0.01202	-0.00882
ES	09305	6.7575	0.55048	-0.25204	0.19002	0	-0.00313
AF	01905	5.8827	0.51479	-0.21501	0.17916	0.03277	-0.00828
PP	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
WB	10105	2.2354	0.66680	-0.11658	0.16927	0	0
LM	11301	4.0181	0.8528	0	0	0	0
PY	23104	6.1297	0.45424	0	0	0	0
YC	04205	3.3756	0.45445	-0.11523	0.22547	0.08756	-0.00894
AS	74605	4.7961	0.64167	-0.18695	0.18581	0	0
CW	74705	4.4327	0.41505	-0.23264	0.41477	0	0
OS	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
OH	31206	7.5183	0.4461	0	0	0	0

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

Table 4.4.2 *MinD* values and data bounds for equations {4.4.1}-{4.4.6} in the BM variant.

Species Code	Equation Number*	*MinD*	EL min	*EL* max	*HI* min	*HI* max	*CW* max
WP	11905	1.0	10	75	n/a	n/a	35
WL	07303	1.0	n/a	n/a	n/a	n/a	40
DF	20205	1.0	1	75	n/a	n/a	80
GF	01703	1.0	n/a	n/a	n/a	n/a	40
MH	26403	n/a	n/a	n/a	n/a	n/a	45
WJ	06405	1.0	n/a	n/a	n/a	n/a	36
LP	10805	1.0	1	79	n/a	n/a	40
ES	09305	1.0	1	85	n/a	n/a	40
AF	01905	1.0	10	85	n/a	n/a	30
PP	12205	1.0	13	75	n/a	n/a	50
WB	10105	1.0	n/a	n/a	n/a	n/a	40
LM	11301	5.0	n/a	n/a	n/a	n/a	25
PY	23104	1.0	n/a	n/a	n/a	n/a	30
YC	04205	1.0	16	62	n/a	n/a	59
AS	74605	1.0	n/a	n/a	n/a	n/a	45
CW	74705	1.0	n/a	n/a	n/a	n/a	56
OS	12205	1.0	13	75	n/a	n/a	50
OH	31206	1.0	n/a	n/a	n/a	n/a	30

Table 4.4.3 BF values for equation {4.4.5} in the BM variant.

Species Code	Location Code				
	604	607	614	616	619
WP	1.081	1	1.128	1	1
WL	0.818	0.879	0.907	0.818	0.818
DF	1.058	1.055	1.055	1	1
GF	1	1	1.076	1	1
MH	1	1	1	1.077	1.077
WJ	1	1	1	1	1
LP	1.196	1.196	1.244	1.114	1.114
ES	1.121	1.169	1.137	1.070	1.070
AF	1.110	1.110	1.110	1	1
PP	1	1	1.035	1	1
WB	1	1	1	1	1
LM	1	1	1	1	1
PY	1	1	1	1	1
YC	1	1	1	1	1
AS	1	1	1	1	1
CW	1	1	1	1	1
OS	1	1	1.035	1	1
OH	1	1	1	1	1

4.5 Crown Competition Factor

The BM variant uses crown competition factor (*CCF*) as a predictor variable in some growth relationships. Crown competition factor (Krajicek and others 1961) is a relative measurement of stand density that is based on tree diameters. Individual tree CCF_t values estimate the percentage of an acre that would be covered by the tree's crown if the tree were open-grown. Stand *CCF* is the summation of individual tree (CCF_t) values. A stand *CCF* value of 100 theoretically indicates that tree crowns will just touch in an unthinned, evenly spaced stand.

For all species except Pacific yew, Alaska cedar, black cottonwood, and other hardwood, crown competition factor for an individual tree is calculated using equation {4.5.1}. Coefficients are either from Paine and Hann (1982) or the Inland Empire variant coefficients (Wykoff, et.al 1982).

{4.5.1} All species except Pacific yew, Alaska cedar, black cottonwood, and other hardwood

$DBH \geq 1.0”$: $CCF_t = R_1 + (R_2 * DBH) + (R_3 * DBH^2)$

$0.1” < DBH < 1.0”$: $CCF_t = R_4 * DBH^{R_5}$

$DBH \leq 0.1”$: $CCF_t = 0.001$

where:

CCFt is crown competition factor for an individual tree
DBH is tree diameter at breast height

$R_1 - R_5$ are species-specific coefficients shown in table 4.5.1

For Pacific yew, Alaska cedar, black cottonwood, and other hardwood, equation {4.5.2} is used. All species coefficients are shown in table 4.5.1.

{4.5.2} CCF equation for Pacific yew, Alaska cedar, black cottonwood, and other hardwood

$DBH \geq 1.0”$: $CCF_t = R_1 + (R_2 * DBH) + (R_3 * DBH\char`^2)$
$DBH < 1.0”$: $CCF_t = (R_1 + R_2 + R_2) * DBH$

where:

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

Table 4.5.1 Coefficients for the CCF equations in the BM variant.

Species Code	Model Coefficients				
	R_1	R_2	R_3	R_4	R_5
WP	0.0186	0.0146	0.00288	0.009884	1.6667
WL	0.0392	0.0180	0.00207	0.007244	1.8182
DF	0.0388	0.0269	0.00466	0.017299	1.5571
GF	0.0690	0.0225	0.00183	0.015248	1.7333
MH	0.03	0.018	0.00281	0.011109	1.7250
WJ	0.01925	0.01676	0.00365	0.009187	1.7600
LP	0.01925	0.01676	0.00365	0.009187	1.7600
ES	0.03	0.0173	0.00259	0.007875	1.7360
AF	0.0172	0.00876	0.00112	0.011402	1.7560
PP	0.0219	0.0169	0.00325	0.007813	1.7780
WB	0.01925	0.01676	0.00365	0.009187	1.7600
LM	0.01925	0.01676	0.00365	0.009187	1.7600
PY	0.0204	0.0246	0.0074	0	0
YC	0.0194	0.0142	0.00261	0	0
AS	0.03	0.0238	0.00490	0.008915	1.7800
CW	0.0204	0.0246	0.0074	0	0
OS	0.0219	0.0169	0.00325	0.007813	1.7780
OH	0.0204	0.0246	0.0074	0	0

4.6 Small Tree Growth Relationships

Trees are considered “small trees” for FVS modeling purposes when they are smaller than some threshold diameter. The threshold diameter is set to 3.0” for all species in the BM variant except western juniper. Western juniper uses the small-tree relationships to predict height and diameter growth for trees of all sizes.

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

4.6.1 Small Tree Height Growth

The small-tree height increment model predicts 10-year height growth (*HTG*) for small trees, based on site index. Potential height growth is estimated using equations {4.6.1.1} – {4.6.1.3}, depending on species, and coefficients shown in table 4.6.1.1.

Potential height growth for western white pine is calculated using equation {4.6.1.1}.

{4.6.1.1} $POTHTG = (SI / c_1) * (1.0 - c_2 * \exp(c_3 * X_2))\hat{\ }c_4 - (SI / c_1) * (1.0 - c_2 * \exp(c_3 * X_1))\hat{\ }c_4$

$X_1 = \text{ALOG}\ [(1.0 - (c_1 / SI * HT)\hat{\ }(1 / c_4)) / c_2] / c_3$

$X_2 = X_1 + A$

Potential height growth for western larch, Douglas-fir, grand fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, whitebark pine, Pacific yew, Alaska cedar, black cottonwood, other softwood, and other hardwood is calculated using equation {4.6.1.2}.

{4.6.1.2} $POTHTG = [(c_1 + c_2 * SI) / (c_3 – c_4 * SI)] * A$

Potential height growth for mountain hemlock is calculated using equation {4.6.1.3}.

{4.6.1.3} $POTHTG = [(c_1 + c_2 * SI) / (c_3 – c_4 * SI)] * A * 3.280833$

Potential height growth for western juniper is calculated using equation {4.6.1.4}.

{4.6.1.4} $POTHTG = [(SI / 5) * (1.5 * SI - HT)] / (SI * 1.5)$ (SI bounded $5.5 \leq SI \leq 75$)

Potential height growth for limber pine is calculated using equation {4.6.1.5}.

{4.6.1.5} $POTHTG = SI / 5$

where:

POTHTG is potential height growth
SI is species site index
A is tree age
HT is tree height
$c_1 – c_4$ are species-specific coefficients shown in table 4.6.1.1

Table 4.6.1.1 Coefficients and equation reference by species in the BM variant.

Species Code	*POTHTG* Equation	Model Coefficients			
		c_1	c_2	c_3	c_4
WP	{4.6.1.1}	0.375045	0.92503	-.020796	2.48811
WL	{4.6.1.2}	-3.9725	0.50995	28.1168	0.05661
DF	{4.6.1.2}	2.0	0.420	28.5	0.05
GF	{4.6.1.2}	4.2435	0.1510	19.0184	0.0570
MH	{4.6.1.3}	0.965758	0.082969	55.249612	1.288852
WJ	{4.6.1.4}	0	0	0	0

Species Code	*POTHTG* Equation	Model Coefficients			
		c_1	c_2	c_3	c_4
LP	{4.6.1.2}	0	0.0200805	1.0	0
ES	{4.6.1.2}	0.09211	0.208517	43.358	0.168166
AF	{4.6.1.2}	6.0	0.14	33.882	0.06588
PP	{4.6.1.2}	-1.0	0.32857	28.0	0.042857
WB	{4.6.1.2}	0	0.0321409	1.0	0
LM	{4.6.1.5}	0	0.2	0	0
PY	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
YC	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
AS	{4.6.1.10}	0	0	0	0
CW	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
OS	{4.6.1.2}	-1.0	0.32857	28.0	0.042857
OH	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586

Potential height growth for all species except quaking aspen is then adjusted based on stand density (*PCTRED*) and crown ratio (*VIGOR*) as shown in equations {4.6.1.6} - {4.6.1.8} to determine an estimated height growth as shown in equation {4.6.1.9}.

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

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

{4.6.1.7} Used for all species except quaking aspen and western juniper

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

Note, for western juniper the VIGOR adjustment is reduced by two-thirds as shown in equation {4.6.1.8}.

{4.6.1.8} Used for western juniper

$VIGOR = 1 - ((1 - VIGOR) /3)$

{4.6.1.9} $HTG = POTHTG * PCTRED * VIGOR$

where:

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

Height growth for quaking aspen is obtained from an aspen height-age curve, equation {4.6.1.10} (Shepperd 1995). Because Shepperd's original curve seemed to overestimate height growth, the BM variant reduces the estimated height growth by 25 percent. A height is estimated from the trees' current age, and then its current age plus 10 years. Height growth is the difference between these two height estimates adjusted to account for cycle length and any user defined small-tree height growth adjustments for aspen. This equation estimates height growth in centimeters so FVS also converts the estimate from centimeters to feet. An estimate of the tree's current age is obtained at the start of a projection using the tree's height and solving equation {4.6.1.10} for age.

{4.6.1.10} $HT = (26.9825 * A^{1.1752}) * (1 + [(SI - SITELO) / (SITEHI - SITELO)]) * 1.8$

where:

HT	is total tree height
A	is total tree age
SI	is quaking aspen site index (bounded $SITELO + 0.5 \leq SI$)
SITEHI	is upper end of the site index range for quaking aspen (66 in the BM variant)

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

Height growth estimates from the small-tree model are weighted with the height growth estimates from the large tree model over a range of diameters (X_{min} and X_{max}) in order to smooth the transition between the two models. The closer a tree's *DBH* value is to the minimum diameter (X_{min}), the more the growth estimate will be weighted towards the small-tree growth model. The closer a tree's *DBH* value is to the maximum diameter (X_{max}), the more the growth estimate will be weighted towards the large-tree growth model. If a tree's *DBH* value falls outside of the range given by X_{min} and X_{max}, then the model will use only the small-tree or large-tree growth model in the growth estimate. The weight applied to the growth estimate is calculated using equation {4.6.1.11}, and applied as shown in equation {4.6.1.12}. The range of diameters for each species is shown in table 4.6.1.2.

{4.6.1.11}

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

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

where:

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

Table 4.6.1.2 Diameter bounds by species in the BM variant.

Species Code	X_{min}	X_{max}
WP	2.0	3.0
WL	1.0	2.0
DF	2.0	4.0
GF	2.0	4.0
MH	1.0	2.0
WJ	90.0	99.0
LP	2.0	4.0
ES	2.0	4.0
AF	2.0	4.0
PP	1.0	5.0
WB	1.5	3.0
LM	2.0	4.0
PY	2.0	4.0
YC	2.0	4.0
AS	2.0	4.0
CW	2.0	4.0
OS	1.0	5.0
OH	2.0	4.0

4.6.2 Small Tree Diameter Growth

As stated previously, for trees being projected with the small tree equations, height growth is predicted first, and then diameter growth. So both height at the beginning of the cycle and height at the end of the cycle are known when predicting diameter growth. Small tree diameter growth for trees over 4.5 feet tall is calculated as the difference of predicted diameter at the start of the projection period and the predicted diameter at the end of the projection period, adjusted for bark ratio. These two predicted diameters are estimated using the species-specific height-diameter relationships. By definition, diameter growth is zero for trees less than 4.5 feet tall.

For western white pine, western larch, Douglas-fir, grand fir, mountain hemlock, Engelmann spruce, subalpine fir, limber pine, and quaking aspen, diameters are predicted using the height-diameter equations discussed in section 4.1; equation {4.6.2.1} is used for lodgepole pine; equation {4.6.2.2} is used for ponderosa pine and other softwood; equation {4.6.2.3} is used for western juniper; equation {4.6.2.4} is used for whitebark pine; equation {4.6.2.5} is used for Pacific yew, Alaska cedar, black cottonwood, and other hardwood with coefficients shown in table 4.6.2.1.

{4.6.2.1} $DBH = [-9.8752 / (\ln(HT - 4.5) - 4.8656)] - 1.0$

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

{4.6.2.3} $DBH = [(HT - 4.5) * 10] / (SI - 4.5)$

{4.6.2.4} $DBH = 0.3 + 0.000231*(HT - 4.5)*CR - 0.00005*(HT - 4.5)*PCCF + 0.001711*CR + 0.17023*(HT - 4.5)$

{4.6.2.5} $DBH = c_1 + c_2*CR / 10 + c_3*\ln(HT) + c_4*HT + c_5*MGD$

where:

DBH	is tree diameter at breast height
HT	is tree height
SI	is the species-specific site index
CR	is the tree's live crown ratio (compacted) expressed as a percent
PCCF	is crown competition factor on the inventory point where the tree is established (bounded $25 \leq PCCF \leq 300$)
MGD	is 1 if the stand is a managed stand; 0 otherwise
c_1 - c_5	are species-specific coefficients shown in table 4.6.2.1

Table 4.6.2.1 Coefficients by species for equation {4.6.2.5} in the BM variant.

Species Code	Model Coefficients				
	c_1	c_2	c_3	c_4	c_5
PY	-2.089	0	1.980	0	0
YC	-0.532	0	1.531	0	0
CW	3.102	0	0	0.021	0
OH	3.102	0	0	0.021	0

4.7 Large Tree Growth Relationships

Trees are considered "large trees" for FVS modeling purposes when they are equal to, or larger than, some threshold diameter. This threshold diameter is set to 3.0" for all species, except western juniper, in the BM variant. Western juniper uses the small-tree relationships to predict height and diameter growth for trees of all sizes.

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

4.7.1 Large Tree Diameter Growth

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

The BM variant uses different equation forms to predict large-tree diameter growth based on species. Equation {4.7.1.1} is used to predict diameter growth for all trees. Coefficients for this equation are shown in tables 4.7.1.1 – 4.7.1.2.

Equation {4.7.1.2} predicts diameter growth in large trees with a *DBH* value less than 10.0" for western white pine, western larch, Douglas-fir, grand fir, mountain hemlock, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine and other softwood. Coefficients for this equation are given in tables 4.7.1.3 – 4.7.1.7. For these 10 species, results from equation {4.7.1.2} are weighted with results from equation {4.7.1.1} over the diameter range 3.0" to 10" using equation {4.7.1.3}. However, equation {4.7.1.2} yields a 5-year estimate which must be expanded to a 10-year basis before the weighting using equation {4.7.1.3}. Expansion, which is not shown here, is in terms of squared diameter in real scale and then converted back to a natural logarithm scale for weighting.

{4.7.1.1} $\ln(DDSL) = b_1 + (b_2 * EL) + (b_3 * EL\text{^}2) + (b_4 * \ln(TSI)) + (b_5 * \sin(ASP)) + (b_6 * \cos(ASP)) + (b_7 * SL) + (b_8 * SL\text{^}2) + (b_9 * \ln(DBH)) + (b_{10} * \ln(BA)) + (b_{11} * CR) + (b_{12} * CR\text{^}2) + (b_{13} * DBH\text{^}2) + (b_{14} * BAL / (\ln(DBH + 1.0))) + (b_{15} * PCCF) + (b_{16} * BAL) + (b_{17} * BA) + (b_{18} * MAI * CCF) + (b_{19} * CCF) + (b_{20} * TSI)$

{4.7.1.2} $\ln(DDSS) = b_1 + (b_2 * EL) + (b_3 * EL\text{^}2) + (b_4 * \sin(ASP)) + (b_5 * \cos(ASP)) + (b_6 * SL) + (b_7 * \ln(DBH)) + (b_8 * \ln(BA)) + (b_9 * CR) + (b_{10} * CR\text{^}2) + (b_{11} * DBH\text{^}2) + (b_{12} * BAL / (\ln(DBH + 1.0))) + (b_{13} * PCCF) + HAB$

{4.7.1.3} $\ln(DDS) = XWT * \ln(DDSS) + (1-XWT) * \ln(DDSL)$

where:

DDS	is the square of the diameter growth increment
DDSL	is the estimated square of the diameter growth increment using equation {4.7.1.1}
DDSS	is the estimated square of the diameter growth increment using equation {4.7.1.2}
EL	is stand elevation in hundreds of feet (bounded to $EL \leq 30$ for species 16 and 18)
TSI	is a site index function based on species *TSI* = *SI* for WP, WL, DF, GF, WJ, ES, AF, PP, WB, LM, PY, YC, AS, CW, OS, OH *TSI* = 3.28 * *SI* for MH *TSI* = -43.78 + (2.16 * *SI*) for LP where: *SI* is the site index for the species
ASP	is stand aspect for species 1-5, 7-10, 13-14, and 16-18 is (stand aspect – 0.7854) for species 6, 11-12, and 15
SL	is stand slope
CR	is crown ratio expressed as a proportion
DBH	is tree diameter at breast height
BA	is total stand basal area
BAL	is total basal area in trees larger than the subject tree for species 1-10, and 13-18 is (total basal area in trees larger than the subject tree / 100) for species 11-12
PCCF	is crown competition factor on the inventory point where the tree is established
MAI	is stand mean annual increment
CCF	is stand crown competition factor

HAB	is a plant association code dependent intercept shown in table 4.7.1.6 and 4.7.1.7
β_1	is a location-specific coefficient shown in tables 4.7.1.2 and 4.7.1.5
β_2 - β_{20}	are species-specific coefficients shown in tables 4.7.1.1 and 4.7.1.4
XWT	is 0 if *DBH* $\geq$ 10" ; 1 if *DBH* < 3" ; and ((10-*DBH*) / 7) otherwise

Table 4.7.1.1 Coefficients (b_2- b_{20}) for equation 4.7.1.1 in the BM variant.

Coefficient	Species Code								
	WP	WL	DF	GF	MH	LP	ES	AF	PP
b_2	0.00279	0	0.00371	-0.00633	0.08520	-0.06908	0	-0.01423	-0.05796
b_3	-0.00001	0	0	0	-0.00094	0.00062	0	0	0.00060
b_4	0	0.47469	0.76217	0.58666	0	0.34450	0.34406	0.51754	0.73067
b_5	-0.19278	0	-0.11862	-0.19627	0.13360	0.09760	0.35781	-0.27729	-0.12480
b_6	0.12915	0	-0.15167	-0.16504	0.17940	-0.37870	-0.11989	-0.44759	-0.02280
b_7	0.77922	0	-0.28123	-0.67496	0.07630	0.03990	0	0.35402	-0.16402
b_8	-0.93813	0	0	0.76704	0	0	0	0	0
b_9	0.77889	0.41802	0.57990	1.01031	0.89780	0.70429	1.12805	0.83642	0.44675
b_{10}	0	0	-0.06574	-0.15658	0	-0.17037	0	-0.18969	-0.10675
b_{11}	3.36606	2.15440	2.13121	2.56530	1.28400	3.00236	3.22770	1.60755	1.70901
b_{12}	-1.80146	-1.03088	-0.40173	-0.91846	0	-1.24947	-1.13951	0	0
b_{13}	-0.00009	0	-0.00038	-0.00054	-0.00048	0	-0.00029	0.00009	-0.00021
b_{14}	-0.00897	-0.00801	-0.00886	-0.00557	-0.00661	-0.00251	-0.00156	-0.00091	-0.01184
b_{15}	0	0	-0.00034	0	-0.00107	-0.00032	-0.00014	-0.00038	-0.00057
b_{16}	0.00121	0	0	0	0	0	0	0	0
b_{17}	0	-0.00070	0	0	0	0	0	0	0
b_{18}	-1.00E-07	0	0	0	0	0	0	0	0
b_{19}	-1.60E-06	0	0	0	0	0	0	0	0
b_{20}	0	0	0	0	0	0	0	0	0

Table 4.7.1.1 (Continued) Coefficients (b_2- b_{20}) for equation 4.7.1.1 in the BM variant.

Coefficient	Species Code						
	WB	LM	PY	YC	CW	OS	OH
b_2	0	0	0	0	-0.075986	-0.05796	-0.075986
b_3	0	0	0	0	0.001193	0.00060	0.001193
b_4	0	0	0.252853	0.244694	0.227307	0.73067	0.227307
b_5	-0.01752	-0.01752	0	0.679903	-0.86398	-0.12480	-0.86398
b_6	-0.609774	-0.609774	0	-0.023186	0.085958	-0.02280	0.085958
b_7	-2.057060	-2.057060	0	0	0	-0.16402	0
b_8	2.11326	2.11326	0	0	0	0	0
b_9	0.213947	0.213947	0.879338	0.816880	0.889596	0.44675	0.889596
b_{10}	0	0	0	0	0	-0.10675	0
b_{11}	1.523464	1.523464	1.970052	2.471226	1.732535	1.70901	1.732535
b_{12}	0	0	0	0	0	0	0

b_{13}	-0.000654	-0.000654	-0.000132	-0.000254	0	-0.00021	0
b_{14}	0	0	-0.004215	-0.005950	-0.001265	-0.01184	-0.001265
b_{15}	0	0	0	0	0	-0.00057	0
b_{16}	-0.358634	-0.358634	0	0	0	0	0
b_{17}	0	0	-0.000173	-0.000147	-0.000981	0	-0.000981
b_{18}	0	0	0	0	0	0	0
b_{19}	-0.001996	-0.001996	0	0	0	0	0
b_{20}	0.001766	0.001766	0	0	0	0	0

Table 4.7.1.2 b_1 values by location code for equation {4.7.1.1} in the BM variant.

Forest Code	Species Code								
	WP	WL	DF	GF	MH	LP	ES	AF	PP
604, 614	-0.23185	-0.56061	-1.69223	-1.16884	-1.6803	1.59448	-2.38952	-0.48027	0.05217
607	-0.23185	-0.56061	-1.69223	-1.16884	-1.6803	1.59448	-2.38952	-0.48027	-0.04456
616, 619	-0.23185	-0.56061	-1.78978	-1.16884	-1.6803	1.49879	-2.38952	-0.48027	0.11197

Table 4.7.1.2 (Continued) b_1 values by location code for equation {4.7.1.1} in the BM variant.

Forest Code	Species Code						
	WB	LM	PY	YC	CW	OS	OH
604, 614	1.91188	1.91188	-1.31007	-1.17804	-0.10765	0.05217	-0.10765
607	1.91188	1.91188	-1.31007	-1.17804	-0.10765	-0.04456	-0.10765
616, 619	1.91188	1.91188	-1.31007	-1.17804	-0.10765	0.11197	-0.10765

Table 4.7.1.3 Classification of species 1-5, 7-10, and 18 (Location Class) for the diameter increment model, equation {4.7.1.2}, in the BM variant; equation {4.7.1.2} does not pertain to species 6 or 11-16.

Species Code									
WP	WL	DF	GF	MH	LP	ES	AF	PP	OS
1	1	2	3	4	4	3	3	5	5

Table 4.7.1.4 Coefficients (b_2- b_{13}) for equation 4.7.1.2 in the BM variant.

	Location Class				
Coefficient	1	2	3	4	5
b_2	0	-0.00823	-0.09472	0.00912	-0.07547
b_3	0	0	0.00092	0	0.00087
b_4	0.12754	0.05022	-0.11202	0.35696	-0.13976
b_5	-0.06358	-0.11174	-0.18548	-0.46361	-0.08695
b_6	-0.41366	-0.36252	-0.16110	0.45733	-0.24248
b_7	1.20856	1.12948	1.52803	1.00488	1.04225
b_8	-0.24782	-0.15369	-0.13405	-0.24135	-0.24965
b_9	1.73596	1.54957	0.66664	2.47118	2.31970
b_{10}	0	0	1.20070	-0.99894	-0.43073
b_{11}	-0.000571	-0.000023	-0.000951	-0.000643	-0.000157
b_{12}	-0.00066	-0.00223	-0.00199	-0.00358	-0.00105

b_{13}	0	-0.00003	-0.00167	0	0

Table 4.7.1.5 b_1 values by location class for equation {4.7.1.2} in the BM variant.

	Location Class				
Forest Code	1	2	3	4	5
604	-0.00991	0.12927	1.31341	-0.21988	1.61313
607	-0.00991	0.12927	1.53206	-0.21988	1.75654
614	0.24298	0.42841	1.78409	0.22239	1.90894
616, 619	-0.00991	0.31221	1.73754	-0.47388	1.75744

Table 4.7.1.6 *HAB* values by habitat class and location class for equation {4.7.1.2} in the BM variant.

	Location Class				
Habitat Class	1	2	3	4	5
0	0	0	0	0	0
1	-0.131277	-0.336855	-0.137259	0.119324	0.482619
2	-0.328134	-1.004248	0.282528	0.425094	0.173487
3	0	-0.195972	0	0	-0.087731
4	0	-0.092403	0	0	0

Table 4.7.1.7 Classification of habitat class by plant association code and location class in the BM variant.

PA Code	Location Class				
	1	2	3	4	5
1	0	1	0	0	0
2	0	1	0	0	0
3	0	3	0	2	0
4	0	3	0	2	0
5	0	3	0	2	0
6	0	3	0	2	0
7	0	3	0	2	0
8	0	3	0	2	0
9	0	3	0	2	0
10	0	3	0	2	0
11	0	4	0	0	0
12	0	4	0	0	0
13	0	3	0	2	0
14	0	0	0	0	0

PA Code	Location Class				
	1	2	3	4	5
47	0	0	0	0	0
48	0	0	0	0	0
49	0	3	0	0	3
50	0	3	0	0	3
51	0	3	0	0	3
52	0	3	0	0	3
53	0	3	0	2	3
54	0	3	0	2	3
55	0	3	0	0	3
56	0	3	0	0	3
57	0	0	0	0	0
58	0	0	0	0	0
59	0	3	0	0	3
60	0	0	0	0	0

PA Code	Location Class					PA Code	Location Class				
	1	2	3	4	5		1	2	3	4	5
15	0	0	0	0	0	61	0	3	0	0	3
16	0	0	0	0	0	62	2	2	0	0	0
17	0	0	0	0	0	63	0	0	0	0	0
18	0	0	0	0	0	64	0	0	0	0	0
19	0	0	0	0	0	65	0	0	0	0	0
20	0	0	0	0	0	66	0	0	0	0	0
21	0	1	0	0	0	67	0	0	0	0	0
22	0	1	0	0	0	68	0	0	0	0	1
23	0	0	0	0	0	69	0	0	0	0	1
24	0	1	0	0	0	70	1	0	0	1	2
25	0	1	0	0	0	71	1	0	0	1	2
26	0	0	0	0	0	72	0	0	0	0	1
27	0	1	0	0	0	73	0	0	0	0	1
28	2	2	0	0	0	74	0	0	0	0	1
29	0	0	0	0	0	75	0	0	0	0	1
30	2	2	0	0	0	76	0	0	0	0	1
31	0	3	0	2	3	77	1	0	0	1	0
32	0	3	0	2	3	78	1	0	0	1	0
33	0	3	0	2	3	79	1	0	0	1	0
34	0	3	0	2	3	80	1	0	0	1	0
35	0	3	0	2	3	81	1	0	0	1	2
36	0	3	0	2	3	82	1	0	0	0	1
37	0	3	0	2	3	83	1	0	0	1	0
38	0	3	0	2	3	84	1	0	0	1	0
39	0	3	0	2	3	85	1	0	0	1	2
40	0	3	0	2	3	86	1	0	2	0	0
41	0	3	0	2	3	87	1	3	1	0	0
42	0	3	0	2	3	88	1	3	1	0	0
43	0	3	0	2	3	89	1	0	2	0	0
44	0	3	0	2	3	90	0	3	0	2	3
45	0	3	0	2	3	91	0	3	0	2	3
46	0	3	0	2	3	92	0	3	0	2	3

*A 0 value means that no habitat code is used.

Large-tree diameter growth for quaking aspen is predicted using the aspen equation from the UT variant identified in equation set {4.7.1.4}. Diameter growth is predicted from a potential diameter growth equation that is modified by stand density, average tree size and site. While not shown here, this diameter growth estimate is eventually converted to the *DDS* scale.

{4.7.1.4} Quaking aspen

$$POTGR = (0.4755 - 0.0000038336 * DBH^{4.1488}) + (0.0451 * CR * DBH^{.67266})$$

$MOD = 1.0 - \exp(-FOFR * GOFAD * ((310-BA)/310)^{0.5})$

$FOFR = 1.07528 * (1.0 - \exp(-1.89022 * DBH / QMD))$

$GOFAD = 0.21963 * (QMD + 1.0)^{0.73355}$

$PREDGR = POTGR * MOD * (.48630 + 0.01258 * SI)$

where:

POTGR	is potential diameter growth
DBH	is tree diameter at breast height
CR	is crown ratio expressed as a percent divided by 10
MOD	is a modifier based on tree diameter and stand density
FOFR	is the relative density modifier
GOFAD	is the average diameter modifier
BA	is total stand basal area
QMD	is stand quadratic mean diameter
PREDGR	is predicted diameter growth
SI	is species site index

4.7.2 Large Tree Height Growth

Height growth equations in the BM variant for all species except western juniper, whitebark pine, limber pine, and quaking aspen are based on the site index curves shown in section 3.4. Equations for whitebark pine, limber pine, and quaking aspen are shown later in this section. Height growth for western juniper of all sizes is estimated as described in section 4.6.1 for all sizes of trees.

Using a species site index and tree height at the beginning of the projection cycle, an estimated tree age is computed using the site index curves. Also, a maximum species height is computed using equation {4.7.2.1}. If tree height at the beginning of the projection cycle is greater than the maximum species height, then height growth is computed using equation {4.7.2.2}.

{4.7.2.1} $HTMAX = a_0 + a_1 * SI$

{4.7.2.2} $HTG = b_0 + b_1 * RELSI$

$RELSI = (SIB - SITELO) / (SITEHI - SITELO)$

where:

HTMAX	is maximum expected tree height in feet for the species in this variant (for mountain hemlock *HTMAX* is multiplied by 3.281 to convert maximum height from meters to feet)
HTG	is estimated 10-year tree height growth (bounded $0.1 \le HTG$)
SI	is species site index
SIB	is species site index [bounded $(SITELO + 0.5) \le SIB \le SITEHI$]
RELSI	is relative site index
SITELO	is minimum expected site index for this species in this variant shown in table 4.7.2.1

SITEHI is maximum expected site index for this species in this variant shown in table 4.7.2.1

$a_0 - a_1$ are species-specific coefficients shown in table 4.7.2.1

$b_0 - b_1$ are species-specific coefficients shown in table 4.7.2.1

Table 4.7.2.3 *SITELO*, *SITEHI*, Maximum Age, and coefficients a_0, a_1, b_o, b_1 in the BM variant.

Species Code	*SITELO*	*SITEHI*	*Max Age*	a_0	a_1	b_0	b_1
WP	20	80	200	2.3	2.39	1.5	0.003
WL	50	110	110	12.86	1.32	2.0	0.0026
DF	50	110	180	-2.86	1.54	0.4	0.0080
GF	50	110	130	21.29	1.24	2.1	0
MH	15	30	250	52.27	1.14	0	0
WJ	-	-	-	-	-	-	-
LP	30	70	140	2.3	1.75	1.5	0
ES	40	120	150	20.0	1.1	1.5	0
AF	50	150	150	45.27	1.24	1.5	0
PP	70	140	200	-5.0	1.3	1.3	0.002
WB	20	65	400	85.0	0	0	0
LM	20	50	400	85.0	0	0	0
PY	5	75	200	50.0	0	0	0
YC	50	110	200	100.0	0	0	0
AS	30	66	100	75.0	0	0	0
CW	10	191	100	125.0	0	0	0
OS	70	140	200	-5.0	1.3	1.3	0.002
OH	5	125	100	100.0	0	0	0

If tree height at the beginning of the projection cycle is less than the maximum species height, then for western white pine, western larch, Douglas-fir, grand fir, mountain hemlock, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, Pacific yew, Alaska cedar, black cottonwood, other softwood, and other hardwood, height increment is obtained by subtracting estimated current height from estimated future height, then adjusting the difference according to tree's crown ratio and height relative to other trees in the stand. Estimated current height (ECH) and estimated future height (H10) are both obtained using the equations shown below. Estimated current height is obtained using estimated tree age at the start of the projection cycle and site index. Estimated future height is obtained using estimated tree age at the start of the projection cycle plus 10-years and site index.

{4.7.2.3} Used for white pine

$$H = SI / [c_0 * (1.0 - c_1 * (\exp(c_2 * A)))^{\wedge}c_3]$$

{4.7.2.4} Used for western larch

$$H = 4.5 + (c_1 * A) + (c_2 * A^{\wedge}2) + (c_3 * A^{\wedge}3) + (c_4 * A^{\wedge}4) + (SI - 4.5) * [c_5 + (c_6 * A) + (c_7 * A^{\wedge}2) + (c_8 * A^{\wedge}3)] - c_9 * [c_{10} + (c_{11} * A) + (c_{12} * A^{\wedge}2) + (c_{13} * A^{\wedge}3)]$$

{4.7.2.5} Used for Douglas-fir and other species

$H = 4.5 + \exp[c_1 + (c_2 * \ln(A)) + (c_3 * \ln(A))^4] + c_4 * [c_5 + (c_6 * (1 - \exp(c_7 * A))^{c_8})] + (SI - 4.5) * [c_5 + c_6 * (1 - \exp(c_7 * A)^{c_8})]$

{4.7.2.6} Used for grand fir

$H = \exp[c_0 + c_1 * \ln(A) + c_2 * (\ln(A))^4 + c_3 * (\ln(A))^9 + c_4 * (\ln(A))^{11} + c_5 * (\ln(A))^{18}] + c_{12} * \exp[c_6 + c_7 * \ln(A) + c_8 * (\ln(A))^2 + c_9 * (\ln(A))^7 + c_{10} * (\ln(A))^{16} + c_{11} * (\ln(A))^{24}] + (SI - 4.5) * \exp[c_6 + c_7 * \ln(A) + c_8 * (\ln(A))^2 + c_9 * (\ln(A))^7 + c_{10} * (\ln(A))^{16} + c_{11} * (\ln(A))^{24}] + 4.5$

{4.7.2.7} Used for mountain hemlock

$H = [(c_0 + (c_1 * SI)) * (1 - \exp(c_2 * \mathrm{SQRT}(SI) * A))^{c_4 + (c_5 / SI)} + 1.37] * 3.281$

{4.7.2.8} Used for lodgepole pine

$H = SI * [c_0 + (c_1 * A) + (c_2 * A^2)]$

{4.7.2.9} Used for Engelmann spruce

$H = 4.5 + [(c_0 * SI^{c_1}) * (1 - \exp(-c_2 * A))^{(c_3 * SI^{c_4})}]$

{4.7.2.10} Used for subalpine fir

$H = SI * [c_0 + (c_1 * A) + (c_2 * A^2)]$

{4.7.2.11} Used for ponderosa pine and other softwood

$H = [c_0 * (1 - \exp(c_1 * A))^{c_2}] - [(c_3 + c_4 * (1 - \exp(c_5 * A))^{c_6}) * c_7] + [(c_3 + c_4 * (1 - \exp(c_5 * A))^{c_6}) * (SI - 4.5)] + 4.5$

{4.7.2.12} Used for Pacific yew, Alaska cedar, black cottonwood and other hardwood

$H = (SI - 4.5) / (c_0 + [c_1 / (SI - 4.5)] + [c_2 * (A)^{-1.4}] + [(c_3 / (SI - 4.5)) * (A)^{-1.4}) + 4.5$

where:

H	is estimated height of the tree
SI	is species site index
A	is estimated age of the tree
$c_0 - c_{13}$	are species-specific coefficients shown in table 4.7.2.2

Table 4.7.2.2 Coefficients (c_0-c_{13}) for height-growth equations in the BM variant.

Coefficient	Species Code				
	WP	WL	DF	GF	MH
c_0	0.37504453	0	0	-0.30935	22.8741
c_1	0.92503	1.46897	-0.37496	1.2383	0.950234
c_2	-0.0207959	0.0092466	1.36164	0.001762	-0.00206465
c_3	-2.4881068	-0.00023957	-0.00243434	-0.0000054	0
c_4	0	1.1122E-06	-79.97	2.046E-07	1.365566
c_5	0	-0.12528	-0.2828	-4.04E-13	2.045963
c_6	0	0.039636	1.87947	-6.2056	0
c_7	0	-0.0004278	-0.022399	2.097	0
c_8	0	1.7039E-06	0.966998	-0.09411	0
c_9	0	73.57	0	-0.00004382	0
c_{10}	0	-0.12528	0	2.007E-11	0
c_{11}	0	0.039636	0	-2.054E-17	0
c_{12}	0	-0.0004278	0	-84.93	0
c_{13}	0	1.7039E-06	0	0	0
Coefficient	Species Code				
	LP	ES	AF	PP, OS	PY, YC, CW, OH
c_0	-0.0968	2.75780	-0.07831	128.8952205	0.6192
c_1	0.02679	0.83312	0.0149	-0.016959	-5.3394
c_2	-0.00009309	0.015701	-0.000040818	1.23114	240.29
c_3	0	22.71944	0	-0.7864	3368.9
c_4	0	-0.63557	0	2.49717	0
c_5	0	0	0	-0.0045042	0
c_6	0	0	0	0.33022	0
c_7	0	0	0	100.43	0
c_8	0	0	0	0	0
c_9	0	0	0	0	0
c_{10}	0	0	0	0	0
c_{11}	0	0	0	0	0
c_{12}	0	0	0	0	0
c_{13}	0	0	0	0	0

Potential 10-year height growth (*POTHTG*) is calculated by using equation {4.7.2.13}. Then, modifiers are applied to the height growth based upon a tree's crown ratio (using equation {4.7.2.14}), and relative height and shade tolerance (using equation {4.7.2.15}). Equation {4.7.2.16} uses the Generalized Chapman – Richard's function (Donnelly et. al, 1992) to calculate a height-growth modifier. Final height growth is calculated using equation {4.7.2.17} as a product of the modifier and potential height growth. The final height growth is then adjusted to the length of the cycle.

{4.7.2.13} *POTHTG = H10 – ECH*

{4.7.2.14} *HGMDCR* = (100 * (*CR* / 100)^^{3}) * exp(-5 * (*CR* / 100))   bounded HGMDCR ≤ 1.0

{4.7.2.15} *HGMDRH* = [1 + ((1 / d_1)^d_2 - 1) – 1) * exp((-1 * (d_3 / (1 – d_4)) * *RELHT*^(1 – d_4)]^(-1 / (d_2 - 1))

{4.7.2.16} *HTGMOD* = (0.25 * *HGMDCR*) + (0.75 * *HGMDRH*)   bounded 0.1 ≤ *HTGMOD* ≤ 2.0

{4.7.2.17} *HTG = POTHTG * HTGMOD*

where:

POTHTG	is potential height growth
H10	is estimated height of the tree in ten years
ECH	is estimated height of the tree at the beginning of the cycle
HGMDCR	is a height growth modifier based on crown ratio
HGMDRH	is a height growth modifier based on relative height and shade tolerance
HTGMOD	is a weighted height growth modifier
CR	is crown ratio expressed as a percent
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand; bounded *RELHT* ≤ 1.5
$d_1 – d_4$	are species-specific coefficients shown in table 4.7.2.3

Table 4.7.2.3 Coefficients ($d_1 – d_4$) for equation 4.7.2.15 in the BM variant.

	Species Code									
Coefficient	**WP**	**WL**	**DF**	**GF**	**MH**	**LP**	**ES**	**AF**	**PP,OS**	**PY**
d_1	0.10	0.01	0.10	0.20	0.20	0.01	0.15	0.15	0.05	0.20
d_2	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
d_3	15.0	12.0	15.0	20.0	20.0	12.0	16.0	16.0	13.0	20.0
d_4	-1.45	-1.60	-1.45	-1.10	-1.10	-1.60	-1.20	-1.20	-1.60	-1.10

	Species Code		
Coefficient	**YC**	**CW**	**OH**
d_1	0.15	0.01	0.10
d_2	1.10	1.10	1.10
d_3	16.0	12.0	15.0
d_4	-1.20	-1.60	-1.45

Whitebark pine, limber pine, and quaking aspen use Johnson's SBB (1949) method (Schreuder and Hafley, 1977) for predicting height growth. Height increment is obtained by subtracting current height from the estimated future height. If tree diameter is greater than (C_1 + 0.1), or tree height is greater than (C_2 + 4.5), where C_1 and C_2 are shown in table 4.7.2.4, parameters of the SBB distribution cannot be calculated and height growth is set to 0.1. Otherwise, the SBB distribution "*Z*" parameter is estimated using equation {4.7.2.18}.

{4.7.2.18} $Z = [C_4 + C_6 * FBY2 - C_7 * (C_3 + C_5 * FBY1)] * (1 - C_7\text{^}2)\text{^}{-0.5}$

FBY1 = ln[Y1/(1 - Y1)]
FBY2 = ln[Y2/(1 - Y2)]
Y1 = (DBH – 0.095) / C1
Y2 = (HT – 4.5) / C2

where:

HT	is tree height at the beginning of the cycle
DBH	is tree diameter at breast height at the beginning of the cycle
$C_1 - C_7$	are coefficients based on species and crown ratio class shown in table 4.7.2.4

Equation {4.7.2.19} is used to eliminate known bias in this methodology.

{4.7.2.19} $Z = Z + (0.1 - 0.10273 * Z + 0.00273 * Z\text{^}2)$ if Z < 0; set Z = 0

If the *Z* value is 2.0 or less, it is adjusted for all younger aged trees using equation {4.7.2.20}. This adjustment is done for trees with an estimated age between 11 and 39 years and a diameter less than 9.0 inches. After this calculation, the value of *Z* is bounded to be 2.0 or less for trees meeting these criteria.

{4.7.2.20} $Z = Z * (0.3564 * DG) * CLOSUR * K$

if CCF > 100: CLOSUR = PCT / 100
if CCF < 100: CLOSUR = 1
if CR > 75 %: K = 1.1
if CR < 75 %: K = 1.0

where:

DG	is diameter growth for the cycle
PCT	is the subject tree's percentile in the basal area distribution of the stand
CCF	is stand crown competition factor

Estimated height 10 years later is calculated using equation {4.7.2.21}, and finally, 10-year height growth is calculated by subtraction using equation {4.7.2.22} and adjusted to the cycle length.

{4.7.2.21} $H10 = [(PSI / (1 + PSI)) * C_2] + 4.5$

$PSI = C_8 * [(D10 - 0.1) / (0.1 + C_1 - D10)]\text{^}C_9 * [e(K)]$
$K = Z * [(1 - C_7\text{^}2)\text{^}0.5 / C_6]$

{4.7.2.22} Height 10 years later

H10 > HT: POTHTG = H10 – HT
H10 $\leq$ HT: POTHTG = 0.1

where:

H10 is estimated height of the tree in ten years
HT is tree height at the beginning of the cycle
D10 is estimated diameter at breast height of the tree in ten years
POTHTG is potential height growth
$C_1 – C_9$ are coefficients based on species and crown ratio class shown in table 4.7.2.4

Table 4.7.2.4 Coefficients in the large tree height growth model, by crown ratio, for species using the Johnson's SBB height distribution in the BM variant.

Coefficient*	WB, LM	AS
C_1 ($CR \leq 24$)	37.0	30.0
C_1 ($25 \leq CR \leq 74$)	45.0	30.0
C_1 ($75 \leq CR \leq 100$)	45.0	35.0
C_2 ($CR \leq 24$)	85.0	85.0
C_2 ($25 \leq CR \leq 74$)	100.0	85.0
C_2 ($75 \leq CR \leq 100$)	90.0	85.0
C_3 ($CR \leq 24$)	1.77836	2.00995
C_3 ($25 \leq CR \leq 74$)	1.66674	2.00995
C_3 ($75 \leq CR \leq 100$)	1.64770	1.80388
C_4 ($CR \leq 24$)	-0.51147	0.03288
C_4 ($25 \leq CR \leq 74$)	0.25626	0.03288
C_4 ($75 \leq CR \leq 100$)	0.30546	-0.07682
C_5 ($CR \leq 24$)	1.88795	1.81059
C_5 ($25 \leq CR \leq 74$)	1.45477	1.81059
C_5 ($75 \leq CR \leq 100$)	1.35015	1.70032
C_6 ($CR \leq 24$)	1.20654	1.28612
C_6 ($25 \leq CR \leq 74$)	1.11251	1.28612
C_6 ($75 \leq CR \leq 100$)	0.94823	1.29148
C_7 ($CR \leq 24$)	0.57697	0.72051
C_7 ($25 \leq CR \leq 74$)	0.67375	0.72051
C_7 ($75 \leq CR \leq 100$)	0.70453	0.72343
C_8 ($CR \leq 24$)	3.57635	3.00551
C_8 ($25 \leq CR \leq 74$)	2.17942	3.00551
C_8 ($75 \leq CR \leq 100$)	2.46480	2.91519
C_9 ($CR \leq 24$)	0.90283	1.01433
C_9 ($25 \leq CR \leq 74$)	0.88103	1.01433
C_9 ($75 \leq CR \leq 100$)	1.00316	0.95244

**CR* represents percent crown ratio

For quaking aspen, if estimated tree age at the beginning of the projection cycle is greater than the expected maximum age for quaking aspen then height increment is set to 0.1 foot.

5.0 Mortality Model

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

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

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

{5.0.2} $RIP = 1 – (1 – RI)^Y$

where:

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

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

Species Code	p_0	p_1
WP	6.5112	-0.0052485
WL	6.5112	-0.0052485
DF	7.2985	-0.0129121
GF	5.1677	-0.0077681
MH	9.6943	-0.0127328
WJ	5.1677	-0.0077681
LP	5.9617	-0.0340128
ES	9.6943	-0.0127328
AF	5.1677	-0.0077681
PP	5.5877	-0.005348
WB	6.5112	-0.0052485
LM	6.5112	-0.0052485
PY	5.5877	-0.005348
YC	5.5877	-0.005348

Species Code	p_0	p_1
AS	5.1677	-0.0077681
CW	5.5877	-0.005348
OS	5.5877	-0.005348
OH	5.9617	-0.0340128

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

Once the amount of stand mortality is determined based on either the summation of background mortality rates or density-related mortality rates, mortality is dispersed to individual tree records in relation to either a tree's DBH or percentile in the basal area distribution (PCT) using equations {5.0.3} or {5.0.4}. This value is then adjusted by a species-specific mortality modifier representing the species shade tolerance shown in equation {5.0.5}.

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

{5.0.3} Used for western white pine, western larch, Douglas-fir, grand fir, mountain hemlock, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood

$MR = [14.94435 – (0.69929 * DBH) + (0.00868 * DBH^2)] * 0.001$

{5.0.4} Used for western juniper, whitebark pine, limber pine, Pacific yew, Alaska cedar, quaking Aspen, black cottonwood, and other hardwood

$MR = [0.84525 – (0.01074 * PCT) + (0.0000002 * PCT^3)] * 0.01$

{5.0.5} $MORT = MR * SPADJ$

where:

MR	is the proportion of the tree record attributed to mortality (bounded: $0.01 \le MR \le 1$)
DBH	is tree diameter at breast height
PCT	is the subject tree's percentile in the basal area distribution of the stand
MORT	is the final mortality rate of the tree record
SPADJ	is the species specific shade tolerance adjustment shown in table 5.0.2

Table 5.0.2 Shade tolerance adjustment (*SPADJ*) used in the density-related mortality equation {5.0.5} in the BM variant.

Species Code	*SPADJ*
WP	1.0

Species Code	***SPADJ***
WL	1.0
DF	1.0
GF	1.0
MH	1.0
WJ	1.1
LP	1.0
ES	1.0
AF	1.0
PP	1.0
WB	0.8
LM	0.8
PY	0.5
YC	0.5
AS	1.3
CW	0.85
OS	1.0
OH	1.0

6.0 Regeneration

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

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

Table 6.0.1 Regeneration parameters by species in the BM variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
WP	No	0.4	0.9	23
WL	No	0.3	1.7	27
DF	No	0.3	1.0	21
GF	No	0.3	1.0	21
MH	No	0.2	0.5	22
WJ	No	0.3	0.5	6
LP	No	0.4	1.3	24
ES	No	0.3	0.5	18
AF	No	0.3	0.5	18
PP	No	0.5	1.0	17
WB	No	0.4	1.0	23
LM	No	0.4	1.0	9
PY	Yes	0.2	1.0	20
YC	No	0.2	1.0	20
AS	Yes	0.2	6.0	16
CW	Yes	0.2	1.0	20
OS	No	0.5	1.0	17
OH	No	0.2	1.0	20

One sprout record is created for Pacific yew, two sprout records for quaking aspen and logic rule {6.0.1} is used to determine the number of sprout records for black cottonwood. The trees-per-acre represented by each sprout record is determined using the general sprouting probability equation {6.0.2}. See table 6.0.2 for species-specific sprouting probabilities, number of sprout records created, and reference information.

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

{6.0.1} For black cottonwood:

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

{6.0.2} $TPA_s = TPA_i * PS$

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

where:

$DSTMP_i$	is the diameter at breast height of the parent tree
NUMSPRC	is the number of sprout tree records
NINT	rounds the value to the nearest integer
TPA_s	is the trees per acre represented by each sprout record
TPA_i	is the trees per acre removed/killed represented by the parent tree
PS	is a sprouting probability (see table 6.0.2)
ASBAR	is the aspen basal area removed
ASTPAR	is the aspen trees per acre removed
RSHAG	is the age of the sprouts at the end of the cycle in which they were created

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

Species Code	Sprouting Probability	Number of Sprout Records	Source
PY	0.4	1	Minore 1996 Ag. Handbook 654
AS	{6.0.3}	2	Keyser 2001
CW	0.9	{6.0.1}	Gom and Rood 2000 Steinberg 2001

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

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

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

7.0 Volume

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

Table 7.0.1 Volume merchantability standards for the BM variant.

Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot
Merchantable Board Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot

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

Common Name	Location Codes	Equation Number	Model Name
western white pine	All	616BEHW119	Behre's Hyperbola
western larch	604	616BEHW073	Behre's Hyperbola
western larch	607	I12FW2W073	Flewelling 2-Point Profile Model
western larch	614	I13FW2W202	Flewelling 2-Point Profile Model
western larch	616	I13FW2W073	Flewelling 2-Point Profile Model
Douglas-fir	604, 607	I12FW2W202	Flewelling 2-Point Profile Model
Douglas-fir	614	I13FW2W017	Flewelling 2-Point Profile Model
Douglas-fir	616	I11FW2W202	Flewelling 2-Point Profile Model
grand fir	616	I11FW2W017	Flewelling 2-Point Profile Model
grand fir	604, 607	I12FW2W017	Flewelling 2-Point Profile Model
grand fir	614	I13FW2W017	Flewelling 2-Point Profile Model
mountain hemlock	All	616BEHW264	Behre's Hyperbola
western juniper	All	616BEHW064	Behre's Hyperbola
lodgepole pine	604, 607	I12FW2W108	Flewelling 2-Point Profile Model
lodgepole pine	614, 616	I00FW2W108	Flewelling 2-Point Profile Model
Engelmann spruce	604, 607	616BEHW093	Behre's Hyperbola
Engelmann spruce	614	I00FW2W093	Flewelling 2-Point Profile Model
Engelmann spruce	616	I11FW2W093	Flewelling 2-Point Profile Model
subalpine fir	604, 607, 616	616BEHW019	Behre's Hyperbola

Common Name	Location Codes	Equation Number	Model Name
subalpine fir	614	I00FW2W019	Flewelling 2-Point Profile Model
ponderosa pine	604, 607	I12FW2W122	Flewelling 2-Point Profile Model
ponderosa pine	614	I13FW2W122	Flewelling 2-Point Profile Model
ponderosa pine	616	I11FW2W122	Flewelling 2-Point Profile Model
whitebark pine	All	616BEHW101	Behre’s Hyperbola
limber pine	All	616BEHW113	Behre’s Hyperbola
Pacific yew	All	616BEHW231	Behre’s Hyperbola
Alaska cedar	All	616BEHW042	Behre’s Hyperbola
quaking aspen	All	616BEHW746	Behre’s Hyperbola
black cottonwood	All	616BEHW747	Behre’s Hyperbola
other softwood	All	616BEHW299	Behre’s Hyperbola
other hardwood	All	616BEHW998	Behre’s Hyperbola

Table 7.0.3 Citations by Volume Model

Model Name	Citation
Behre’s Hyperbola	USFS-R6 Sale Preparation and Valuation Section of Diameter and Volume Procedures - R6 Timber Cruise System. 1978.
Flewelling 2-Point Profile Model	Unpublished. Based on work presented by Flewelling and Raynes. 1993. Variable-shape stem-profile predictions for western hemlock. Canadian Journal of Forest Research Vol 23. Part I and Part II.

8.0 Fire and Fuels Extension (FFE-FVS)

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

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

9.0 Insect and Disease Extensions

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

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11.0 Appendices

11.1 Appendix A. Distribution of Data Samples

The following tables contain distribution information of data used to fit species relationships in this variant's geographic region (information from original variant overview).

Table 11.1.1. Distribution of samples by National Forest, expressed in whole percent of total observations for each species.

Species	National Forest				Total Number of Observations
	Malheur	Ochoco	Umatilla	Wallowa-Whitman	
western larch	14	18	51	17	1209
Douglas-fir	28	13	36	22	3478
grand fir	27	16	40	18	2963
lodgepole pine	33	13	34	20	1117
Engelmann spruce	6	6	66	23	596
subalpine fir	11	8	48	32	599
ponderosa pine	44	25	20	12	6577

Table 11.1.2. Distribution of samples for diameter breast high, expressed in whole percent of total observations for each species.

Species	DBH Range								
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40+
western larch	0	26	24	19	13	8	6	3	2
Douglas-fir	0	26	28	18	12	7	4	3	2
grand fir	0	28	26	18	11	8	6	2	2
lodgepole pine	<1	73	23	3	1	<1	0	0	0
Engelmann spruce	0	22	22	23	14	9	6	3	2
subalpine fir	0	42	29	16	10	3	<1	0	0
ponderosa pine	<1	22	19	15	15	13	9	5	3

Table 11.1.3. Distribution of samples by Crown Ratio group, expressed in whole percent of total observations for each species.

Species	Crown Code (1=1-10,2=11-20,…,9=81-100)								
	1	2	3	4	5	6	7	8	9
western larch	2	10	26	28	19	11	4	1	0
Douglas-fir	1	3	7	16	21	22	16	11	4
grand fir	0	3	9	15	21	21	17	10	40
lodgepole pine	4	19	32	18	13	8	3	3	1
Engelmann spruce	0	2	6	12	17	22	19	15	6
subalpine fir	0	2	7	9	16	22	24	16	5

Species	Crown Code (1=1-10,2=11-20,…,9=81-100)								
	1	2	3	4	5	6	7	8	9
ponderosa pine	0	2	8	18	27	25	13	5	1

Table 11.1.4. Distribution of samples by Aspect Code, expressed in percent of total observations for each species.

Species	Aspect Code								
	North	North-east	East	South-east	South	South-west	West	North-west	Level
western larch	26	17	10	7	5	5	13	11	7
Douglas-fir	21	13	12	6	10	6	13	11	7
grand fir	19	16	10	8	8	7	14	12	7
lodgepole pine	21	10	9	9	5	9	14	10	14
Engelmann spruce	21	15	7	8	8	4	8	16	13
subalpine fir	19	10	11	9	14	6	9	15	10
ponderosa pine	9	10	9	11	16	14	12	7	13

Table 11.1.5. Distribution of samples by Slope Code, expressed in percent of total observations for each species.

Species	Slope code									
	≤ 5	6-15	16-25	26-35	36-45	46-55	56-65	66-75	76-85	≥ 86
western larch	10	24	23	17	10	9	5	3	0	0
Douglas-fir	9	18	18	13	13	12	10	6	0	0
grand fir	10	20	22	15	12	10	7	3	1	0
lodgepole pine	22	34	22	13	5	4	1	1	0	-
Engelmann spruce	16	31	23	9	10	6	4	1	0	-
subalpine fir	12	38	17	15	9	5	2	-	4	-
ponderosa pine	19	28	21	12	9	6	3	1	0	0

Table 11.1.6. Distribution of samples by total stand basal area per acre, expressed in percent of total for each species.

Species	Basal Area								
	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	≥ 400
western larch	-	<1	7	35	45	13	-	-	-
Douglas-fir	2	21	35	21	13	6	2	<1	<1
grand fir	1	10	21	25	25	14	4	1	1
lodgepole pine	2	9	35	33	14	6	1	<1	-
Engelmann spruce	1	5	12	21	27	25	10	1	-
subalpine fir	-	3	11	24	30	24	7	2	-
ponderosa pine	3	36	41	15	4	1	0	0	0

Table 11.1.7. Distribution of samples by diameter growth, expressed in percent for each species.

Species	Diameter Growth (inches/10 years)							
	< 0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	≥ 3.5
western larch	39	37	17	5	2	-	<1	-
Douglas-fir	15	32	26	14	8	3	2	1
grand fir	10	31	30	16	7	3	2	1
lodgepole pine	31	43	18	5	2	<1	<1	<1
Engelmann spruce	11	36	28	12	8	2	3	2
subalpine fir	22	42	22	9	3	1	<1	-
ponderosa pine	27	37	22	9	3	1	<1	<1

Table 11.1.8. Distribution of samples by elevation, expressed in percent for each species.

Species	Elevation					
	< 2000	2000-3000	3000-4000	4000-5000	5000-6000	≥ 6000
western larch	-	<1	7	35	45	13
Douglas-fir	-	1	10	41	40	9
grand fir	-	<1	4	31	47	17
lodgepole pine	-	-	1	16	62	20
Engelmann spruce	-	<1	2	31	39	28
subalpine fir	-	-	-	8	44	49
ponderosa pine	-	<1	5	39	53	3

11.2 Appendix B. Plant Association Codes

Table 11.2.1 Plant association codes recognized in the BM variant.

FVS Seq. Num. = PA Type	PA Name	Alpha Code	SP	Site SP	Site Index	Site Source	Max SDI	Max SDI Source	Reference
1 = ABLA2/CAGE	Subalpine fir/elk sedge	CAG111	DF		48	P			R6 E TP-036-92, p. 37
			WL		65	P			
			LP	X	78	P	346	P	
			ES		66	P			
			AF		62	P	465	P	
2 =ABLA2/STOC	Subalpine fir/western featherbells	CAG4	DF		56	P			R6-ERW-TP-036-92
			LP	X	78	P	346	P	
			ES		64	P			
			AF		48	P	465	P	
3 = PSME/CAGE-BLUE	Douglas-fir/elk sedge (Blue Mountains)	CDG111	PP	X	77	P	278	P	R6 E TP-036-92 , p. 93
			DF		52	P	351	P	
			WL		59	P			
			GF		62	P			
4 = PSME/CARU-BLUE	Douglas-fir/pinegrass (Blue Mountains)	CDG112	PP	X	83	P	329	P	R6 E TP-036-92, p. 91
			DF		53	P	330	P	
			WL		55	P			

FVS Seq. Num. = PA Type	PA Name	Alpha Code	SP	Site SP	Site Index	Site Source	Max SDI	Max SDI Source	Reference
			GF		48	P			
5 = PSME/CARU	Douglas-fir/pinegrass	CDG121	PP	X	86	P	451	P	R6 E TP-255-86, p. 93
			DF		55	P	475	P	
6 = PSME/HODI	Douglas-fir/oceanspray	CDS611	PP		86	P	425	P	R6 E TP-036-92, p. 85
			DF	X	64	P	319	P	
7 = PSME/SYAL-WALLO	Douglas-fir/common snowberry (Wallowa)	CDS622	PP	X	84	P	416	P	R6 E TP-255-86, p. 358
			DF		60	P	475	P	
8 = PSME/SYOR-WALLO	Douglas-fir/mountain snowberry (Wallowa)	CDS623	PP	X	90	P	451	P	R6 E TP-255-86, p. 365
			DF		55	P			
9 = PSME/SYAL-BLUE	Douglas fir/common snowberry (Blue Mountains)	CDS624	PP		81	P	341	P	R6 E TP-036-92, p. 87
			DF	X	61	P	390	P	
			WL				256	P	
			GF		70	P			
10= PSME/SPBE	Douglas-fir/spiraea	CDS634	PP	X	82	P	441	P	R6 E TP-255-86, p. 352
			DF		61	P	464	P	
11 = PSME/PHMA-BLUE	Douglas-fir/ninebark	CDS711	PP		87	P	343	P	R6 E TP-036-92, p. 83
			DF	X	59	P	281	P	
			WL		64	P	320	P	
12 = PSME/ACGL-PHMA	Douglas-fir/Rocky Mountain maple-ninebark	CDS722	DF	X	64	P	346	P	R6 E TP-255-86, p. 339
			PP		96	P	351	P	
13 = PSME/VAME-BLUE	Douglas-fir/big huckleberry (Blue Mountains)	CDS821	PP		92	P	241	P	R6 E TP-036-92, p. 81
			DF	X	53	P	229	P	
14 = ABLA2/LIBO2	Subalpine fir/twinflower	CEF221	WL		62	P	348	P	R6 E TP-255-86, p. 268
			LP	X	65	P	333	P	
			ES		67	P	538	P	
			AF		40	P	488	P	
15 = ABLA2/STAM	Subalpine fir/twisted stalk	CEF311	LP	X	65	P	346	P	R6 E TP-255-86, p. 275
			ES		69	P	586	P	
			GF		57	P			
			AF		65	P	443	P	
16 = ABLA2/TRCA3-BLUE	Subalpine fir/false bugbane (Blue Mountains)	CEF331	LP	X	65	P	346	P	R6 E TP-036-92, p. 25
			ES		60	P	430	P	
			AF				478	P	
17 = ABLA2/POPU	Subalpine fir/Woodrush	CEF411	DF		59	P	475	P	R6-ECOL-TP-255A86
			WL				513	P	
			LP	X	65	P	346	P	
			ES		58	P	568	P	
			GF		54	P			
			AF		54	P	483	P	
18 = PIEN/CAEU	Engelmann spruce/widefruit sedge	CEM111	ES	X	80		635	H	R6 E TP-279-87, p. 55
19 = PIEN/EQAR-STRO	Engelmann spruce/common horsetail-rosy twisted stalk	CEM221	ES	X	90		712	H	R6 E TP-279-87, p. 57
20 = PIEN/CLUN	Engelmann spruce/queen's cup beadlily	CEM222	ES	X	15		842	H	R6 E Tp-279-87, p. 49
21 = PIEN/VAOC2-FORB	Englemann spruce/bog blueberry/forb	CEM311	ES	X	85		643	H	R6 E TP-004-88, p. 59

FVS Seq. Num. = PA Type	PA Name	Alpha Code	SP	Site SP	Site Index	Site Source	Max SDI	Max SDI Source	Reference
22 = PIEN/VAOC2/CAEU	Engelmann spruce/bog blueberry/ widefruit sedge	CEM312	ES	X	76		444	H	R6 E TP-006-88, p. 45
23 = ABLA2/CLUN	Subalpine fir/queen's cup beadily	CES131	PP				379	P	R6 E TP-255-86 , p. 262
			WL	X	83	P	414	P	
			ES		72	P	586	P	
			GF		77	P	681	P	
			AF		69	P	429	P	
24 = ABLA2/MEFE	Subalpine fir/fool's huckleberry	CES221	DF		56	P			R6 E TP-255-86, p. 238
			LP	X	65	P	346	P	
			ES				460	P	
			AF				410	P	
25 = ABLA2/VAME-BLUE	Subalpine fir/big huckleberry (Blue Mountains)	CES311	WL		63	P	478	P	R6 E TP-036-92, p. 33
			LP				319	P	
			ES		58	P	478	P	
			GF		72	P			
			AF	X	51	P	331	P	
26 = ABLA2/CLUN-BLUE	Subalpine fir/queen's cup beadily (Blue Mountains)	CES314	WL	X	79	P	513	P	R6 E TP-036-92, p. 27
			ES		69	P	586	P	
			GF		69	P			
			AF		53	P	520	P	
27 = ABLA2/VAME-WALLO	Subalpine fir/big huckleberry (Wallowa)	CES315	DF		55	P	475	P	R6 E TP-255-86, p. 253
			WL		62	P	460	P	
			LP	X	82	P	346	P	
			ES		65	P	573	P	
			GF		55	P			
			AF		63	P	425	P	
28 = ABLA2/VASC-BLUE	Subalpine fir/grouse huckleberry (Blue Mountains)	CES411	DF				458	P	R6 E TP-036-92, p. 35
			WL		46	P	475	P	
			LP	X	66	P	346	P	
			ES		53	P	458	P	
			GF		61	P			
			AF		44	P	456	P	
			WB		19	P			
29 = ABLA2/LIBO2	Subalpine fir/twinflower	CES414	DF		64	P			R6 E TP-036-92, p. 29
			WL		58	P	513	P	
			LP		66	P			
			ES		60	P	474	P	
			GF		52	P			
			AF	X	53	P	419	P	
30 = ABLA2/VASC/POPU	Subalpine fir/grouse huckleberry/skunk-leaved polem	CES415	DF				475	P	R6 E TP-255-86, p. 244
			WL		51	P	513	P	
			LP	X	70	P	346	P	
			ES		57	P	568	P	
			GF		51	P			
			AF		48	P	483	P	
31 = PICO/LIBO2	Lodgepole pine/twinflower	CLF211	WL		55	P			R6 E TP-255-86, p. 305
			LP	X	72	P	690	C	
32 = PICO/CARU-VASC	Lodgepole pine/pinegrass-grouse huckleberry	CLG211	LP	X	39		395	H	R6 AG 3-1-73, p. 34

FVS Seq. Num. = PA Type	PA Name	Alpha Code	SP	Site SP	Site Index	Site Source	Max SDI	Max SDI Source	Reference
33 = PICO/POPR	Lodgepole pine/Kentucky bluegrass	CLM112	PP	X	97		538	H	R6 E TP-279-87, p. 29
34 = PICO/CAEU	Lodgepole pine/widefruit sedge	CLM113	LP	X	57		491	H	R6 E TP-279-87, p. 41
35 = PICO/CAAQ	Lodgepole pine/aquatic sedge	CLM114	LP	X	45		549	H	R6 E TP-279-87, p. 43
36 = PICO/VAOC2/CAEU	Lodgepole pine/bog blueberry/widefruit sedge	CLM312	LP	X	54		466	H	R6 E TP-279-87, p. 39
37 = PICO/SPDO/FORB	Lodgepole pine/Douglas spiraea/forb	CLM313	LP	X	51		558	H	R6 E TP-279-87, p. 33
38 = PICO/SPDO/CAEU	Lodgepole pine/Douglas spiraea/widefruit sedge	CLM314	LP	X	59		519	H	R6 E TP-279-87, p. 35
39 = PICO-PIEN/ELPA2	Lodgepole pine-Engelmann spruce/few-flow spikerush	CLM911	LP	X	35		495	C	R6 E TP-279-87, p. 45
40 = PICO/VASC-BLUE	Lodgepole pine/grouse huckleberry (Blue Mountains)	CLS411	LP	X	34		331	H	R6 AG 3-1-73, p. 36
41 = PICO/VASC/POPU-WALLO	Lodgepole pine/grouse huckleberry/skunk-leaved polem	CLS415	WL		45	P			R6 E TP-255-86, p. 250
			LP	X	61	P	785	C	
			ES		52	P			
			AF		42	P			
42 = PICO/CARU	Lodgepole pine/pinegrass	CLS416	PP		78	P			R6 E TP-036-92, p. 79
			DF		53	P			
			WL		55	P			
			LP	X	66	P	279	P	
43 = PICO(ABGR)/VAME-LIBO2	Lodgepole pine/thinleaf huckleberry/pinegrass	CLS5	PP				456	P	R6-ERW-TP-036-92
			DF		55	P	475	P	
			WL		52	P	463	P	
			LP	X	67	P	346	P	
			ES		56	P	499	P	
			GF		52	P	645	P	
			AF				466	P	
44 = PICO/VAME-BLUE	Lodgepole pine/big huckleberry (Blue Mountains)	CLS511	LP	X	30	P	348	H	R6 AG 3-1-73, p. 35
45 = PICO/VAME-WALLO	Lodgepole pine/big huckleberry (Wallowa)	CLS515	WL		46	P			R6 E TP-255-86, p. 259
			LP	X	65	P	414	H	
			ES		46	P			
46 = PICO(ABGR)/ALSI	Lodgepole pine/Sitka alders	CLS6	DF				475	P	R6-ERW-TP-036-92
			WL		59	P	513	P	
			LP	X	65	P	346	P	
			ES				586	P	
			GF				700	P	
47 = TSME/VASC-WALLO	Mountain hemlock/grouse huckleberry (Wallowa)	CMS131	LP	X	68	P	283	P	R6 E TP-255-86, p.230
			ES				371	P	
			AF				520	P	
			MH		16	P	610	C	
48 = TSME/VAME-WALLO	Mountain hemlock/big huckleberry (Wallowa)	CMS231	LP	X	68	P	283	P	R6 E TP-255-86, p. 230
			ES				371	P	
			AF				520	P	
			MH		15	P	745	C	

FVS Seq. Num. = PA Type	PA Name	Alpha Code	SP	Site SP	Site Index	Site Source	Max SDI	Max SDI Source	Reference
49 = PIPO/AGSP-BLUE	Ponderosa pine/bluebunch wheatgrass (Blue Mountains)	CPG111	PP	X	72	P	166	P	R6 E TP-036-92, p. 121
			DF		52	P			
			GF		69	P			
50 = PIPO/FEID-BLUE	Ponderosa pine/Idaho fescue (Blue Mountains)	CPG112	PP	X	74	P	243	P	R6 E TP-036-92, p. 119
			DF		59	P			
51 = PIPO/FEID-WALLO	Ponderosa pine/Idaho fescue (Wallowa)	CPG131	PP	X	79	P	259	P	R6 E TP-255-86, p. 378
			DF		57	P			
52 = PIPO-AGSP-WALLO	Ponderoas Pine/bluebunch wheatgrass (Wallowa)	CPG132	PP	X	77	P	233	P	R6 E TP-255-86, p. 383
			DF		62	P			
53 = PIPO/CARU	Ponderosa pine/pinegrass	CPG221	PP	X	77	P	456	P	R6 E TP-036-92, p. 107
			DF		55	P			
			GF		66	P			
54 = PIPO/CAGE	Ponderosa pine/elk sedge	CPG222	PP	X	73	P	251	P	R6 E TP-036-92, p. 109
			DF		51	P			
			LP		70	P			
55 = PIPO/ELGL	Ponderosa pine/blue wildrye	CPM111	PP	X	80	?	235	H	R6 AG 3-1-73, p. 28
56 = PIPO/ARTR/FEID-AGSP	Ponderosa Pine/mtn big sagebrush/ID fescue-wheatgrass	CPS131	PP	X	73	P	238	P	R6 E TP-036-92, p. 117
57 = PIPO/PUTR/CARO	Ponderosa pine/bitterbrush/Ross' edge	CPS221	PP	X	74	P	304	P	R6 E TP-036-92, p. 111
58 = PIPO/PUTR/CAGE	Ponderosa pine/bitterbrush/elk sedge	CPS222	PP	X	79	P	255	P	R6 E TP-036-92, p. 113
59 = PIPO/PUTR/FEID-AGSP	Ponderosa pine/bitterbrush/ID fescue-bluebunch wheatgr.	CPS226	PP	X	64	P	231	P	R6 E TP-036-92, p. 115
60 = PIPO/CELE/CAGE	Ponderosa pine/mountain-mahogany/elk sedge	CPS232	PP	X	65	P	290	P	R6 E TP-036-92, p. 97
			DF		53	P			
61 = PIPO/CELE/PONE	Ponderosa pine/mountain-mahogany/Wheeler's bluegrass	CPS233	PP	X	67	P	199	P	R6 E TP-036-92, p. 99
62 = PIPO/CELE/FEID-AGSP	Pond. pine/mtn mahogany/ID fescue-bluebunch wheatgr.	CPS234	PP	X	66	P	196	P	R6 E TP-036-92, p. 101
			DF		51	P			
63 = PIPO/SYAL-FLOOD	Ponderosa pine/common snowberry-floodplain	CPS511	PP	X	101		516	H	R6 E TP-279-87, p. 27
64 = PIPO/SYAL-WALLO	Ponderosa pine/common snowberry (Wallowa)	CPS522	PP	X	85	P	301	P	R6 E TP-255-86, p. 372
			DF		70	P			
65 = PIPO/SPBE	Ponderosa pine/spiraea	CPS523	PP	X	96	P	276	P	R6 E TP-255-86, p. 377
			DF		71	P			
66 = PIPO/SYAL	Ponderosa pine/common snowberry	CPS524	PP	X	81	P	398	P	R6 E TP-036-92, p. 103
			DF		56	P			
67 = PIPO/SYOR	Ponderosa pine/mountain snowberry	CPS525	PP	X	79	P	325	P	R6 E TP-036-92, p. 105
68 = ABGR/TABR/CLUN		CWC811	ES	X	76	P	533	P	

FVS Seq. Num. = PA Type	PA Name	Alpha Code	SP	Site SP	Site Index	Site Source	Max SDI	Max SDI Source	Reference
	Grand fir/Pacific yew/queen's cup beadily		GF		69	P	700	P	R6 E TP-036-92, p. 51
69 = ABGR/TABR/LIBO2	Grand fir/Pacific yew/twinflower	CWC812	DF		76	P	475	P	R6 E TP-036-92, p. 53
			WL				378	P	
			ES	X	66	P	374	P	
			GF		90	P	700	P	
70 = ABGR/LIBO2	Grand fir/twinflower	CWF311	PP		104	P			R6 E TP-255-86, p. 298
			DF		60	P	475	P	
			WL		60	P	511	P	
			LP	X	73	P	346	P	
			ES		59	P			
			GF		59	P	700	P	
71 = ABGR/LIBO2-BLUE	Grand fir/twin flower (Blue Mountains)	CWF312	PP		92	P	456	P	R6 E TP-036-92, p. 59
			DF		62	P	475	P	
			WL		58	P	463	P	
			LP	X	72	P	346	P	
			ES		53	P	499	P	
			GF		56	P	645	P	
			AF				466	P	
72 = ABGR/CLUN-WALLO	Grand fir/queen's cup beadily (Wallowa)	CWF421	PP		111	P	456	P	R6 E TP-255-86, p. 279
			DF		69	P	475	P	
			WL		79	P	455	P	
			LP	X	81	P	346	P	
			ES		72	P	586	P	
			GF		74	P	700	P	
			WP		40	P			
73 = ABCO/CLUN	White fir/queen's cup beadily	CWF431	DF	X	77		872	H	R6 E TP-279-87, p. 47
74 = ABGR/TRCA3	Grand fir/false bugbane	CWF512	DF		75	P			R6 E TP-036-92, p. 49
			WL				498	P	
			ES	X	72	P	485	P	
			GF		79	P	693	P	
75 = ABGR/GYDR	Grand fir/oakfern	CWF611	GF	X	79	P	691	P	R6 E TP-036-92, p. 45
76 = ABGR/POMU-ASCA3	Grand fir/sword fern ginger	CWF612	WL	X	79	P	438	P	R6 E TP-036-92, p. 47
			ES				586	P	
			GF		78	P	608	P	
77 = ABGR/CAGE-BLUE	Grand fir/elk sedge (Blue Mountains)	CWG111	PP	X	81	P	263	P	R6 E TP-036-92, p. 73
			DF		56	P	376	P	
			WL		64	P			
			LP		70	P			
			ES		68	P			
			GF		50	P	700	P	
78 = ABGR/CARU	Grand fir/pinegrass	CWG112	PP	X	90	P	456	P	R6 E TP-255-86, p. 320
			DF		60	P	475	P	
			WL		55	P			
			ES		75	P			
			GF		56	P			

FVS Seq. Num. = PA Type	PA Name	Alpha Code	SP	Site SP	Site Index	Site Source	Max SDI	Max SDI Source	Reference
79 = ABGR/CARU-BLUE	Grand fir/pinegrass (Blue Mountains)	CWG113	PP	X	80	P	395	P	R6 E TP-036-92, p. 71
			DF		56	P	446	P	
			WL		59	P	384	P	
			LP		76	P	346	P	
			GF		52	P	555	P	
80 = ABGR/BRVU	Grand fir/Columbia brome	CWG211	WL	X	79	P	513	P	R6 E TP-036-92, p. 67
			ES				586	P	
			GF		57	P	700	P	
			AF		55	P			
81 = ABGR/VAME	Grand fir/big huckleberry	CWS211	PP		86	P	424	P	R6 E TP-255-86, p. 290
			DF		66	P	439	P	
			WL		84	P	464	P	
			LP	X	54	P	331	P	
			ES		66	P	586	P	
			GF		61	P	700	P	
82 = ABGR/VAME-BLUE	Grand fir/big huckleberry	CWS212	PP		79	P	365	P	R6 E TP-036-92, p. 61
			DF		61	P	475	P	
			WL		57	P	513	P	
			LP	X	68	P	298	P	
			ES		67	P	426	P	
			GF		60	P	569	P	
			AF				515	P	
83 = ABGR/SPBE	Grand fir/spiraea	CWS321	PP	X	92	P	456	P	R6 E TP-255-86, p. 315
			DF		58	P	475	P	
			LP		74	P			
			GF		65	P			
84 = ABGR/SPBE-BLUE	Grand fir/birchleaf spiraea	CWS322	PP		82	P	319	P	R6 E TP-036-92, p. 69
			DF	X	57	P	248	P	
			LP		60	P			
			GF		49	P	443	P	
85 = ABGR/AGGL-PHMA	Grand fir/Rocky Mountain maple-ninebark	CWS412	PP		107	P			R6 E TP-255-86, p. 325
			DF	X	66	P	475	P	
			WL		79	P	444	P	
			GF		65	P	628	P	
86 = ABGR/ACGL	Grand fir/Rocky Mountain maple	CWS541	DF	X	70	P	301	P	R6 E TP-036-92, p. 55
			WL				439	P	
			ES				405	P	
			GF		71	P	576	P	
87 = ABGR/VASC	Grand fir/grouse huckleberry	CWS811	PP		101	P	215	P	R6 E TP-036-92, p. 65
			DF		59	P	343	P	
			WL		61	P	380	P	
			LP	X	65	P	346	P	
			ES		43	P			
			GF		48	P	460	P	
88 = ABGR/VASC-LIBO2	Grand fir/grouse huckleberry-twinflower	CWS812	PP		81	P			R6 E TP-036-92, p. 63
			DF		56	P	434	P	
			WL	X	56	P	316	P	
			LP		75	P	346	P	
			ES		70	P	436	P	
			GF		56	P	618	P	
			AF				230	P	

FVS Seq. Num. = PA Type	PA Name	Alpha Code	SP	Site SP	Site Index	Site Source	Max SDI	Max SDI Source	Reference
89 = ABGR/ACGL	Grand fir/Rocky Mountain maple	CWS912	PP				456	P	R6 E TP-255-86, p. 310
			DF	X	67	P	475	P	
			WL		64	P			
			GF		69	P	700	P	
90 = POTR/ELGL	Quaking aspen/blue wildrye	HQM121	LP	X	55		464	H	R6 E TP-279-87, p. 61
91 = POTR-PICO/SPDO/CAEU	Quaking Aspen-Lodgepole pine/Doug spiraea/wildfruit sedge	HQM411	LP	X	59		640	H	
92 = POTR/SYAL/ELGL	Quaking aspen/common snowberry/blue wildrye	HQS221	PP	X	101		596	H	

*Site index estimates are from GBA analysis. Site index and SDI maximums are set by GBA analysis, Source=H (Hall 1983); CVS plot analysis, Source=C (Crookston 2008); or Blue Mountains Variant Analysis, Source = P (Powell 2009).

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