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Eastern Montana (EM) Variant Overview of the Forest Vegetation Simulator

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Beartooth Mountain Range, Custer National Forest
(Jason McGaughey, FS-R1)

Eastern Montana (EM) 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 1981. 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. Robert Havis 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.

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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)	108 – Custer National Forest	
Plant Association Code	260 (PSME/PHME)	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation	55 (5500 feet)	
Latitude / Longitude	Latitude	Longitude
All location codes	46	111
Site Species	Varies by habitat type	
Site Index	Varies by species and habitat type	
Maximum Stand Density Index	Species Specific	
Maximum Basal Area	Varies by habitat type	
Volume Equations	National Volume Estimator Library	
Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All other 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 other location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Basal Area Factor	40 BAF	
Small-Tree Fixed Area 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 United States.

The Eastern Montana (EM) variant has the distinction of being the first variant calibrated for a geographic area outside of Northern Idaho. It was developed in 1980 by Ralph Johnson, who worked for Region 1 in State and Private Forestry and covers all forested lands east of the continental divide in Montana. Since its initial development, many of the functions have been adjusted and improved as more data has become available and model technology has advanced. In 2009 this variant was expanded from its 8 original species to 19 species.

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

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

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

2.0 Geographic Range

The EM variant was fit to data representing forest types in central and eastern Montana. Data used in initial model development came from forest inventories, silviculture stand examinations, and permanent plots from the Northern Region of the Forest Service. Distribution of data samples for species fit from this data are shown in Appendix A.

The EM variant covers forest areas in central and eastern Montana. The suggested geographic range of use for the EM variant is shown in figure 2.0.1.

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

3.0 Control Variables

FVS users need to specify certain variables used by the EM 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-digit code where, in general, the first digit of the code represents the USDA 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 EM variant, a default forest code of 108 (Custer National Forest) will be used. Location codes recognized in the EM variant are shown in tables 3.1.1 and 3.1.2.

Table 3.1.1 Location codes used in the EM variant.

Location Code	Location
102	Beaverhead National Forest
108	Custer National Forest
109	Deerlodge National Forest
111	Gallatin National Forest
112	Helena National Forest
115	Lewis and Clark National Forest

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

Location Code	Location
7101	Cheyenne River Reservation (mapped to 108)
7102	Fort Berthold Reservation (mapped to 108)
7103	Spirit Lake Reservation (mapped to 108)
7107	Lake Traverse Reservation (mapped to 108)
7108	Standing Rock Reservation (mapped to 108)
7109	Turtle Mountain Off-Reservation Trust Land (mapped to 108)
7301	Blackfeet Indian Reservation (mapped to 115)
7302	Crow Reservation (mapped to 108)
7303	Fort Belknap (mapped to 115)
7304	Fort Peck Indian Reservation (mapped to 115)
7305	Northern Cheyenne Indian Reservation (mapped to 108)
7307	Rocky Boy's Reservation (mapped to 115)

3.2 Species Codes

The EM variant recognizes 17 species, plus two other composite species categories. You may use FVS species codes, Forest Inventory and Analysis (FIA) species codes, or USDA Natural Resources Conservation Service PLANTS symbols to represent these species in FVS input data. Any valid western species code identifying species not recognized by the variant will be mapped to a similar species in the variant. The species mapping crosswalk is available on the FVS website variant documentation webpage. Any non-valid species code will default to the "other hardwood" category.

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

When entering tree data, users should substitute diameter at root collar (DRC) for diameter at breast height (DBH) for woodland species (Rocky Mountain juniper).

Table 3.2.1 Species codes used in the EM variant.

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name[1]	Common Name[1]
1	WB	101	PIAL	*Pinus albicaulis*	whitebark pine
2	WL	073	LAOC	*Larix occidentalis*	western larch
3	DF	202	PSME	*Pseudotsuga menziesii*	Douglas-fir
4	LM	113	PIFL2	*Pinus flexilis*	limber pine
5	LL	072	LALY	*Larix lyallii*	subalpine larch
6	RM	066	JUSC2	*Juniperus scopulorum*	Rocky Mountain 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	GA	544	FRPE	*Fraxinus pennsylvanica*	green ash
12	AS	746	POTR5	*Populus tremuloides*	quaking aspen
13	CW	747	POBAT	*Populus balsamifera* ssp. *trichocarpa*	black cottonwood
14	BA	741	POBA2	*Populus balsamifera*	balsam poplar
15	PW	745	PODEM	*Populus deltoides* ssp. *monolifera*	plains cottonwood
16	NC	749	POAN3	*Populus angustifolia*	narrowleaf cottonwood
17	PB	375	BEPA	*Betula papyrifera*	paper birch
18	OS	299	2TN		other softwood[2]
19	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

Habitat type codes that are recognized in the EM variant are listed in Appendix B table 11.2.1. If the habitat type code is blank or not recognized, the default 260 (PSME/PHMA) will be used. Habitat type is used for all forests in this variant.

Habitat types used in this variant are also mapped to one of the original 30 habitat types used to develop the Northern Idaho (NI) variant. This mapping is shown in Appendix B table 11.2.2. This mapping facilitates setting default values for some of the variables and enables this variant to use some of the NI variant equations and coefficients.

3.4 Site Index

Site index is used in some of the growth equations for the EM 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 EM variant.

Species	Reference	BHA or TTA*	Base Age
DF	Monserud, (1985)	BHA	50
WB, WL, LM, LP, OS	Alexander, Tackle, and Dahms (1967)	TTA	100
ES, AF	Alexander, (1967)	BHA	100
PP	Meyer, (1961.rev)	TTA	100
AS, PB	Edminster, Mowrer, and Shepperd (1985)	BHA	80
RM	Any juniper 100 year base total age curve	TTA	100
GA, CW, BA, PW, NC, OH	Any hardwood 100 year base total age curve	TTA	100
LL	Does not use site index		
* Equation is based on total tree age (TTA) or breast height age (BHA)			

If site index is missing or incorrect, the default site species and site index values are assigned as shown in table 3.4.1 from the NI habitat mapping index shown in Appendix B table 11.2.2.

Table 3.4.1 Default site index values by species and site species by NI habitat mapping index in the EM variant.

NI Habitat Mapping Index	Site Index										Site Species
	WB, WL, OS	PP	DF	LP	ES	AF	LM, LL	RM	AS, PB	GA, CW, BA, PW, NC, OH	
1	35	46	26	46	46	46	25	6	36	44	PP
2	51	68	44	68	68	68	29	8	43	57	PP

NI Habitat Mapping Index	Site Index										Site Species
	WB, WL, OS	PP	DF	LP	ES	AF	LM, LL	RM	AS, PB	GA, CW, BA, PW, NC, OH	
3	57	76	49	76	76	76	35	10	51	76	DF
4	60	80	51	80	78	80	35	10	50	62	DF
5	48	64	41	75	64	64	32	9	44	72	DF
6	55	73	47	73	73	73	34	10	49	72	DF
7	45	67	39	72	61	61	35	10	48	71	DF
8	38	67	33	70	51	51	32	9	46	67	DF
9	44	59	38	63	59	59	27	7	41	55	DF
10	60	80	51	80	80	80	39	11	55	86	ES
11	64	85	42	80	85	85	37	9	46	67	ES
12	47	62	40	62	68	62	32	11	52	80	DF
13	47	62	40	62	68	62	36	12	59	95	DF
14	47	62	40	62	68	62	41	12	58	93	DF
15	47	62	40	62	68	62	41	12	58	93	DF
16	47	62	40	62	68	62	41	12	58	93	DF
17	47	62	40	62	68	62	43	13	60	98	DF
18	47	62	40	62	68	62	38	11	54	84	AF
19	47	62	40	62	68	62	39	11	55	86	AF
20	53	70	46	74	75	70	32	9	46	67	AF
21	50	67	43	76	68	67	36	10	49	73	AF
22	57	76	49	76	78	76	34	10	52	80	AF
23	49	65	42	68	80	76	34	10	52	80	DF
24	57	76	42	68	80	76	32	9	46	67	AF
25	49	65	42	68	80	76	36	10	52	80	DF
26	49	65	42	65	67	65	36	10	52	80	AF
27	47	62	30	35	64	62	36	10	52	80	AF
28	41	55	36	51	53	55	26	7	38	49	AF
29	26	35	23	35	45	35	22	6	33	36	DF
30	60	80	51	80	78	80	26	7	38	49	DF

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 the user-specified, or default, habitat type 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 maximum SDI for all species is assigned from habitat type as shown in Appendix B, table 11.2.2. 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:

SDIMAXi	is the species-specific SDI maximum
BAMAX	is the user-specified 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 their 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 EM variant, height-diameter relationships are a logistic functional form, as shown in equation {4.1.1} (Wykoff and others, 1982). The equation was fit to data of the same species used to develop other FVS variants. Coefficients for equation {4.1.1} are shown are shown in table 4.1.1.

When heights are given in the input data for 3 or more trees of a given species, the value of b_1 in equation {4.1.1} for that species is recalculated from the input data and replaces the default value shown in table 4.1.1. In the event that the calculated value is less than zero, the default is used.

{4.1.1} $HT = 4.5 + \exp(b_1 + b_2 / (DBH + 1.0))$

where:

HT	is tree height
DBH	is tree diameter at breast height
b_1 - b_2	are species-specific coefficients shown in table 4.1.1

Table 4.1.1 Coefficients for the logistic Wykoff equation {4.1.1} in the EM variant.

Species Code	Default b_1	b_2
WB	4.1539	-4.212
WL	4.1539	-4.212
DF	4.4161	-6.962
LM	4.1920	-5.1651
LL	4.76537	-7.61062
RM	3.2	-5.0
LP	4.5356	-5.692
ES	4.7537	-8.356
AF	4.5788	-7.138
PP	4.4140	-8.907
GA	4.4421	-6.5405
AS	4.4421	-6.5405
CW	4.4421	-6.5405
BA	4.4421	-6.5405

Species Code	Default b_1	b_2
PW	4.4421	-6.5405
NC	4.4421	-6.5405
PB	4.4421	-6.5405
OS	4.1539	-4.212
OH	4.4421	-6.5405

4.2 Bark Ratio Relationships

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

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

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

where:

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

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

Species Code	b_1	b_2	Equation Source
WB	0.934	0	NI western hemlock
WL	0.934	0	NI western hemlock
DF	0.867	0	NI Douglas-fir
LM	0.969	0	NI western redcedar
LL	0.937	0	NI subalpine fir
RM*	0.9002	-0.3089	
LP	0.969	0	NI lodgepole pine
ES	0.956	0	NI Engelmann spruce
AF	0.937	0	NI subalpine fir
PP	0.890	0	NI ponderosa pine
GA	0.892	-0.086	CR cottonwood
AS	0.950	0	UT aspen
CW	0.892	-0.086	CR cottonwood
BA	0.892	-0.086	CR cottonwood
PW	0.892	-0.086	CR cottonwood
NC	0.892	-0.086	CR cottonwood
PB	0.950	0	UT aspen
OS	0.934	0	NI western hemlock
OH	0.892	-0.086	CR cottonwood

*DBH is bounded between 1.0 and 19.0

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 EM variant, crown ratios missing in the input data are predicted using different equations depending on tree species and size. Live trees less than 1.0" in diameter and dead trees of all sizes for whitebark pine, western larch, Douglas-fir, limber pine, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, quaking aspen, paper birch, and other softwood use equations {4.3.1.1} and {4.3.1.2}. Live trees less than 3.0" in diameter and dead trees of all sizes for subalpine larch use equations {4.3.1.1} and {4.3.1.2}. Equation coefficients are found in table 4.3.1.1.

{4.3.1.1} $X = R_1 + R_2 * DBH + R_3 * HT + R_4 * BA + R_5 * PCCF + R_6 * HT_{Avg} / HT + R_7 * HT_{Avg} + R_8 * BA * PCCF + R_9 * MAI + N(0,SD)$

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

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

Table 4.3.1 Coefficients for the crown ratio equation {4.3.1} in the EM variant.

Coefficient	Species Code				
	WB, WL, LM, LP, PP	**LL**	**DF, ES, AF**	**AS, PB**	**OS**
R_1	-1.66949	-0.89014	-0.426688	-0.426688	-2.19723
R_2	-0.209765	-0.18026	-0.093105	-0.093105	0
R_3	0	0.02233	0.022409	0.022409	0
R_4	0.003359	0.00614	0.002633	0.002633	0
R_5	0.011032	0	0	0	0
R_6	0	0	-0.045532	-0.045532	0

Coefficient	Species Code				
	WB, WL, LM, LP, PP	LL	DF, ES, AF	AS, PB	OS
R_7	0.017727	0	0	0	0
R_8	-0.000053	0	0.000022	0.000022	0
R_9	0.014098	0	-0.013115	-0.013115	0
SD	0.5*	0.8871	0.6957	0.9310	0.2

*SD for LP = 0.6124; SD for PP = 0.4942

For whitebark pine, western larch, Douglas-fir, limber pine, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, quaking aspen, paper birch, and other softwood live trees 1.0" in diameter or larger, a Weibull-based crown model developed by Dixon (1985) as described in Dixon (2002) is used to predict missing crown ratio. To estimate crown ratio using this methodology, the average stand crown ratio is estimated from the stand density index using equation {4.3.1.3}. Weibull parameters are then estimated from the average stand crown ratio using equations in equation set {4.3.1.4}. Individual tree crown ratio is then set from the Weibull distribution, equation {4.3.1.5} based on a tree's relative position in the diameter distribution and multiplied by a scale factor, shown in equation {4.3.1.6}, 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 for these equations are shown in table 4.3.1.2.

{4.3.1.3} $ACR = d_0 + d_1 * RELSDI * 100.0$

where: $RELSDI = SDI_{stand} / SDI_{max}$

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

$A = a_0$
$B = b_0 + b_1 * ACR \quad (B \geq 1)$
$C = c_0 + c_1 * ACR \quad (C \geq 2)$

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

{4.3.1.6} $SCALE = 1 - 0.00167 * (SCCF - 100)$

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 4.3.2

Table 4.3.2 Coefficients for the Weibull parameter equations {4.3.1.3} and {4.3.1.4} in the EM variant.

Species Code	Model Coefficients						
	a_0	b_0	b_1	c_0	c_1	d_0	d_1
WB, WL	0	0.11035	1.10085	0.02774	0.35524	5.68625	-0.04470
DF	0	0.14652	1.09052	1.04746	0.39752	5.92714	-0.03346
LM	1	-0.82631	1.06217	3.31429	0	6.19911	-0.02216
LP	0	-0.00359	1.12728	2.60377	0	5.05870	-0.03307
ES	0	0.67059	0.99349	-4.25938	1.35687	7.41093	-0.03467
AF	0	0.73693	0.98414	-4.16681	1.33779	7.36476	-0.03761
PP	0	0.02663	1.11477	2.95048	0	5.61047	-0.03557
AS, PB	0	-0.08414	1.14765	2.77500	0	4.01678	-0.01516
OS	0	0.11035	1.10085	0.02774	0.35524	5.68625	-0.04470

Equation {4.3.1.7} is used to predict missing crown ratio missing in live trees 3.0" in diameter or larger for subalpine larch.

{4.3.1.7} $\ln(CR) = HAB - 0.00190 * BA + 0.23372 * \ln(DBH) - 0.28433 * \ln(HT) + 0.001903 * PCT$

where:

CR	is predicted crown ratio expressed as a proportion
HAB	is a habitat-dependent coefficient shown in table 4.3.1.3
BA	is total stand basal area
DBH	is tree diameter at breast height
HT	is tree height
PCT	is the subject tree's percentile in the basal area distribution of the stand

Table 4.3.1.3 *HAB* values by habitat class for equation {4.3.1.7} in the EM variant.

	Habitat Class									
Species Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
LL	0.09453	-0.0774	0.07113	0.2039	0.06176	0.1513	0.09086	0.1580	0.09229	0.01551

Table 4.3.1.4 Habitat class by mapped NI habitat code, Appendix B table 11.2.2, for HAB values in equation {4.3.1.7} in the EM variant.

Mapped NI Habitat Code	Habitat Class
130	2
170	2
250	2
260	2
280	2
290	2
310	2
320	2
330	2

Mapped NI Habitat Code	Habitat Class
420	2
470	2
510	2
520	2
530	3
540	4
550	4
570	4
610	4
620	5
640	6
660	6
670	7
680	6
690	1
710	8
720	1
730	9
830	10
850	10
999	6

Rocky Mountain juniper, green ash, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, and other hardwood use equation {4.3.1.8} or {4.3.1.9} to estimate crown ratio for live and dead trees missing crown ratios in the inventory. Rocky Mountain juniper uses equation {4.3.1.8}; the remaining species use equation {4.3.1.9}.

{4.3.1.8} $CR = [-0.59373 + (0.67703 * HF)] / HF$

{4.3.1.9} $CR = [5.17281 + (0.32552 * HF) – (0.01675 * BA)] / HF$

where:

CR	is crown ratio expressed as a proportion (bounded to $0.05 \leq CR \leq 0.95$)
BA	is total stand basal area
HF	is end of cycle tree height (*HT* + height growth)

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 whitebark pine, western larch, Douglas-fir, limber pine, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, quaking aspen, paper birch and other softwood using the Weibull distribution, equations{4.3.1.3}-{4.3.1.6}. Live Rocky Mountain juniper uses equation {4.3.1.8}. Live green ash, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, and other hardwood use equation 4.3.1.9. For live subalpine larch trees greater than 3” in dbh, crown change is predicted using equation {4.3.1.7}. 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.

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 EM 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

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

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

{4.4.2} Bechtold (2004); Equation 02

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

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

{4.4.3} Crookston (2003); Equation 03

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

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

{4.4.4 Crookston (2005); Equation 04

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

{4.4.5} Crookston (2005); Equation 05

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

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

{4.4.6} Donnelly (1996); Equation 06

$DBH \geq MinD$: $CW = a_1 * DBH$^a_2

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

where:

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

Table 4.4.1 Coefficients for crown width equations {4.4.1} – {4.4.6} in the EM variant.

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
WB	10105	2.2354	0.6668	-0.11658	0.16927	0	0
WL	07303	1.02478	0.99889	0.19422	0.59423	-0.09078	-0.02341
DF	20203	1.01685	1.48372	0.27378	0.49646	-0.18669	-0.01509
LM	11301	4.0181	0.8528	0	0	0	0
LL	07204	2.2586	0.68532	0	0	0	0
RM	06405	5.1486	0.73636	-0.46927	0.39114	-0.05429	0
LP	10803	1.03992	1.58777	0.30812	0.64934	-0.38964	0
ES	09303	1.02687	1.28027	0.2249	0.47075	-0.15911	0
AF	01903	1.02886	1.01255	0.30374	0.37093	-0.13731	0
PP	12203	1.02687	1.49085	0.1862	0.68272	-0.28242	0
GA	74902	4.1687	1.5355	0	0	0	0.1275
AS	74605	4.796	0.64167	-0.18695	0.18581	0	0
CW	74902	4.1687	1.5355	0	0	0	0.1275

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
BA	74902	4.1687	1.5355	0	0	0	0.1275
PW	74902	4.1687	1.5355	0	0	0	0.1275
NC	74902	4.1687	1.5355	0	0	0	0.1275
PB	37506	5.8980	0.4841	0	0	0	0
OS	26405	3.7854	0.54684	-0.12954	0.16151	0.03047	-0.00561
OH	74902	4.1687	1.5355	0	0	0	0.1275

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

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

Species Code	Equation Number*	*MinD*	*EL min*	*EL* max	*HI* min	*HI* max	*CW* max
WB	10105	1.0	n/a	n/a	n/a	n/a	40
WL	07303	1.0	n/a	n/a	n/a	n/a	40
DF	20203	1.0	n/a	n/a	n/a	n/a	80
LM	11301	5.0	n/a	n/a	n/a	n/a	25
LL	07204	1.0	n/a	n/a	n/a	n/a	33
RM	06405	1.0	n/a	n/a	n/a	n/a	36
LP	10803	0.7	n/a	n/a	n/a	n/a	40
ES	09303	1.0	n/a	n/a	n/a	n/a	40
AF	01903	0.1	10	85	n/a	n/a	30
PP	12203	2.0	n/a	n/a	n/a	n/a	46
GA	74902	5.0	n/a	n/a	-26	-2	35
AS	74605	1.0	n/a	n/a	n/a	n/a	45
CW	74902	5.0	n/a	n/a	-26	-2	35
BA	74902	5.0	n/a	n/a	-26	-2	35
PW	74902	5.0	n/a	n/a	-26	-2	35
NC	74902	5.0	n/a	n/a	-26	-2	35
PB	37506	1.0	n/a	n/a	n/a	n/a	25
OS	26405	1.0	10	79	n/a	n/a	45
OH	74902	5.0	n/a	n/a	-26	-2	35

4.5 Crown Competition Factor

The EM variant uses crown competition factor (*CCF*) as a predictor variable in some growth relationships. Crown competition factor (Krajicek and others 1961) is a relative measurement of stand density that is based on tree diameters. Individual tree CCF_t values estimate the percentage of an acre that would be covered by the tree's crown if the tree were open-grown. Stand *CCF* is the summation of individual tree (CCF_t) values. A stand *CCF* value of 100 theoretically indicates that tree crowns will just touch in an unthinned, evenly spaced stand. Crown competition factor for an individual tree is calculated using equation {4.5.1}. All species coefficients are shown in table 4.5.1.

{4.5.1} *CCF* equations for individual trees

$DBH \geq$ d": $CCF_t = R_1 + (R_2 * DBH) + (R_3 * DBH\text{^}2)$
0.1" < DBH < d": $CCF_t = R_4 * DBH \text{ ^}R_5$
$DBH \leq$ 0.1": $CCF_t = 0.001$

where:

CCF_t	is crown competition factor for an individual tree
DBH	is tree diameter at breast height
$R_1 – R_5$	are species-specific coefficients shown in table 4.5.1
d	is 10.0" for green ash, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, and other hardwood; 1.0" for all other species

Table 4.5.1 Coefficients for CCF equation {4.5.1} in the EM variant.

Species Code	Model Coefficients				
	R_1	R_2	R_3	R_4	R_5
WB	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
LM	0.01925	0.01676	0.00365	0.009187	1.7600
LL	0.03	0.0216	0.00405	0.011402	1.7560
RM	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
GA	0.03	0.0215	0.00363	0.011109	1.7250
AS	0.03	0.0238	0.00490	0.008915	1.7800
CW	0.03	0.0215	0.00363	0.011109	1.7250
BA	0.03	0.0215	0.00363	0.011109	1.7250
PW	0.03	0.0215	0.00363	0.011109	1.7250
NC	0.03	0.0215	0.00363	0.011109	1.7250
PB	0.03	0.0238	0.00490	0.008915	1.7800
OS	0.0204	0.0246	0.0074	0.011109	1.7250
OH	0.03	0.0215	0.00363	0.011109	1.7250

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 1.0" for green ash, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, and other hardwood, and is set to 3.0" for all other species in the EM variant except Rocky Mountain juniper. Rocky Mountain 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 and diameter growth is estimated from height growth. These relationships are discussed in the following sections.

4.6.1 Small Tree Height Growth

The small-tree height growth equations in the EM variant predict 5-year height growth (*HTG*) for whitebark pine, western larch, Douglas-fir, limber pine, subalpine larch, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood, and 10-year height growth for Rocky Mountain juniper, green ash, quaking aspen, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, paper birch, and other hardwood. Different equation forms are used for different species.

Height growth for whitebark pine, western larch, Douglas-fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood in the EM variant is estimated as a function of crown ratio, and point crown competition factor using equation {4.6.1.1}. Coefficients for this equation are shown in table 4.6.1.1.

{4.6.1.1} $HTG = \exp[c_1 + (c_2 * \ln(CCF))] + CR * \exp[c_3 + (c_4 * \ln(CCF))]$

where:

HTG	is estimated 5-year height growth
CCF	is point crown competition factor (bounded to $25 \leq CCF \leq 300$)
CR	is a tree's live crown ratio (compacted) expressed as a percent
$c_1 - c_4$	are species-specific coefficients shown in table 4.6.1.1

Table 4.6.1.1 Coefficients for equation {4.6.1.1} in the EM variant.

Species Code	Model Coefficients			
	c_1	c_2	c_3	c_4
WB	1.17527	-0.42124	-2.56002	-0.58642
WL	1.17527	-0.42124	-2.56002	-0.58642
DF	-4.35709	0.67307	-2.49682	-0.51938
LP	-0.90086	0.16996	-1.50963	-0.61825
ES	-0.55052	-0.02858	-2.26007	-0.67115
AF	-4.35709	0.67307	-2.49682	-0.51938
PP	0.405	0	-1.50963	-0.61825
OS	1.17527	-0.42124	-2.56002	-0.58642

The remaining species in the EM variant use small-tree height growth equations taken from other variants.

Height growth for subalpine larch is estimated using equation {4.6.1.2) which is the subalpine fir equation from the Northern Idaho variant.

{4.6.1.2} $HTG = \exp[x]$

$$X = -0.2785 + HAB + 1.0667 + 0.3740 * \ln(HT) - 0.00391 * CCF - 0.22957 * BAL + 0.22157 * SL * \cos(ASP) - 0.12432 * SL * \sin(ASP) - 0.10987 * SL$$

where:

HTG	is estimated 5-year height growth
HAB	is a habitat type dependent intercept shown in table 4.6.1.2, mapped as shown in table 4.6.1.3 and Appendix B table 11.2.2
CCF	is stand crown competition factor
BAL	is total basal area in trees larger than the subject tree
ASP	is stand aspect
SL	is stand slope
HT	is tree height
$c_1 - c_2$	are species-specific coefficients shown in table 4.6.1.1

Table 4.6.1.2 *HAB* values by habitat class for equation {4.6.1.2} in the EM variant.

	Habitat Class				
Code	**1**	**2**	**3**	**4**	**5**
LL	-0.2146	-0.0941	-0.4916	-0.3582	0.0

Table 4.6.1.3 Habitat class by mapped NI habitat code, Appendix B table 11.2.2, for HAB values in equation {4.6.1.2} in the EM variant.

Mapped NI Habitat Code	Habitat Class
130	4
170	4
250	4
260	4
280	4
290	4
310	4
320	4
330	4
420	4
470	4
510	4
520	3
530	2
540	5
550	5
570	5
610	5
620	1
640	4

Mapped NI Habitat Code	Habitat Class
660	4
670	4
680	4
690	4
710	4
720	4
730	1
830	3
850	3
999	4

Height growth for limber pine is estimated using equation {4.6.1.3} which is from the Tetons variant.

{4.6.1.3} *HTG* = exp[1.17527 - (0.42124 * ln(*TPCCF*))] + *CR* * exp[-2.56002 - (0.58642 * ln(*TPCCF*))]

where:

HTG is estimated 5-year height growth
TPCCF is total crown competition factor on the inventory point where the tree is established (bounded to $25 \leq TPCCF \leq 300$)
CR is a tree's live crown ratio (compacted) expressed as a percent

For Rocky Mountain juniper, potential 10-year height growth is estimated using equation {4.6.1.4}. The reduction proportion due to stand density (*PCTRED*) is computed with equation {4.6.1.5} and the reduction proportion due to crown ratio (*VIGOR*) is computed with equation {4.6.1.6}, to determine an estimated 10-year height growth as shown in equation {4.6.1.7}. These equations are from the Utah variant.

{4.6.1.4} *POTHTG* = (*SI* / 10.0) * ((*SI* * 1.5) - *HT*) / (*SI* * 1.5)

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

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

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

{4.6.1.7} *HTG = POTHTG * PCTRED * VIGOR*

where:

HTG is estimated 10-year height growth
POTHTG is potential 10-year height growth
PCTRED is reduction in height growth due to stand density (bounded: $0.01 \leq PCTRED \leq 1.0$)
HT_{Avg} is average height of the 40 largest diameter trees in the stand
HT is total tree height at the beginning of the projection cycle

CR	is a tree's live crown ratio (compacted) expressed as a proportion
CCF	is stand crown competition factor
VIGOR	is reduction in height growth due to tree vigor (bounded to $VIGOR \leq 1.0$)
SI	is species site index bounded by ($SITELO + 0.5$) and *SITEHI*
SITELO	is lower end of the site range for this species shown in table 4.6.1.4
SITEHI	is upper end of the site range for this species shown in table 4.6.1.4

Green ash, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, and other hardwood use the cottonwood species equations from the Central Rockies variant. Potential height growth is estimated using equation {4.6.1.8}, and then adjusted based on stand density (*PCTRED*) and crown ratio (*VIGOR*) as shown in equations {4.6.1.5} and {4.6.1.9} respectively, to determine an estimated height growth as shown in equation {4.6.1.7}.

{4.6.1.8} $POTHTG = SITE / (15.0 - 4.0 * (SI - SITELO) / (SITEHI - SITELO))$

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

where:

POTHTG	is potential 10-year height growth
CR	is a tree's live crown ratio (compacted) expressed as a proportion
VIGOR	is reduction in height growth due to tree vigor (bounded to $VIGOR \leq 1.0$)
SI	is species site index bounded by ($SITELO + 0.5$) and *SITEHI*
SITE	is species site index
SITELO	is lower end of the site range for this species shown in table 4.6.1.4
SITEHI	is upper end of the site range for this species shown in table 4.6.1.4

Height growth for quaking aspen and paper birch is obtained from an aspen height-age curve (Shepperd 1995). Because Shepperd's original curve seemed to overestimate height growth, the EM variant reduces the estimated height growth by 25 percent (shown in equation {4.6.1.10}). 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} $HTG = (26.9825 * A^{1.1752}) * 0.375 * (1 + [(SI - SITELO) / (SITEHI - SITELO)]$

where:

HTG	is estimated 10-year height growth for the cycle
SI	is species site index bounded by *SITELO* and *SITEHI*
SITELO	is lower end of the site range for this species shown in table 4.6.1.4
SITEHI	is upper end of the site range for this species shown in table 4.6.1.4
A	is tree age

If the site index for the species is less than or equal to the lower site limit, it is set to the lower limit + 0.5 for the calculation of RELSI. Similarly, if the site index for the species is greater than the upper site limit, it is set to the upper site limit for the calculation of RELSI.

Table 4.6.1.4 *SITELO* and *SITEHI* values for equations {4.6.1.8} and {4.6.1.10} in the EM variant.

Species Code	*SITELO*	*SITEHI*
RM	5	15
GA	30	120
AS	30	70
CW	30	120
BA	30	120
PW	30	120
NC	30	120
PB	30	70
OH	30	120

For all species, a small random error is then added to the height growth estimate. The estimated height growth 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. For example, the closer a tree's *DBH* value is to the minimum diameter (X_{min}), the more the growth estimate will be weighted towards the small-tree growth model. The closer a tree's *DBH* value is to the maximum diameter (X_{max}), the more the growth estimate will be weighted towards the large-tree growth model. If a tree's *DBH* value falls outside of the range given by X_{min} and X_{max}, then the model will use only the small-tree or large-tree growth model in the growth estimate. The weight applied to the growth estimate is calculated using equation {4.6.1.11}, and applied as shown in equation {4.6.1.12}. The range of diameters for each species is shown in table 4.6.1.5.

{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 4.6.1.5 X_{min} and X_{max} values for equation {4.6.1.11} in the EM variant.

Species Code	X_{min}	X_{max}
WB	1.5	3.0
WL	1.5	3.0
DF	1.5	3.0
LM	1.5	3.0
LL	2.0	10.0
RM	90.0	99.0
LP	1.5	3.0
ES	1.5	3.0
AF	1.5	3.0
PP	1.5	3.0
GA	0.5	2.0
AS	2.0	4.0
CW	0.5	2.0
BA	0.5	2.0
PW	0.5	2.0
NC	0.5	2.0
PB	2.0	4.0
OS	1.5	3.0
OH	0.5	2.0

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. For most species in the EM variant, 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. By definition, diameter growth is zero for trees less than 4.5 feet tall.

For whitebark pine, western larch, Douglas-fir, limber pine, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood, small-tree diameter is estimated using equation {4.6.2.1} or {4.6.2.2}, and coefficients shown in table 4.6.2.1.

{4.6.2.1} $DBH = [b_1 * (HT - 4.5) * CR + b_2 * (HT - 4.5) * PCCF + b_3 * CR + b_4 * (HT - 4.5)] + 0.3$

{4.6.2.2} $DBH = b_1 + (b_2 * HT) + (b_3 * CR) + (b_4 * PCCF)$

where:

DBH	is tree diameter at breast height
HT	is tree height
CR	is a tree's live crown ratio (compacted) expressed as a percent
PCCF	is crown competition factor on the inventory point where the tree is established
$b_1 - b_4$	are species-specific coefficients shown in table 4.6.2.1

Table 4.6.2.1 Coefficients (b_1 - b_4) for equations {4.6.2.1} and {4.6.2.2} in the EM variant.

Species Code	Equation Used	Model Coefficients			
		b_1	b_2	b_3	b_4
WB	{4.6.2.1}	0.000231	-0.00005	0.001711	0.17023
WL	{4.6.2.1}	0.000231	-0.00005	0.001711	0.17023
DF	{4.6.2.2}	-0.28654	0.13469	0.002736	0.00036
LM	{4.6.2.1}	0.000231	-0.00005	0.001711	0.17023
LP	{4.6.2.2}	-0.41227	0.16944	0.003191	-0.0022
ES	{4.6.2.2}	0.04125	0.17486	-0.00237	-0.0007
AF	{4.6.2.2}	-0.15906	0.15323	0	0
PP	{4.6.2.1}	0.000335	-0.0002	0.002621	0.15622
OS	{4.6.2.1}	0.000231	-0.00005	0.001711	0.17023

For green ash, quaking aspen, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, paper birch, and other hardwood these two predicted diameters are estimated using the species-specific height-diameter relationships discussed in section 4.1.

For subalpine larch, these two predicted diameters are estimated using equations {4.6.2.3} – {4.6.2.6}.

{4.6.2.3} $DHAT = 0.0658 * (HT - 4.5)^{1.3817} + DADJ$

{4.6.2.4} $DADJ = DELMAX * RELH * RELH - 2 * DELMAX * RELH + 0.65$

{4.6.2.5} $RELH = (HT - 4.5) / (AH - 4.5)$

{4.6.2.6} $DELMAX = (AH / 36) * (0.01232 * CCF - 1.75)$

where:

DHAT is estimated tree diameter at breast height
HT is tree height
DADJ is an adjustment factor to correct for bias, relative tree size, and stand density
RELH is relative tree height (bounded $0 \leq RELHT \leq 1$)
AH is average height of the 40 largest diameter trees
DELMAX is an adjustment factor based on relative tree size and stand density (bounded $DELMAX \leq 0$)
CCF is stand crown competition factor

Rocky Mountain juniper uses equation {4.6.2.7} to estimate the diameters.

{4.6.2.7} $DHAT = (HT - 4.5) * 10 / (SI - 4.5)$

where:

DHAT is estimated tree diameter at breast height
HT is tree height
SI is species site index

4.7 Large Tree Growth Relationships

Trees are considered "large trees" for FVS modeling purposes when they are equal to, or larger than, some threshold diameter. This threshold diameter is set to 3.0" for most species in the EM variant. For green ash (11), black cottonwood (13), balsam poplar (14), plains cottonwood (15), narrowleaf cottonwood (16) and other hardwood (19) the threshold diameter is 1.0". Rocky Mountain juniper (6) only 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.

For whitebark pine, western larch, Douglas-fir, limber pine, subalpine larch, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood, the EM variant predicts diameter growth using equation {4.7.1.1.}. Coefficients for this equation are shown in tables 4.7.1.1 - 4.7.1.6.

{4.7.1.1} $\ln(DDS) = b_1 + (b_2 * EL) + (b_3 * EL^2) + (b_4 * \sin(ASP) * SL) + (b_5 * \cos(ASP) * SL) + (b_6 * SL) + (b_7 * SL^2) + (b_8 * \ln(DBH)) + (b_9 * \ln(BAL)) + (b_{10} * CR) + (b_{11} * CR^2) + (b_{12} * BAL / (\ln(DBH + 1.0))) + (b_{13} * CCF^2) + (b_{14} * \ln(CCF)) + (b_{15} * PCCF * DUM_1) + (b_{16} * PCCF * DUM_2) + (b_{17} * DBH^2) + (b_{18} * 0.01 * CCF) + (b_{19} * SI) + HAB$

where:

DDS	is the predicted periodic change in squared inside-bark diameter
EL	is stand elevation in hundreds of feet
ASP	is stand aspect (for limber pine, Rocky Mountain juniper, aspen and paper birch, *ASP* = -0.7854)
SL	is stand slope for limber pine and subalpine larch; is stand slope / 10 for whitebark pine, western larch, Douglas-fir, lodgepole pine, Engelmann spruce, subalpine fir, and ponderosa pine; is equal to 0 for other softwood
CR	is a tree's live crown ratio (compacted) expressed as a proportion
DBH	is tree diameter at breast height
BAL	is total basal area in trees larger than the subject tree (*BAL*/100. is used as the variable for limber pine and subalpine larch)
CCF	is stand crown competition factor
PCCF	is crown competition factor on the inventory point where the tree is established
HAB	is a plant association code dependent coefficient shown in tables 4.7.1.5 and 4.7.1.6

DUM_{1-2}	are dummy variables depending on whether or not the stand is managed:		
	$DUM_1 = 0$, $DUM_2 = 1.0$	for unmanaged stands	
	$DUM_1 = 1.0$, $DUM_2 = 0$	for managed stands	
SI	is species specific site index		
b_1	is a location and species specific coefficient shown in tables 4.7.1.2 and 4.7.1.3		
b_2 - b_{16}	are species-specific coefficients shown in table 4.7.1.1		
b_{17}	is a location and species specific coefficient shown in tables 4.7.1.1 and 4.7.1.4		
b_{18}	is a location and species specific coefficient shown in table 4.7.1.1 and 4.7.1.7		
b_{19}	is a species specific coefficient shown in table 4.7.1.1		

Table 4.7.1.1 Coefficients (b_2- b_{19}) for equation 4.7.1.1 in the EM variant.

	Species Code							
Coefficient	**WB**	**WL**	**DF**	**LP**	**ES**	**AF**	**PP**	**OS**
b_2	-0.00565	-0.00565	-0.00196	-0.01234	0.08677	-0.00885	-0.07453	-0.00565
b_3	0	0	0	0	-0.00072	-0.00002	0.0006	0
b_4	-0.01606	-0.01606	0.06124	-0.00393	0.03982	0.01463	0.20328	-0.01606
b_5	0.00270	0.00270	-0.04290	-0.02355	-0.15989	-0.20925	0.06497	0.00270
b_6	-0.20011	-0.20011	-0.39500	-0.21964	0.06898	-0.03350	-0.95238	-0.20011
b_7	0	0	0	0	-0.34251	-0.11164	0.61813	0
b_8	0.80110	0.80110	0.82617	0.75719	0.83323	0.89571	0.58932	0.80110
b_9	0.00064	0.00064	0.00216	0.00556	0.00443	0.00350	0.00710	0.00064
b_{10}	1.02878	1.02878	1.41015	1.43611	1.10040	1.30934	1.94874	1.02878
b_{11}	-0.45448	-0.45448	-0.55362	-0.44926	0	-0.17348	-0.88761	-0.45448
b_{12}	-0.00328	-0.00328	-0.00889	-0.01282	-0.01281	-0.00764	-0.02316	-0.00328
b_{13}	0	0	0.000003	0.000002	0.000002	-0.000003	0.000005	0
b_{14}	-0.25717	-0.25717	-0.11974	-0.12332	0	0	0	-0.25717
b_{15}	0	0	-0.00211	-0.00120	-0.00155	-0.00164	-0.00297	0
b_{16}	0	0	-0.00232	-0.00145	-0.00123	-0.00232	-0.00254	0
b_{17}	0	0	**	-0.000402	-0.000034	0	**	0
b_{18}	0	0	0	0	0	0	0	0
b_{19}	0	0	0	0	0	0	0	0

Table 4.7.1.1 Continued Coefficients (b_2- b_{19}) for equation 4.7.1.1 in the EM variant.

	Species Code	
Coefficient	**LM**	**LL**
b_2	0	0.06313
b_3	0	-0.000676
b_4	-0.01752	-0.06862
b_5	-0.609774	-0.12473
b_6	-2.05706	0.30070
b_7	2.113263	-0.62224
b_8	0.213947	0.86240

Coefficient	Species Code	
	LM	LL
b_9	-0.358634	0
b_{10}	1.523464	0.52044
b_{11}	0	0.86236
b_{12}	0	-0.51270
b_{13}	0	0
b_{14}	0	0
b_{15}	0	0
b_{16}	0	0
b_{17}	-0.0006538	-0.000283
b_{18}	-0.199592	*
b_{19}	0.001766	0

*See table 4.7.1.7, as indexed by values in tables 4.7.1.6 and 11.2.2

**See table 4.7.1.4

Table 4.7.1.2 b_1 values by location class for equation {4.7.1.1} in the EM variant.

Location Class	Species Code									
	WB	WL	DF	LM	LL	LP	ES	AF	PP	OS
1	1.5675	1.5675	1.10349	1.568742	0	1.75497	-2.45844	0.46110	3.57069	1.5675
2	0	0	1.55392	0	0	1.89439	-2.14138	-0.16517	3.45044	0
3	0	0	1.04495	0	0	1.63227	-2.55288	0.35319	3.67551	0
4	0	0	1.27679	0	0	1.65474	-2.42650	0.64719	0	0
5	0	0	0	0	0	1.51043	0	0.40140	0	0
6	0	0	0	0	0	0	0	0.33757	0	0

Table 4.7.1.3 Location class by species and forest code for assigning b_1 values in equation {4.7.1.1} in the EM variant.

Location Code	Species Code									
	WB	WL	DF	LM	LL	LP	ES	AF	PP	OS
102 - Beaverhead	1	1	1	1	1	1	1	1	1	1
108 - Custer	1	1	2	1	1	2	2	2	2	1
109 - Deerlodge	1	1	3	1	1	3	3	3	3	1
111 - Gallatin	1	1	4	1	1	2	2	4	3	1
112 - Helena	1	1	3	1	1	4	3	5	2	1
115 - Lewis and Clark	1	1	1	1	1	5	4	6	2	1

Table 4.7.1.4 Douglas-fir and ponderosa pine b_{17} values by location code for equation {4.7.1.1} in the EM variant.

Location Code	Species Code	
	DF	PP
102	-0.000251	-

		0.000248
108	0	-0.000991
109	-0.000412	-0.000248
111	-0.000251	-0.000248
112	0	-0.000248
115	-0.000412	-0.000248

Table 4.7.1.5 *HAB* values by habitat class for equation {4.7.1.1} in the EM variant.

Habitat Class	Species Code							
	WB	WL	DF	LP	ES	AF	PP	OS
1	0	0	0	0	0	0	0	0
2	-0.20842	-0.20842	-0.20240	-0.06686	0.23303	0.12967	-0.19356	-0.20842
3	0.01545	0.01545	-0.03260	0.00921	-0.01746	0.33768	-0.07999	0.01545
4	0.29742	0.29742	0.05559	-0.17011	0.11129	0.25940	0.03500	0.29742
5	0	0	-0.12847	-0.11806	0.19065	0.48657	-0.13880	0
6	0	0	-0.07100	-0.22504	0.40362	0	-1.04929	0
7	0	0	-0.31860	0.06528	0	0	-0.32378	0
8	0	0	0	0.14340	0	0	0	0

Table 4.7.1.5 Continued *HAB* values by habitat class for equation {4.7.1.1} in the EM variant.

Habitat Class	Species Code	
	LM	LL
1	0	-0.96389
2	0	-0.72415
3	0	-0.57308
4	0	-0.82218
5	0	-1.24093
6	0	-1.10746
7	0	0
8	0	0

Table 4.7.1.6 Habitat class by plant association code and species in the EM variant.

EM Habitat Code	Species Code							
	WB	WL	DF	LP	ES	AF	PP	OS
10	4	4	5	1	4	3	1	4
65	4	4	5	7	4	2	1	4
70	3	3	7	6	4	2	1	3
74	3	3	4	1	4	2	1	3
79	3	3	4	2	4	2	1	3
91	3	3	7	6	4	2	1	3
92	2	2	7	6	4	2	1	2
93	2	2	3	8	4	2	1	2
95	2	2	5	7	4	2	1	2
100	2	2	5	1	4	2	1	2
110	2	2	5	1	4	2	1	2
120	2	2	6	8	4	2	1	2
130	2	2	4	3	4	2	2	2
140	2	2	4	8	4	2	2	2
141	2	2	4	2	4	2	2	2
161	2	2	4	1	4	2	3	2
170	2	2	4	8	4	2	3	2
171	2	2	4	1	4	2	2	2
172	2	2	4	3	4	2	3	2
180	2	2	4	1	4	2	4	2
181	2	2	4	1	4	2	5	2
182	2	2	4	1	4	2	4	2
200	4	4	4	8	4	2	1	4
210	4	4	4	8	4	2	2	4
220	4	4	2	3	5	2	2	4
221	4	4	4	3	1	2	2	4
230	4	4	5	2	4	2	6	4
250	3	3	5	7	5	2	3	3
260	3	3	3	3	6	5	3	3
261	4	4	3	7	6	5	4	4
262	4	4	4	1	3	5	4	4
280	3	3	5	1	4	2	4	3
281	3	3	5	2	4	2	4	3
282	3	3	3	3	5	2	4	3
283	3	3	7	1	5	2	4	3
290	4	4	5	3	4	2	4	4
291	3	3	5	3	4	2	4	3
292	3	3	5	1	4	2	4	3
293	3	3	7	1	4	2	4	3

EM Habitat Code	Species Code							
	WB	WL	DF	LP	ES	AF	PP	OS
310	3	3	5	7	3	5	5	3
311	3	3	4	3	3	5	5	3
312	3	3	4	7	3	5	5	3
313	3	3	5	1	4	5	5	3
315	3	3	5	1	4	5	5	3
320	3	3	2	2	4	5	5	3
321	4	4	6	3	2	5	5	4
322	3	3	5	3	5	5	5	3
323	3	3	3	1	6	5	5	3
330	4	4	3	2	4	5	7	4
331	4	4	3	2	4	5	7	4
332	4	4	3	2	4	5	7	4
340	4	4	3	3	5	5	7	4
350	3	3	7	7	4	2	7	3
360	3	3	7	6	4	5	7	3
370	2	2	7	1	4	5	3	2
371	2	2	5	1	4	5	3	2
400	3	3	5	2	4	4	7	3
410	3	3	6	7	5	4	7	3
430	3	3	6	3	5	4	7	3
440	2	2	6	8	5	4	7	2
450	3	3	6	8	4	4	7	3
460	3	3	5	7	5	4	7	3
461	2	2	5	7	4	4	7	2
470	3	3	5	7	4	4	7	3
480	3	3	3	8	2	4	7	3
591	3	3	7	6	2	4	7	3
610	3	3	3	8	1	3	7	3
620	3	3	3	6	4	3	7	3
624	3	3	6	1	4	3	7	3
625	3	3	6	7	1	3	7	3
630	3	3	3	3	2	3	7	3
632	3	3	3	6	4	1	7	3
640	3	3	3	2	5	3	7	3
641	3	3	3	3	5	2	7	3
642	3	3	3	2	5	2	7	3
650	3	3	5	2	3	2	7	3
651	2	2	6	2	4	2	7	2
653	2	2	6	2	2	2	7	2

EM Habitat Code	Species Code							
	WB	WL	DF	LP	ES	AF	PP	OS
654	2	2	5	7	2	4	7	2
655	3	3	5	2	4	2	7	3
660	3	3	5	3	2	4	7	3
661	2	2	5	1	4	4	7	2
662	2	2	4	7	4	3	7	2
663	3	3	3	2	2	3	7	3
670	3	3	5	2	3	2	7	3
674	3	3	5	2	4	2	7	3
690	1	1	7	5	4	2	7	1
691	3	3	7	1	4	2	7	3
692	3	3	7	2	3	2	7	3
700	3	3	5	7	4	3	7	3
710	3	3	6	8	4	3	7	3
720	3	3	6	2	4	4	7	3
730	3	3	5	4	3	2	7	3
731	3	3	5	2	4	3	7	3
732	3	3	5	5	4	2	7	3
733	2	2	5	2	2	3	7	2
740	3	3	5	1	2	4	7	3
750	3	3	4	3	2	3	7	3
751	3	3	6	3	6	3	7	3
770	3	3	1	1	5	3	7	3
780	3	3	5	1	4	3	7	3
790	4	4	3	1	4	3	7	4
791	3	3	3	3	3	5	7	3
792	2	2	5	1	5	3	7	2
810	3	3	5	6	4	2	7	3
820	2	2	5	6	3	2	7	2
830	3	3	5	6	4	2	7	3
832	2	2	5	6	4	2	7	2
850	3	3	5	2	4	2	7	3
860	2	2	5	6	4	2	7	2
870	2	2	5	6	4	2	7	2
900	3	3	4	6	6	5	7	3
910	3	3	4	5	6	5	7	3
920	3	3	4	3	6	5	7	3
930	3	3	4	6	6	5	7	3
940	3	3	4	3	6	5	7	3
950	4	4	4	7	6	5	7	4

Table 4.7.1.6 Continued Habitat class and b_{18} coefficient index by NI mapping index (Appendix B table 11.2.2) and species in the EM variant.

NI Mapping Index	Species Code		
	LM	LL	b_{18} Index LL
1	1	6	3
2	1	6	3
3	1	6	3
4	1	6	3
4	1	6	3
6	1	6	3
7	1	6	3
8	1	6	3
9	1	6	3
10	1	6	3
11	1	6	3
12	1	6	3
13	1	1	1
14	1	2	1
15	1	3	1
16	1	3	1
17	1	4	1
18	1	3	1
19	1	1	1
20	1	6	3
21	1	6	1
22	1	6	1
23	1	6	2
24	1	6	2
25	1	6	1
26	1	6	3
27	1	1	1
28	1	5	1
29	1	5	3
30	1	6	3

Table 4.7.1.7 Subalpine larch *CCF* coefficient, equation 4.7.1.1, as determined by the b_{18} Index value by NI habitat mapping index, table 4.7.1.6

b_{18} Index	LL Coefficient
1	-0.01598
2	-0.04477
3	-0.07392

Large-tree diameter growth for Rocky Mountain juniper is predicted using equations from the UT variant identified in equation set {4.7.1.2}. Diameter at the end of the growth cycle is predicted first. Then diameter growth is calculated as the difference between the diameters at the beginning of the cycle and end of the cycle, adjusted for bark ratio. While not shown here, this diameter growth estimate is eventually converted to the *DDS* scale.

{4.7.1.2} $DF = 0.25897 + 1.03129 * DBH - 0.0002025464 * BA + 0.00177 * SI$

$DG = (DF - DBH) * BRATIO$

where:

DF	is tree diameter outside-bark at the end of the cycle
DBH	is tree diameter outside-bark at the start of the cycle
BA	is total stand basal area
SI	is species site index
DG	is tree diameter growth
BRATIO	is species-specific bark ratio

Large-tree diameter growth for quaking aspen and paper birch is predicted using the aspen equation from the UT variant identified in equation set {4.7.1.3}. 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} $POTGR = (0.4755 - 0.0000038336 * DBH^{4.1488}) + (0.0451 * CR * DBH^{0.67266})$

$MOD = 1.0 - \exp(-FOFR * GOFAD * ((310-BA)/310)^{0.5})$
$FOFR = 1.07528 * (1.0 - \exp(-1.89022 * DBH / QMD))$
$GOFAD = 0.21963 * (QMD + 1.0)^{0.73355}$
$PREDGR = POTGR * MOD * (.48630 + 0.01258 * SI)$

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 bounded $BA \leq 310$

QMD	is stand quadratic mean diameter
PREDGR	is predicted diameter growth
SI	is species site index

Large-tree diameter growth for green ash, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, and other hardwood is predicted using equations from the CR variant identified in equation set {4.7.1.5}. Diameter at the end of the growth cycle is predicted first. Then diameter growth is calculated as the difference between the diameters at the beginning of the cycle and end of the cycle, adjusted for bark ratio. While not shown here, this diameter growth estimate is eventually converted to the *DDS* scale.

{4.7.1.6} $DF = 0.24506 + 1.01291 * DBH - 0.00084659 * BA + 0.00631 * SI$

$DG = (DF - DBH) * BRATIO$

where:

DF	is tree diameter at breast height at the end of the cycle (bounded $DBH \leq DF \leq$ 36")
DG	is tree diameter growth
DBH	is tree diameter at breast height at the start of the cycle
BA	is total stand basal area
SI	is species site index
BRATIO	is species-specific bark ratio
DDS	is the predicted periodic change in squared inside-bark diameter

4.7.2 Large Tree Height Growth

The height growth functions used for the original 8 species in the EM variant are not similar to those reported by Wykoff (1986). For these 8 species, a potential height growth is calculated for a tree and then reduced to reflect suppression effects. This technique is described in specific terms in Wensel and others (1978) and Richie and Hann (1986). These authors constructed site curves and then height growth curves with modifiers off the same data. In the EM variant, the site curves referenced are those described in section 3.4.

Potential 10-year height growth can then be calculated by incrementing the approximate age (or more appropriately called an effective age), by 10 years and solving for a new height. Potential height growth is the difference in the heights at two points in time. For a specific site, this would be the best growth expected, if the tree is to follow the site or height growth curve. This potential growth is reduced for suppression and other tree characteristics, and adjusted to the projection cycle length.

Potential height growth is calculated by using equations {4.7.2.1} – {4.7.2.4}. Whitebark pine, western larch, lodgepole pine, and other softwood use equation {4.7.2.1}. Douglas-fir uses equation {4.7.2.2}. Engelmann spruce and subalpine fir use equation {4.7.2.3} and ponderosa pine uses equation {4.7.2.4} to calculate potential height growth. Two modifiers are calculated using equations {4.7.2.5} and {4.7.2.6} are applied to the potential height growth to obtain a final height growth (equation {4.7.2.7}).

Note: *MOD2* is from a paper by Richie and Hahn (1986) for height growth in the Oregon Cascades. The relationship is assumed to be consistent with tree growth in the Northern Rockies.

{4.7.2.1} Used for whitebark pine, Western larch, lodgepole pine, and other softwood

$POTHTG = -2.3733 + 0.0016 * (EFAG10^2 - EFAGE^2) + (0.149 * SI100) - (0.00005 * SI100 * (EFAG10^2 - EFAGE^2))$

$EFAGE = (-B + TEM^{0.5}) / (C * 2.0)$

$TEM = B^2 - (4 * A * C)$ bounded to be ≥ 0.0

$A = 9.72443 - (0.11375 * SI_{100}) - HT$

$B = -0.23733 + (0.0149 * SI_{100})$

$C = 0.0016 - (0.00005 * SI_{100})$

$EFAG10 = EFAGE + 10.0$

{4.7.2.2} Used for Douglas-fir

$POTHTG = (42.397 * (SI_{50} - 4.5)^{0.3197}) / [1.0 + \exp(9.7278 - 1.2934 * \ln(EFAG10) - (\ln(SI_{50} - 4.5) * 1.0232))] - (HT - 4.5)$

$EFAG10 = 10 + \exp[(TERM + 1.0232 * \ln(SI_{50} - 4.5) - 9.7278) / -1.2934]$

$TERM = \ln[(42.397 * (SI_{50} - 4.5)^{0.3197}) / ((SI_{50} - 4.5) -1)]$

{4.7.2.3} Used for Engelmann spruce and subalpine fir

$POTHTG = [SI_{100} * (1 - 0.931764 * \exp(-0.01679 * EFAG10))^{1.43345}] - HT$

$EFAG10 = 10 + (TERM / -0.01679)$

$TERM = \ln[(1 - (HT / SI_{100})^{0.69762}) / 0.931764]$

{4.7.2.4} Used for ponderosa pine

$POTHTG = [(3.635794 * SI_{100}^{0.916307}) / (1 + \exp(6.09478 - 0.96483 * \ln(EFAG10) - 0.277025 * \ln(SI_{100})))] - HT$

$EFAG10 = 10 + \exp[(TERM - 6.09478 + 0.277025 * \ln(SI_{100})) / -0.96483]$

$TERM = \ln[((3.635794 * SI_{100}^{0.916307}) / HT) - 1]$

{4.7.2.5} $MOD1 = 0.706 * (1 - \exp(-10.19 * CR)) * (1 - \exp(-1.8158 * DG))^{0.944} + (0.0265 * HT)$

{4.7.2.6} $MOD2 = \exp(2.54119 * ((RELHT^{0.250537}) -1.0))$

{4.7.2.7} $HTG = POTHTG * MOD1 * MOD2$

where:

POTHTG	is potential height growth
SI_{50}, SI_{100}	are species site index values based on a 50-year and 100-year base age, respectively
HT	is tree height
CR	is a tree's live crown ratio (compacted) expressed as a proportion
DG	is diameter growth for the cycle
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand

MOD1, *MOD2* are height growth modifiers
HTG is estimated height growth for the cycle
EFAGE is estimated effective age of the tree at the start of the projection cycle
EFAG10 is EFAGE plus 10 years
A, B, C, TEM,
TERM are intermediate variables used in the calculations

Subalpine larch uses equation set {4.7.2.8} to estimate large tree height growth. This is the subalpine fir equation from the Northern Idaho variant.

{4.7.2.8} $HTG = \exp[x] + .4809$

$X = HAB - 0.5478 + b_1 * HT^2 - 0.1997 * \ln(DBH) + 0.23315 * \ln(HT) + b_2 * \ln(DG)$

where:

HTG is estimated height growth for the cycle (bounded to be $\geq$ 0.1 foot)
HAB is a plant association code dependent intercept shown in table 4.7.2.1
HT is tree height at the beginning of the cycle
DBH is tree diameter at breast height
DG is diameter growth for the cycle
b_1, b_2 are habitat-dependent coefficients shown in table 4.7.2.1

Table 4.7.2.1 Coefficients (b_1, b_2, and *HAB*) by NI mapping index (Appendix B table 11.2.2) for the subalpine larch height-growth equation in the EM variant.

NI Mapping Index	Coefficient		
	b_1	b_2	*HAB*
1, 2, 21, 27-30	-13.358E-5	0.62144	2.03035
3-9	-3.809E-5	1.02372	1.72222
10, 11	-3.715E-5	0.85493	1.19728
12, 19, 20, 22, 23	-2.607E-5	0.75756	1.81759
13	-5.200E-5	0.46238	2.14781
14	-1.605E-5	0.49643	1.76998
15-18	-3.631E-5	0.37042	2.21104
24-26	-4.460E-5	0.34003	1.74090

Limber pine, green ash, quaking aspen, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, paper birch, and other hardwood 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 4.7.2.2, 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 {4.7.2.9}.

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

$FBY1 = \ln[Y1/(1 - Y1)]$

$FBY2 = \ln[Y2/(1 - Y2)]$
$Y1 = (DBH - 0.1) / C_1$
$Y2 = (HT - 4.5) / C_2$

where:

HT	is tree height at the beginning of the cycle
DBH	is tree diameter at breast height at the beginning of the cycle (bounded to be $\geq$ 0.2 inch)
$C_1 - C_7$	are coefficients based on species and crown ratio class shown in table 4.7.2.2

The equation for limber pine is from the Tetons (TT) variant. The equation for quaking aspen is from the Utah (UT) variant, and is also used for green ash, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, paper birch, and other hardwood.

For green ash, quaking aspen, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, paper birch, and other hardwood, equation {4.7.2.10} is used to eliminate known bias in this methodology.

{4.7.2.10} $Z = Z + (0.1 - 0.10273 * Z + 0.00273 * Z^2)$ bounded $Z \geq 0$

For all 9 species using the SBB methodology, if the *Z* value is 2.0 or less, it is adjusted for all younger aged trees using equation {4.7.2.11}. This adjustment is done for trees with an estimated age greater than 10 years and less than 40 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.

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

CCF $\geq$ 100: CLOSUR = PCT / 100
CCF < 100: CLOSUR = 1
CR $\geq$ 75%: K = 1.1
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
CR	is tree crown ratio expressed as a percent

Estimated height 10 years into the future is calculated using equation {4.7.2.12}, and finally, 10-year height growth is calculated by subtraction using equation {4.7.2.13} and adjusted to the cycle length.

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

PSI = C8 * [(D10 – 0.1) / (0.1 + C1– D10)]^C9 * [exp(K)]
K = Z * [(1 - C7^2)^(0.5 / C6)]

{4.7.2.13}

for H10 > HT: HTG = H10 – HT
for H10 $\leq$ HT: HTG = 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
HTG	is estimated 10-year height growth
$C_1 – C_9$	are coefficients based on species and crown ratio class shown in table 4.7.2.3

Table 4.7.2.3 Coefficients in the large tree height growth model, by crown ratio, for species using the Johnson's SBB height distribution in the EM variant.

Coefficient*	LM	GA, AS, CW, BA, PW, NC, PB, OH
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

Rocky Mountain juniper uses the equations described in the small tree height growth model (see section 4.6.1) to calculate height growth for all sized trees.

5.0 Mortality Model

In the EM variant, a blend of two different types of mortality models are used depending upon the species. The original 8 species in this variant, whitebark pine, western larch, Douglas-fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood, use mortality models based on Stand Density Index; the remaining species use the Prognosis-type mortality model. These models are described in detail in sections 7.3.1 and 7.3.2 of Essential FVS: A User's Guide to the Forest Vegetation Simulator (Dixon 2002, abbreviated EFVS).

In the SDI-based mortality model there are two mortality rates. The first is background mortality which accounts for occasional tree deaths in stands when the stand density is below a specified level. The second is density-related mortality which determines mortality rates for individual trees based on their relationship with the stand's maximum stand density.

In the Prognosis-type mortality model there is only one mortality rate calculated.

5.1 SDI-Based Mortality Model

The equation used to calculate background mortality for whitebark pine, western larch, Douglas-fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood, is shown in equation {5.1.1}, and this is then adjusted to the length of the cycle by using a compound interest formula as shown in equation {5.1.2}. Coefficients for these equations are shown in table 5.1.1.

{5.1.1} $RI = [1 / (1 + \exp(p_1 + p_2 * DBH + p_3 * DBH^2))] * 0.5$

{5.1.2} $RIP = 1 - (1 - RI)^Y$

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_1 and p_2	are species-specific coefficients shown in Table 5.1.1

Table 5.1.1 Coefficients used in the background mortality equation {5.1.1} in the EM variant.

Species Code	p_1	p_2	p_3
WB	5.45676	-0.0118233	0
WL	5.26043	-0.0097092	0
DF	5.55086	-0.0129121	0
LP	3.87794	0.3078	-0.0174
ES	6.41265	-0.0127328	0
AF	5.88697	-0.0333752	0
PP	5.58766	-0.0052485	0

OS	7.47709	-0.0395156	0

When density-related mortality is in effect, mortality is determined based on the trajectory developed from the relationship between stand SDI and the maximum SDI for the stand. The equation used to calculate density-related mortality for whitebark pine, western larch, Douglas-fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood, is shown in equation {5.1.3}, and adjusted to the length of the cycle as shown.

{5.1.3} $RN = 1 - (1 - ((T - TN10)/T))^{(1/Y)}$

where:

RN is the final mortality rate adjusted to the length of the cycle
T is trees per acre at the start of a projection cycle
TN10 is trees per acre at the end of a projection cycle as determined by the stand development trajectory
Y is length of the current projection cycle in years

5.2 Prognosis-Type Mortality Rate

In the EM variant, limber pine, subalpine larch, Rocky Mountain juniper, green ash, quaking aspen, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, paper birch, and other hardwood use the Prognosis-type mortality model (Hamilton 1986). Two mortality rates are independently calculated and then weighted to form the final mortality rate applied to an individual tree record.

The first mortality rate estimate, *RA*, predicts individual tree mortality based on habitat type, species, diameter, diameter increment, estimated potential diameter increment, stand basal area, and a trees' diameter relative to the average stand diameter. The equation used to calculate the first mortality rate for these species is shown in equation set {5.2.1}.

{5.2.1} $RA = [1 / (1 + \exp(X))] * RADJ$

$X = (b_0 + 2.76253 + 0.22231 * \sqrt{DBH} + -0.0460508 * \sqrt{BA} + 11.2007 * G + 0.246301 * RDBH + ((-0.55442 + 6.07129 * G) / DBH))$

Bounded $-70 \leq X \leq 70$

$DBH > 5.0"$: $G = 0.90 / (0.20 + (0.05 * I)) * DG$
$RADJ = (1 - ((0.20 + (0.05 * I)) /20 + 1)^{-1.605}) / 0.06821$

$DBH \leq 5.0"$: $G = 2.50 / (0.20 + (0.05 * I)) * DG$
$RADJ = (1 - ((0.20 + (0.05 * I)) + 1)^{-1.605}) / 0.86610$

where:

RA is the estimated annual mortality rate
RADJ is a factor based on Reineke's (1933) Stand Density Index that accounts for expected differences in mortality rates on different habitat types and National Forests
DBH is tree diameter at breast height

BA	is total stand basal area
RDBH	is the ratio of tree *DBH* to the arithmetic mean stand d.b.h.
DG	is periodic annual d.b.h. increment for the previous growth period
G	is periodic annual d.b.h. increment for the previous growth period adjusted for differences in potential annual d.b.h. increment indexed by habitat type and National Forest
I	is a diameter growth index value determined by habitat type and location code for *I* values of trees with *DBH* > 5.0”, see table 5.2.2 for *I* values of trees with *DBH* $\leq$ 5.0”, see table 5.2.3
b_0	is a species-specific coefficient shown in table 5.2.1

Table 5.2.1 Values of the b_0 coefficient by species used in mortality equation {5.2.1} in the EM variant.

Species Code	b_0
LM	0
LL	0.2118
RM	0
GA	0
AS	0
CW	0
BA	0
PW	0
NC	0
PB	0
OH	0

Table 5.2.2 Index, *I*, values by forest and NI mapping index (Appendix B table 11.2.2) for trees with DBH > 5.0” in the EM variant.

NI Mapping Index	National Forest Location Code					
	102	108	109	111	112	115
1	7	7	7	7	7	7
2	6	6	6	6	7	7
3	6	6	6	6	7	7
4	6	6	6	6	7	7
5	6	6	6	6	6	6
6	6	6	6	6	7	7
7	5	5	5	5	5	5
8	6	6	6	6	6	6
9	5	5	5	5	7	7
10	6	6	6	6	6	6
11	6	6	6	6	6	6

NI Mapping Index	National Forest Location Code					
	102	108	109	111	112	115
12	6	6	6	6	7	7
13	6	6	6	6	7	7
14	8	8	8	8	9	9
15	7	7	7	7	9	9
16	7	7	7	7	8	8
17	7	7	7	7	9	9
18	7	7	7	7	8	8
19	7	7	7	7	8	8
20	5	5	5	5	5	5
21	3	3	3	3	3	3
22	4	4	4	4	5	5
23	3	3	3	3	4	4
24	4	4	4	4	5	5
25	4	4	4	4	5	5
26	6	6	6	6	7	7
27	5	5	5	5	5	5
28	1	1	1	1	2	2
29	1	1	1	1	4	4
30	6	6	6	6	7	7

Table 5.2.3 Index, *I*, values by forest and NI mapping index (Appendix B table 11.2.2) for trees with DBH < 5.0" in the EM variant.

NI Mapping Index	National Forest Location Code					
	102	108	109	111	112	115
1	30	30	30	30	31	31
2	29	29	29	29	29	29
3	29	29	29	29	30	30
4	29	29	29	29	31	31
5	28	28	28	28	29	29
6	28	28	28	28	30	30
7	27	27	27	27	29	29
8	31	31	31	31	33	33
9	27	27	27	27	31	31
10	27	27	27	27	30	30
11	28	28	28	28	29	29
12	31	31	31	31	34	34
13	32	32	32	32	34	34
14	32	32	32	32	35	35
15	31	31	31	31	34	34

NI Mapping Index	National Forest Location Code					
	102	108	109	111	112	115
16	31	31	31	31	34	34
17	32	32	32	32	35	35
18	31	31	31	31	33	33
19	31	31	31	31	33	33
20	25	25	25	25	27	27
21	23	23	23	23	23	23
22	24	24	24	24	26	26
23	23	23	23	23	26	26
24	24	24	24	24	27	27
25	24	24	24	24	26	26
26	27	27	27	27	31	31
27	26	26	26	26	26	26
28	18	18	18	18	19	19
29	16	16	16	16	23	23
30	27	27	27	27	31	31

The second mortality rate estimate, *RB*, is dependent on the proximity of stand basal area to the site maximum (see section 3.5), and the rate of basal area increment. As stand basal area approaches the maximum for the site, *RB* approaches 1. The calculation of *RB* is described by Wykoff and others (1982) and Dixon (2002).

The mortality rate applied to a tree record is a weighted average of *RA* and *RB* with the weight also dependent on the proximity of stand basal area to the maximum for the site. This is also described by Wykoff and others (1982), and in section 7.3 of the Essential FVS guide (Dixon 2002), and is not shown here. The combined estimate is adjusted to the length of the cycle using a compound interest formula as shown in equation {5.2.2}.

{5.2.2} $RT = 1 - (1 - RC)^Y$

where:

RT	is the mortality rate applied to an individual tree record for the growth period
RC	is the combined estimate of the annual mortality rate for the tree record
Y	is length of the current projection cycle in years

For Rocky Mountain juniper equation {5.2.2} is modified by 80%; for limber pine, green ash, quaking aspen, black cottonwood, balsam poplar, plains cottonwood, narrowleaf cottonwood, paper birch, and other hardwood equation {5.2.2} is modified by 40%.

6.0 Regeneration

The EM variant contains a full establishment model which is explained in section 5.4.2 of the Essential FVS Users Guide (Dixon 2002). In short, the full establishment model automatically adds regeneration following significant stand disturbances and adds ingrowth periodically during the simulation. Users may also input regeneration and ingrowth into simulations manually through the establishment model keywords as explained in section 5.4.3 of the Essential FVS Users Guide (Dixon 2002). The following description applies to entering regeneration and ingrowth through keywords.

The regeneration model is used to simulate stand establishment from bare ground, or to bring seedlings and sprouts into a simulation with existing trees. In the EM variant, 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 EM variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
WB	No	0.4	1	23
WL	No	0.3	1	27
DF	No	0.3	1	21
LM	No	0.3	1	27
LL	No	0.3	0.5	18
RM	No	0.3	0.5	6
LP	No	0.4	1	24
ES	No	0.3	0.5	18
AF	No	0.3	0.5	18
PP	No	0.5	1	17
GA	Yes	0.2	3	16
AS	Yes	0.2	6	16
CW	Yes	0.2	3	16
BA	Yes	0.2	3	16
PW	Yes	0.2	3	16
NC	Yes	0.2	3	16
PB	Yes	0.2	6	16
OS	No	0.2	0.5	22
OH	No	0.2	3	16

One sprouting record is created for green ash and paper birch; two sprouting records are created for quaking aspen; and logic rule {6.0.1} is used to determine the number of sprouting records for root suckering species. 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 root suckering hardwood species

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

{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 EM variant.

Species Code	Sprouting Probability	Number of Sprout Records	Source
GA	0.8 for DBH < 12", 0.5 for DBH > 12"	1	Ag. Handbook 654
AS	{6.0.3}	2	Keyser 2001
CW	0.9	{6.0.1}	Gom and Rood 2000 Steinberg 2001
BA	0.8 for DBH < 25”, 0.5 for DBH > 25”	{6.0.1}	Ag. Handbook 654
PW	0.9	{6.0.1}	Taylor 2001
NC	0.8	{6.0.1}	Simonin 2001
PB	0.7	1	Hutnik and Cunningham 1965 Bjorkbom 1972

Regeneration of seedlings may be specified by using 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 keywords; 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

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

Table 7.0.1 Default volume merchantability standards for the EM 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

* Board foot volume is not calculated for green ash (11), black cottonwood (13), balsam poplar (14), plains cottonwood (15), narrowleaf cottonwood (16), paper birch (17), or other hardwood (19) when using the default equations.

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

Common Name	**Location Code**	**Equation Number**	**Reference**
whitebark pine	102, 108, 109, 111, 112, 115	I00FW2W012	Flewelling's 2-Point Profile Model
western larch	102, 108, 109, 111, 112, 115	I00FW2W073	Flewelling's 2-Point Profile Model
Douglas-fir	102, 108, 109, 111, 112, 115	I00FW2W202	Flewelling's 2-Point Profile Model
limber pine	102, 108, 109, 111, 112, 115	I00FW2W073	Flewelling's 2-Point Profile Model
subalpine larch	102, 108, 109, 111, 112, 115	I00FW2W019	Flewelling's 2-Point Profile Model
Rocky Mountain juniper	102, 108, 109, 111, 112, 115	102DVEW106	Kemp Equation
lodgepole pine	102, 108, 109, 111, 112, 115	I00FW2W108	Flewelling's 2-Point Profile Model
Engelmann spruce	102, 108, 109, 111, 112, 115	I00FW2W093	Flewelling's 2-Point Profile Model
subalpine fir	102, 108, 109, 111, 112,	I00FW2W019	Flewelling's 2-Point Profile

Common Name	Location Code	Equation Number	Reference
	115		Model
ponderosa pine	102, 109, 111, 112, 115	I00FW2W122	Flewelling's 2-Point Profile Model
ponderosa pine	108	203FW2W122	Flewelling's 2-Point Profile Model
green ash	102, 108, 109, 111, 112, 115	101DVEW740	Kemp Equation
quaking aspen	102, 108, 109, 111, 112, 115	102DVEW746	Kemp Equation
black cottonwood	102, 108, 109, 111, 112, 115	102DVEW740	Kemp Equation
balsam poplar	102, 108, 109, 111, 112, 115	101DVEW740	Kemp Equation
plains cottonwood	102, 108, 109, 111, 112, 115	102DVEW740	Kemp Equation
narrowleaf cottonwood	102, 108, 109, 111, 112, 115	102DVEW740	Kemp Equation
paper birch	102, 108, 109, 111, 112, 115	101DVEW375	N. Central Station Equation
other softwood	102, 108, 109, 111, 112, 115	I00FW2W260	Flewelling's 2-Point Profile Model
other hardwood	102, 108, 109, 111, 112, 115	200DVEW746	Kemp Equation

Table 7.0.3 Citations by Volume Model

Model Name	Citation
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.
Kemp Equations	Kemp, P.D. 1958. Unpublished report on file at USDA, Forest Service, Rocky Mountain Research Station, Interior West Resource Inventory, Monitoring, and Evaluation Program, Ogden, UT.
N. Central Station Equation	Hahn, Jerold T. 1984. Tree Volume and Biomass Equations for the Lake States. Research Paper NC-250. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station

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 EM 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 EM 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).

10.0 Literature Cited

Alexander, R.R. 1967. Site Indices for Engelmann Spruce. Res. Pap. RM-32. Forest Service, Rocky Mountain Research Station. 7p.

Alexander, R.R., Tackle, D., and Dahms, W.G. 1967. Site Indices for Lodgepole Pine with Corrections for Stand Density Methodology. Res. Pap. RM-29. Forest Service, Rocky Mountain Research Station. 18 p.

Bechtold, William A. 2004. Largest-crown-diameter Prediction Models for 53 Species in the Western United States. WJAF. Forest Service. 19(4): pp 241-245.

Bjorkbom, John C. 1972. Stand changes in the first 10 years after seedbed preparation for paper birch. USDA Forest Service, Research Paper NE-238. Northeastern Forest Experiment Station, Upper Darby, PA. 10 p.

Burns, R. M., & Honkala, B. H. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods Agriculture Handbook 654. US Department of Agriculture, Forest Service, Washington, DC.

Cole, D. M.; Stage, A. R. 1972. Estimating future diameters of lodgepole pine. Res. Pap. INT-131. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 20p.

Crookston, Nicholas. 2003. Internal Document on File. Moscow, ID: Data provided from region 1.

Crookston, Nicholas. 2005. Draft: Allometric Crown Width Equations for 34 Northwest United States Tree Species Estimated Using Generalized Linear Mixed Effect Models.

Dixon, G. E. 1985. Crown ratio modeling using stand density index and the Weibull distribution. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 13p.

Dixon, Gary E. comp. 2002 (revised frequently). Essential FVS: A user's guide to the Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center.

Donnelly, Dennis. 1996. Internal document on file. Data provided from Region 6. Fort Collins, CO: Forest Service.

Edminster, Carleton B., Mowrer, H. Todd, and Shepperd, Wayne D. 1985. Site Index Curves for Aspen in the Central Rocky Mountains. Res. Note RM-453. Forest Service, Rocky Mountain Research Station. 4 p.

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.

Gom, L. A., & Rood, S. B. (2000). Fire induces clonal sprouting of riparian cottonwoods. Canadian Journal of Botany, 77(11), 1604-1616.

Hahn, Jerold T. 1984. Tree Volume and Biomass Equations for the Lake States. Research Paper NC-250. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station

Hamilton, D. A., Jr. 1986. A logistic model of mortality in thinned and unthinned mixed conifer stands of northern Idaho. For. Science 32(4): 989-1000.

Hutnik, Russell J., and Frank E. Cunningham. 1965. Paper birch (Betula papyrifera Marsh.). In Silvics of forest trees of the United States. p. 93-98. H. A. Fowells, comp. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC.

Johnson, N.L. 1949. Bivariate distributions based on simple translation systems. Biometrika 36:297-304.

Kemp, P.D. 1958. Unpublished report on file at USDA, Forest Service, Rocky Mountain Research Station, Interior West Resource Inventory, Monitoring, and Evaluation Program, Ogden, UT.

Keyser, C.E. 2001. Quaking Aspen Sprouting in Western FVS Variants: A New Approach. Unpublished Manuscript.

Krajicek, J.; Brinkman, K.; Gingrich, S. 1961. Crown competition – a measure of density. Forest Science. 7(1):35-42.

Meyer, Walter H. 1961.rev. Yield of even-aged stands of ponderosa pine. Tech. Bull. No. 630. Washington D.C.: Forest Service

Mosenrud, R.A. 1985. Applying Height Growth and Site index Curves for inland Douglas-fir. Intermountain Research Paper. INT-347.

Rebain, Stephanie A. comp. 2010 (revised frequently). The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 379 p.

Reinhardt, Elizabeth; Crookston, Nicholas L. (Technical Editors). 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-116. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p.

Richie, Martin W., and Hann, David W. 1986. Development of a tree height growth model for Douglas-fir. Forest Ecology and Management. 15: pp 135-145.

Schreuder, H.T. and W.L. Hafley. 1977. A Useful Distribution for Describing Stand Structure of Tree Heights and Diameters. Biometrics 33, 471-478.

Shepperd, Wayne D. 1995. Unpublished equation. Data on file. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Simonin, Kevin A. 2001. Populus angustifolia. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).

Stage, A. R. 1973. Prognosis Model for stand development. Res. Paper INT-137. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32p.

Steinberg, Peter D. 2001. Populus balsamifera subsp. trichocarpa. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).

Taylor, Jennifer L. 2001. Populus deltoides. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).

Van Dyck, Michael G.; Smith-Mateja, Erin E., comps. 2000 (revised frequently). Keyword reference guide for the Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center.

Wensel, L.C., W.J. Meerschaert, and G.S. Bigging. 1978. Tree height and diameter growth models for northern California. Hilgardia 55(8): 1-20.

Wykoff, W. R. 1990. A basal area increment model for individual conifers in the northern Rocky Mountains. For. Science 36(4): 1077-1104.

Wykoff, William R. 1986. Supplement to the User's guide for the Stand Prognosis Model-Version 5.0. Gen. Tech. Rep. INT-208. Ogden, UT: Forest Service, Intermountain Research Station. 36 p.

Wykoff, William R., Crookston, Nicholas L., and Stage, Albert R. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: Forest Service, Intermountain Forest and Range Experiment Station. 112p.

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
	Beaverhead	Custer	Deerlodge	Gallatin	Helena	Lewis & Clark	
Douglas-fir	13	1	21	34	15	17	30767
lodgepole pine	32	1	24	26	10	8	56939
Engelmann spruce	23	1	18	42	5	12	7991
subalpine fir	24	0	14	48	7	8	7927
ponderosa pine	<1	65	<1	5	6	24	5232
whitebark pine	27	0	15	36	6	16	2747

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+
Douglas-fir	6	32	33	19	7	3
lodgepole pine	14	56	27	4	1	0
Engelmann spruce	6	30	31	21	8	3
subalpine fir	16	52	25	6	1	<1
ponderosa pine	10	31	32	20	5	1
whitebark pine	9	48	32	9	2	<1

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
Douglas-fir	2	7	16	19	18	15	12	8	3
lodgepole pine	6	19	28	20	11	7	5	3	1
Engelmann spruce	1	2	6	11	14	18	19	13	12
subalpine fir	1	2	6	10	15	17	18	18	11
ponderosa pine	3	11	25	22	16	12	7	4	1
whitebark pine	5	14	23	19	14	10	8	5	2

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
Douglas-fir	20	16	11	10	7	9	11	16	1
lodgepole pine	18	15	13	9	6	8	10	14	8
Engelmann spruce	28	21	12	5	4	5	7	16	3
subalpine fir	22	24	17	7	4	5	6	14	2
ponderosa pine	23	17	13	5	7	12	11	11	2
whitebark pine	16	18	12	7	7	8	12	18	1

Table 11.1.5. 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
Douglas-fir	5	24	39	25	6	1
lodgepole pine	6	26	43	20	4	1
Engelmann spruce	3	18	39	30	10	1
subalpine fir	3	25	40	24	7	1
ponderosa pine	5	45	38	9	2	1
whitebark pine	2	20	35	32	10	2

Table 11.1.6. 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
Douglas-fir	46	39	11	3	1	1	1	1
lodgepole pine	54	36	7	2	1	1	1	1
Engelmann spruce	31	42	19	6	2	1	1	0
subalpine fir	34	45	16	4	1	1	1	0
ponderosa pine	26	42	20	8	3	1	1	1
whitebark pine	71	26	3	1	1	0	0	0

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

Species	Elevation				
	<5000	5000-6000	6000-7000	7000-8000	8000-9000
Douglas-fir	1	21	54	23	1
lodgepole pine	5	42	44	9	0

Species	Elevation				
	<5000	5000-6000	6000-7000	7000-8000	8000-9000
Engelmann spruce	5	31	45	18	1
subalpine fir	2	23	54	21	1
ponderosa pine	71	23	5	1	0
whitebark pine	4	13	37	44	2

11.2 Appendix B. Habitat Codes

Table 11.2.1 Habitat codes recognized in the EM variant.

Habitat Code	Abbreviation	Habitat Type Name
10	SCREE	*Scree*
65	GRASS	*Grass type*
70	FORB	*Forb type*
74	SAL	*Willow*
79	POTRI	*Balsam poplar*
91	PIFL2/PSSPS	*Limber pine/bluebunch wheatgrass*
92	PIFL2/FEID	*Limber pine/Idaho fescue*
93	PIFL2/FEID-FEID	*Limber pine/Idaho fescue-Idaho fescue*
95	PIFL/JUCO	*Limber pine/common juniper*
100	PIPO	*Ponderosa pine series*
110	PIPO/ANDRO2	*Ponderosa pine/bluestem*
120	PIPO/STOC	*Ponderosa pine/western needlegrass*
130	PIPO/AGSP2	*ponderosa pine/ bluebunch wheatgrass*
140	PIPO/FEID	*Ponderosa pine/Idaho fescue*
141	PIPO/FEID/FEID	*Ponderosa pine/Idaho fescue/Idaho fescue*
161	PIPO/PUTR/AGSP	*Ponderosa pine/bitterbrush/Idaho fescue*
170	PIPO/SYAL	*Ponderosa pine/Common snowberry*
171	PIPO/SYAL/SYAL	*Ponderosa pine/common snowberry/common snowberry*
172	PIPO/SYAL/MARE11	*Ponderosa pine/common snowberry/creeping barberry*
180	PIPO/PRVI	*Ponderosa pine/chokecherry*
181	PIPO/PRVI/PRVI	*Ponderosa pine/chokecherry/chokecherry*
182	PIPO/PRVI/SHCA	*Ponderosa pine/chokecherry/russet buffaloberry*
200	PSME	*Douglas-fir series*
210	PSME/AGSP	*Douglas-fir/Bluebench wheatgrass*
220	PSME/FEID	*Douglas-fir/Idaho fescue*
221	PSME/FEID/FEID	*Douglas-fir/Idaho fescue/Idaho fescue*
230	PSME/FEAL	*Douglas-fir/altai fescue*
250	PSME/VACA	*Douglas-fir/Dwarf huckleberry*
260	PSME/PHMA	*Douglas-fir/ninebark*

Habitat Code	Abbreviation	Habitat Type Name
261	PSME/PHMA/PHMA	*Douglas-fir/ninebark/ninebark*
262	PSME/PHMA/CARU	*Douglas-fir/ninebark/pinegrass*
280	PSME/VAGL	*Douglas-fir/blue huckleberry*
281	PSME/VAME/VAME	*Douglas-fir/thinleaf huckleberry/thinleaf huckleberry*
282	PSME/VAME/ARUV	*Douglas-fir/thinleaf huckleberry/kinnikinnick*
283	PSME/VAME/XETE	*Douglas-fir/thinleaf huckleberry/common beargrass*
290	PSME/LIBO	*Douglas-fir/twinflower*
291	PSME/LIBO/SYAL	*Douglas-fir/twinflower/common snowberry*
292	PSME/LIBO/VAME	*Douglas-fir/twinflower/thinleaf huckleberry*
293	PSME/LIBO/VAME	*Douglas-fir/twinflower/thinleaf huckleberry*
310	PSME/SYAL	*Douglas-fir/common snowberry*
311	PSME/SYAL/PSSPS	*Douglas-fir/common snowberry/bluebunch wheatgrass*
312	PSME/SYAL/CARU	*Douglas-fir/common snowberry/pinegrass*
313	PSME/SYAL/SYAL	*Douglas-fir/common snowberry/common snowberry*
315	PSME/SYAL/PIPO	*Douglas-fir/common snowberry/ponderosa pine*
320	PSME/CARU	*Douglas-fir/pinegrass*
321	PSME/CARU/PSSPS	*Douglas-fir/pinegrass/bluebunch wheatgrass*
322	PSME/CARU/ARUV	*Douglas-fir/pinegrass/kinnikinnick*
323	PSME/CARU/CARU	*Douglas-fir/pinegrass/pinegrass*
330	PSME/CAGE	*Douglas-fir/elk sedge*
331	PSME/CAGE/CAGE	*Douglas-fir/elk sedge/elk sedge*
332	PSME/CAGE/SYOR	*Douglas-fir/elk sedge/mountain snowberry*
340	PSME/SPBE	*Douglas-fir/white spirea*
350	PSME/ARUV	*Douglas-fir/kinnikinnick*
360	PSME/JUCO	*Douglas-fir/common juniper*
370	PSME/ARCO	*Douglas-fir/Heartleaf arnica*
371	PSME/ARCO/ARCO	*Douglas-fir/Heartleaf arnica/heartleaf arnica*
400	PIECA	*Spruce series*
410	PIECA /EQAR	*Spruce/common horsetail*
430	PIECA/PHMA5	*Spruce/mallow ninebark*
440	PIECA /GART	*Spruce/sweetscented bedstraw*
450	PICEA/VACA13	*Spruce/dwarf bilberry*
460	PICEA/PAST10	*Spruce/rocky mountain groundsel*
461	PICEA/PAST10/PSME	*Spruce/rocky mountain groundsel/douglas-fir*
470	PICEA/LIBO	*Spruce/twinflower*
480	PICEA/MAST	*Spruce/starry false lily of the valley*
591	ABGR/LIBO/LIBO	*Grand-fir/twinflower/twinflower*
610	ABLA/OPHO	*Subalpine fir/devilsclub*
620	ABLA/CLUN	*Subalpine fir/twisted stalk*
624	ABLA/CLUN/CETE	*Subalpine fir/twisted stalk/beargrass*

Habitat Code	Abbreviation	Habitat Type Name
625	ABLA/CLUN/MEFE	*Subalpine fir/twisted stalk/menziesia*
630	ABLA/GART	*Subalpine fir/fragrant bedstraw*
632	ABLA/GATR3/VASC	*Subalpine fir/fragrant bedstraw/grouse whortleberry*
640	ABLA/VACA	*Subalpine fir/dwarf huckleberry*
641	ABLA/VACA-VACA	*Subalpine fir/dwarf huckleberry/dwarf huckleberry*
642	ABLA/VACA-CACA	*Subalpine fir/dwarf huckleberry/bluejoint*
650	ABLA/CACA	*Subalpine fir/bluejoint*
651	ABLA/CACA/CACA	*Subalpine fir/bluejoint/bluejoint*
653	ABLA/CACA/GATR	*Subalpine fir/bluejoint/fragrant bedstraw*
654	ABLA/CACA/VACA	*Subalpine fir/bluejoint/dwarf huckleberry*
655	ABLA/CACA/LEGL	*Subalpine fir/bluejoint/Labrador tea*
660	ABLA/LIBO	*Subalpine fir/twinflower*
661	ABLA/LIBO/LIBO	*Subalpine fir/twinflower/twinflower*
662	ABLA/LIBO/XETE	*Subalpine fir/twinflower/beargrass*
663	ABLA/LIBO/VASC	*Subalpine fir/twinflower/grouse whortleberry*
670	ABLA/MEFE	*Subalpine fir/menziesia*
674	ABLA/MEFE/VASC	*Subalpine fir/menziesia/grouse whortleberry*
690	ABLA/XETE	*Subalpine fir/beargrass*
691	ABLA/XETE/VAGL	*Subalpine fir/beargrass/blue huckleberry*
692	ABLA/XETE/VASC	*Subalpine fir/beargrass/grouse whortleberry*
700	ABLA	*Subalpine fir, lower subalpine*
710	TSME/XETE	*Mountain hemlock/beargrass*
720	ABLA/VAGL	*Subalpine fir/blue huckleberry*
730	ABLA/VASC	*Subalpine fir/grouse whortleberry*
731	ABLA/VASC/CARU	*Subalpine fir/grouse whortleberry/pinegrass*
732	ABLA/VASC/VASC	*Subalpine fir/grouse whortleberry/grouse whortleberry*
733	ABLA/VASC/THOC	*Subalpine fir/grouse whortleberry/western meadow rue*
740	ABLA/ALSI	*Subalpine fir/sitka alder*
750	ABLA/CARU	*Subalpine fir/pinegrass*
751	ABLA/CARU-CARU	*Subalpine fir/pinegrass/pinegrass*
770	ABLA/CLCOC	*Subalpine fir/rock clematis*
780	ABLA/ARCO	*Subalpine fir/heartleaf arnica*
790	ABLA/CAGE	*Subalpine fir/elk sedge*
791	ABLA/CAGE/CAGE	*Subalpine fir/elk sedge/elk sedge*
792	ABLA/CAGE/PSME	*Subalpine fir/elk sedge/douglas-fir*
810	ABLA/RIMO	*Subalpine fir/mountain gooseberry*
820	ABLA/PIAL/VASC	*Subalpine fir/whitebark pine/grouse whortleberry*
830	ABLA/LUHI	*Subalpine fir/smooth woodrush*
832	ABLA/LUGLH/MEFE	*Subalpine fir/smooth woodrush/rusty menziesia*
850	PIAL-ABLA	*Whitebark pine-subalpine fir*

Habitat Code	Abbreviation	Habitat Type Name
860	LALY-ABLA2	*Alpine larch-subalpine fir*
870	PIAL	*Whitebark pine series*
900	PICO	*Lodgepole pine series*
910	PICO/PUTR	*Lodgepole pine/antelope bitterbrush*
920	PICO/VACA	*Lodgepole pine/dwarf huckleberry*
930	PICO/LIBO	*Lodgepole pine/twinflower*
940	PICO/VASC	*Lodgepole pine/grouse whortleberry*
950	PIPO/CARU	*Lodgepole pine/pinegrass*
999	Other	----

Table 11.2.2 EM habitat code mapping to original NI habitat codes and their associated default value for maximum stand density index.

EM Habitat Code	Abbreviation	Mapping Index	NI Habitat Code	Abbreviation	Maximum SDI
10	SCREE	1	130	PIPO/AGSP	634
66	GRASS	1	130	PIPO/AGSP	634
70	FORB	1	130	PIPO/AGSP	634
74	SAL	1	130	PIPO/AGSP	634
79	POTRI	1	130	PIPO/AGSP	634
91	PIFL2/PSSPS	1	130	PIPO/AGSP	634
92	PIFL2/FEID	1	130	PIPO/AGSP	634
93	PIFL2/FEID-FEID	1	130	PIPO/AGSP	634
95	PIFL/JUCO	1	130	PIPO/AGSP	634
100	PIPO	1	130	PIPO/AGSP	775
110	PIPO/ANDRO2	1	130	PIPO/AGSP	775
120	PIPO/STOC	1	130	PIPO/AGSP	775
130	PIPO/AGSP2	1	130	PIPO/AGSP	775
140	PIPO/FEID	1	130	PIPO/AGSP	775
141	PIPO/FEID/FEID	1	130	PIPO/AGSP	775
161	PIPO/PUTR/AGSP	2	170	PIPO/SYAL	775
170	PIPO/SYAL	2	170	PIPO/SYAL	775
171	PIPO/SYAL/SYAL	2	170	PIPO/SYAL	775
172	PIPO/SYAL/MARE11	2	170	PIPO/SYAL	775
180	PIPO/PRVI	2	170	PIPO/SYAL	775
181	PIPO/PRVI/PRVI	2	170	PIPO/SYAL	775
182	PIPO/PRVI/SHCA	2	170	PIPO/SYAL	775
200	PSME	4	260	PSME/PHMA	467
210	PSME/AGSP	1	130	PIPO/AGSP	467
220	PSME/FEID	1	130	PIPO/AGSP	467
221	PSME/FEID/FEID	1	130	PIPO/AGSP	467
230	PSME/FEAL	1	130	PIPO/AGSP	467

EM Habitat Code	Abbreviation	Mapping Index	NI Habitat Code	Abbreviation	Maximum SDI
250	PSME/VACA	3	250	PSME/VACA	768
260	PSME/PHMA	4	260	PSME/PHMA	696
261	PSME/PHMA/PHMA	4	260	PSME/PHMA	696
262	PSME/PHMA/CARU	4	260	PSME/PHMA	696
280	PSME/VAGL	5	280	PSME/VAGL	775
281	PSME/VAME/VAME	5	280	PSME/VAGL	775
282	PSME/VAME/ARUV	5	280	PSME/VAGL	775
283	PSME/VAME/XETE	5	280	PSME/VAGL	775
290	PSME/LIBO	6	290	PSME/LIBO	768
291	PSME/LIBO/SYAL	6	290	PSME/LIBO	768
292	PSME/LIBO/VAME	6	290	PSME/LIBO	768
293	PSME/LIBO/VAME	6	290	PSME/LIBO	768
310	PSME/SYAL	7	310	PSME/SYAL	696
311	PSME/SYAL/PSSPS	7	310	PSME/SYAL	467
312	PSME/SYAL/CARU	7	310	PSME/SYAL	696
313	PSME/SYAL/SYAL	7	310	PSME/SYAL	696
315	PSME/SYAL/PIPO	7	310	PSME/SYAL	696
320	PSME/CARU	8	320	PSME/CARU	634
321	PSME/CARU/PSSPS	8	320	PSME/CARU	467
322	PSME/CARU/ARUV	8	320	PSME/CARU	634
323	PSME/CARU/CARU	8	320	PSME/CARU	634
330	PSME/CAGE	9	330	PSME/CAGE	634
331	PSME/CAGE/CAGE	9	330	PSME/CAGE	634
332	PSME/CAGE/SYOR	9	330	PSME/CAGE	634
340	PSME/SPBE	8	320	PSME/CARU	634
350	PSME/ARUV	8	320	PSME/CARU	634
360	PSME/JUCO	9	330	PSME/CAGE	634
370	PSME/ARCO	7	310	PSME/SYAL	634
371	PSME/ARCO/ARCO	7	310	PSME/SYAL	634
400	PIECA	10	420	PICEA/CLUN	707
410	PIEN/EQAR	10	420	PICEA/CLUN	707
430	PIECA/PHMA5	4	260	PSME/PHMA	696
440	PIEN/GART	11	470	PICEA/LIBO	707
450	PICEA/VACA13	20	640	ABLA/VACA	707
460	PICEA/PAST10	29	850	PIAL-ABLA	635
461	PICEA/PAST10/PSME	29	850	PIAL-ABLA	635
470	PICEA/LIBO	11	470	PICEA/LIBO	768
480	PICEA/MAST	11	470	PICEA/LIBO	768
591	ABGR/LIBO/LIBO	12	510	ABGR/XETE	707
610	ABLA/OPHO	18	610	ABLA/OPHO	707

EM Habitat Code	Abbreviation	Mapping Index	NI Habitat Code	Abbreviation	Maximum SDI
620	ABLA/CLUN	19	620	ABLA/CLUN	707
624	ABLA/CLUN/CETE	19	620	ABLA/CLUN	707
625	ABLA/CLUN/MEFE	19	620	ABLA/CLUN	707
630	ABLA/GART	21	660	ABLA/LIBO	707
632	ABLA/GATR3/VASC	21	660	ABLA/LIBO	707
640	ABLA/VACA	20	640	ABLA/VACA	707
641	ABLA/VACA-VACA	20	640	ABLA/VACA	707
642	ABLA/VACA-CACA	20	640	ABLA/VACA	707
650	ABLA/CACA	20	640	ABLA/VACA	707
651	ABLA/CACA/CACA	20	640	ABLA/VACA	707
653	ABLA/CACA/GATR	20	640	ABLA/VACA	707
654	ABLA/CACA/VACA	20	640	ABLA/VACA	707
655	ABLA/CACA/LEGL	20	640	ABLA/VACA	707
660	ABLA/LIBO	21	660	ABLA/LIBO	768
661	ABLA/LIBO/LIBO	21	660	ABLA/LIBO	768
662	ABLA/LIBO/XETE	21	660	ABLA/LIBO	768
663	ABLA/LIBO/VASC	21	660	ABLA/LIBO	768
670	ABLA/MEFE	22	670	ABLA/MEFE	661
674	ABLA/MEFE/VASC	22	670	ABLA/MEFE	661
690	ABLA/XETE	24	690	ABLA/XETE	775
691	ABLA/XETE/VAGL	24	690	ABLA/XETE	775
692	ABLA/XETE/VASC	24	690	ABLA/XETE	775
700	TSME	27	730	ABLA/VASC	707
710	TSME/XETE	25	710	TSME/XETE	707
720	ABLA/VAGL	26	720	ABLA/VAGL	775
730	ABLA/VASC	27	730	ABLA/VASC	751
731	ABLA/VASC/CARU	27	730	ABLA/VASC	751
732	ABLA/VASC/VASC	27	730	ABLA/VASC	751
733	ABLA/VASC/THOC	27	730	ABLA/VASC	707
740	ABLA/ALSI	22	670	ABLA/MEFE	661
750	ABLA/CARU	24	690	ABLA/XETE	635
751	ABLA/CARU-CARU	24	690	ABLA/XETE	635
770	ABLA/CLCOC	27	730	ABLA/VASC	635
780	ABLA/ARCO	24	690	ABLA/XETE	635
790	ABLA/CAGE	27	730	ABLA/VASC	635
791	ABLA/CAGE/CAGE	27	730	ABLA/VASC	635
792	ABLA/CAGE/PSME	27	730	ABLA/VASC	635
810	ABLA/RIMO	28	830	ABLA/LUHI	635
820	ABLA/PIAL/VASC	29	850	PIAL-ABLA	635
830	ABLA/LUHI	28	830	ABLA/LUHI	635

EM Habitat Code	Abbreviation	Mapping Index	NI Habitat Code	Abbreviation	Maximum SDI
832	ABLA/LUGLH/MEFE	28	830	ABLA/LUHI	635
850	PIAL-ABLA	29	850	PIAL-ABLA	635
860	LALY-ABLA2	29	850	PIAL-ABLA	635
870	PIAL	29	850	PIAL-ABLA	635
900	PICO	27	730	ABLA/VASC	707
910	PICO/PUTR	9	330	PSME/CAGE	707
920	PICO/VACA	20	640	ABLA/VACA	707
930	PICO/LIBO	21	660	ABLA/LIBO	768
940	PICO/VASC	27	730	ABLA/VASC	751
950	PIPO/CARU	24	690	ABLA/XETE	635
999	Other	30	999	Other	775

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