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Tetons (TT) Variant Overview of the Forest Vegetation Simulator

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Spread Creek, Bridger-Teton National Forest
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Tetons (TT) 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 1982. The original author was Gary Dixon. In 2008, the previous document was replaced with an updated variant overview. Gary Dixon, Christopher Dixon, Robert Havis, Chad Keyser, Stephanie Rebain, Erin Smith-Mateja, and Don Vandendriesche were involved with that update. Don Vandendriesche cross-checked the information contained in that variant overview update with the FVS source code. In 2010, Gary Dixon expanded the species list and made significant updates to this variant overview.

FVS Staff. 2008 (revised October 5, 2021). Tetons (TT) Variant Overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 59p.

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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)	415 – Targhee National Forest	
Plant Association Code	0 (unknown)	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation	65 (6500 feet)	
Latitude / Longitude	Latitude	Longitude
All location codes	44	111
Site Species	DF	
Site Index	50	
Maximum Stand Density Index	Species specific	
Maximum Basal Area	Based on maximum stand density index	
Volume Equations	National Volume Estimator Library	
Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	7.0 / 6.0 inches	8.0 / 6.0 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	7.0 / 6.0 inches	8.0 / 6.0 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Large Trees (variable radius plot)	40 BAF	
Small Trees (fixed radius plot)	1/300th Acre	
Breakpoint DBH	5.0 inches	

1.0 Introduction

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

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

The Tetons (TT) variant was developed in 1982. It covers western Wyoming and eastern Idaho and includes the Bridger, Caribou, Targhee, and Teton National Forests.

Since the variant’s development in 1982, many of the functions have been adjusted and improved as more data has become available and as model technology has advanced. In 2010 this variant was expanded from 8 species to 18 species. Ponderosa pine was added using ponderosa pine equations from the Central Idaho variant; singleleaf pinyon was added using the common pinyon growth equations from the Utah variant; blue spruce was added using the Engelmann spruce equations; Rocky Mountain juniper and Utah juniper were added and use the western juniper equations from the Utah variant; bigtooth maple was added using bigleaf maple equations from the SO variant and other equations from the Utah variant; Rocky Mountain maple was added using Rocky Mountain maple equations from the Inland Empire variant; narrowleaf cottonwood was added using cottonwood equations from the Central Rockies variant; curl-leaf mountain mahogany was added using equations from the South Central Oregon / Northeastern California and Utah variants; and the grouping for all other species was eliminated and replaced with groupings for other softwood using the equations for the previous other species grouping (singleleaf pinyon), and other hardwood using cottonwood equations from the Central Rockies variant.

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 TT variant was fit to data representing forest types in western Wyoming and eastern Idaho. The TT variant covers forest areas in eastern Idaho and western Wyoming. The suggested geographic range of use for the TT variant is shown in figure 2.0.1.

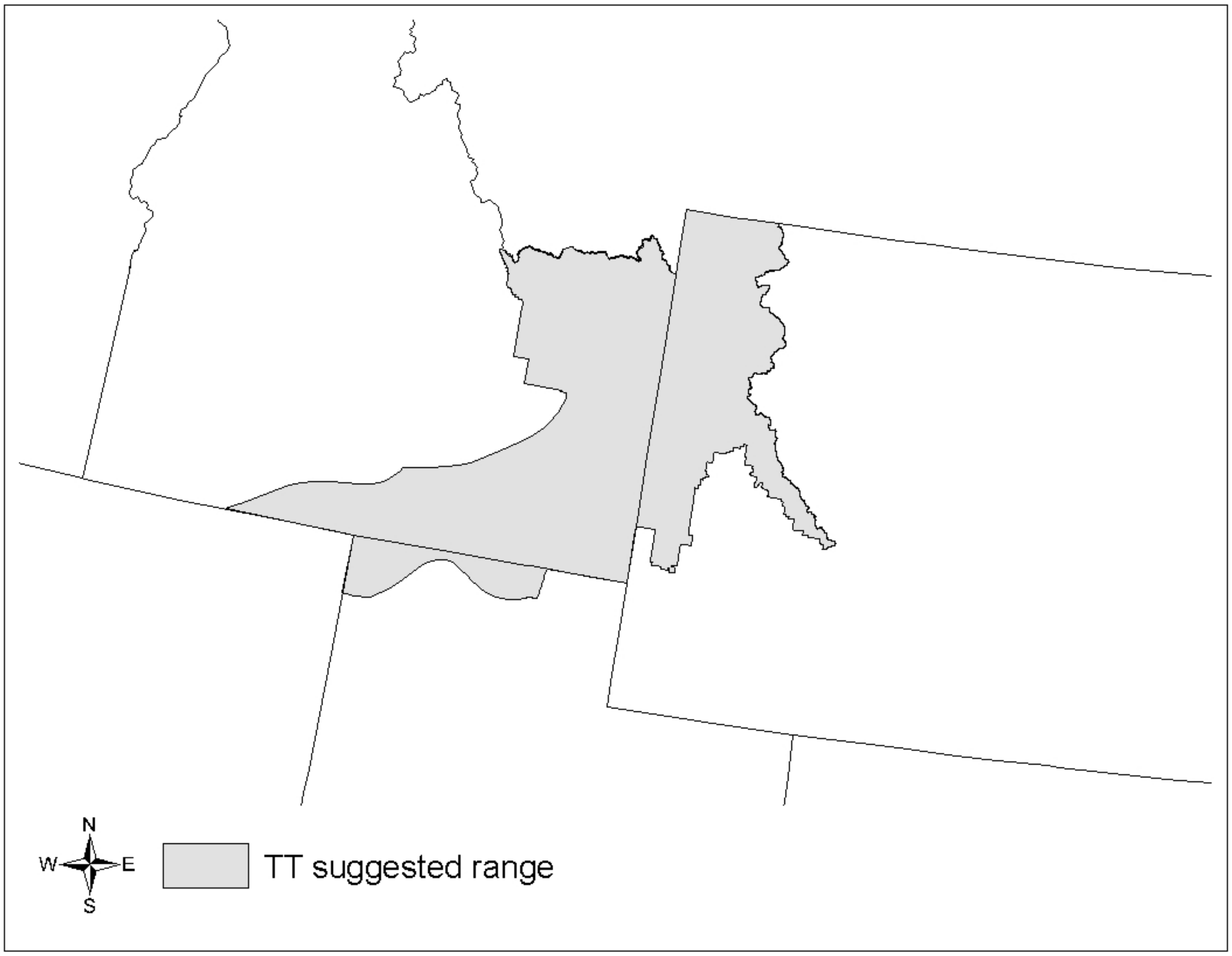

Figure 2.0.1 Suggested geographic range of use for the TT variant.

3.0 Control Variables

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

3.1 Location Codes

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

If the location code is missing or incorrect in the TT variant, a default forest code of 415 (Targhee National Forest) will be used. Location codes recognized in the TT variant are shown in tables 3.1.1 and 3.1.2.

Table 3.1.1 Location codes used in the TT variant.

Location Code	Location
403	Bridger National Forest
405	Caribou National Forest
415	Targhee National Forest
416	Tetons National Forest

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

Location Code	Location
7306	Wind River Reservation (mapped to 403)
8107	Fort Hall Reservation (mapped to 405)

3.2 Species Codes

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

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

When entering tree data, users should substitute diameter at root collar (DRC) for diameter at breast height (DBH) for woodland species (pinyon and junipers).

Table 3.2.1 Species codes used in the TT variant.

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name[1]	Common Name[1]
1	WB	101	PIAL	*Pinus albicaulis*	whitebark pine
2	LM	113	PIFL2	*Pinus flexilis*	limber pine
3	DF	202	PSME	*Pseudotsuga menziesii*	Douglas-fir
4	PM	133	PIMO	*Pinus monophylla*	singleleaf pinyon
5	BS	096	PIPU	*Picea pungens*	blue spruce
6	AS	746	POTR5	*Populus tremuloides*	quaking aspen
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	UJ	065	JUOS	*Juniperus osteosperma*	Utah juniper
12	RM	066	JUSC2	*Juniperus scopulorum*	Rocky Mountain juniper
13	BI	322	ACGR3	*Acer grandidentatum*	bigtooth maple
14	MM	321	ACGL	*Acer glabrum*	Rocky Mountain maple
15	NC	749	POAN3	*Populus angustifolia*	narrowleaf cottonwood
16	MC	475	CELE3	*Cercocarpus ledifolius*	curl-leaf mountain mahogany
17	OS	299	2TN		other softwood[2]
18	OH	998	2TB		other hardwood[2]

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

3.3 Habitat Type, Plant Association, and Ecological Unit Codes

In the TT variant, habitat type codes are used in the Fire and Fuels Extension (FFE) to set fuel loading in cases where there are no trees in the first cycle. They are also used in large tree diameter growth for ponderosa pine. Habitat type codes recognized in the TT variant are shown in Appendix A. If an incorrect habitat type code is entered or no code is entered, FVS will use the default habitat type code, which is 0 (unknown). Users may enter the habitat type code or the habitat type FVS sequence number on the STDINFO keyword, when entering stand information from a database, or when using the SETSITE keyword without the PARMS option. If using the PARMS option with the SETSITE keyword, users must use the FVS sequence number for the habitat type.

3.4 Site Index

Site index is used in some of the growth equations in the TT variant. When possible, users should enter their own values instead of relying on the default values assigned by FVS. If site index information is available, a single site index can be specified for the whole stand, a site index for each individual species can be specified, or a combination of these can be entered. If the user does not supply site index values, then default values will be used. When entering site index in the TT variant, the sources shown in table 3.4.1 should be used if possible. The default site species is Douglas-fir with a site index of 50.

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

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

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

where:

RELSI	is the relative site index of the site species
SI	is species site index
SITELO	is the lower bound of the *SI* range for a species
SITEHI	is the upper bound of the *SI* range for a species
$_{site}$	is the site species
$_i$	is the species for which site index is to be calculated

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

Species Code	Reference	BHA or TTA*	REF Base Age
DF	Brickell Res. Pap. INT-75	TTA	50
AS, MM	Edminster, Mowrer, and Shepperd Res. Note RM-453	BHA	80
LP, WB, LM, OS	Alexander, Tackle, and Dahms Res. Paper RM-29	TTA	100**
BS, ES, AF	Alexander Res. Paper RM-32	BHA	100**
PM, UJ, RM	Any 100-year base age curve	TTA	100
PP	Meyer (1961.rev) Tech. Bulletin 630	TTA	100
MC, BI	Curtis, R. O., et. al. (1974) Forest Science	BHA	100
NC, OH	Alexander Res. Paper RM-32	BHA	100

*Equation is based on total tree age (TTA) or breast height age (BHA)
**Site index for these species will be converted to a 50-year age basis within FVS since growth equations for these species were fit with a 50-year age based site index

Table 3.4.1 *SITELO* and *SITEHI* values for equations {3.4.1} and {3.4.2} in the TT variant.

Species Code	*SITELO*	*SITEHI*
WB	25	50
LM	25	50
DF	20	60

PM	5	20
BS	40	100
AS	30	70
LP	20	100
ES	40	100
AF	40	90
PP	40	80
UJ	5	15
RM	5	15
BI	5	30
MM	5	30
NC	30	120
MC	5	15
OS	20	50
OH	5	20

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

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

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

where:

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

Table 3.5.1 Stand density index maximums by species in the TT variant.

Species Code	SDI Maximum	Mapped to
WB	621	

Species Code	SDI Maximum	Mapped to
LM	409	
DF	570	
PM	358	
BS	620	Engelmann spruce
AS	562	
LP	679	
ES	620	
AF	602	
PP	446	
UJ	497	
RM	411	
BI	619	
MM	680	
NC	452	black cottonwood
MC	501	
OS	409	limber pine
OH	452	black cottonwood

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

4.0 Growth Relationships

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

4.1 Height-Diameter Relationships

Height-diameter relationships in FVS are primarily used to estimate tree heights missing in the input data, and occasionally to estimate diameter growth on trees smaller than a given threshold diameter. In the TT variant, height-diameter relationships for all species except bigtooth maple (BI) and curl-leaf mountain mahogany (MC) are a logistic functional form, as shown in equation {4.1.1} (Wykoff, et.al. 1982). The equation was fit to data of the same species used to develop other FVS variants. 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. Automatic calibration of the logistic height-diameter relationship is turned on by default for all species except bigtooth maple and curl-leaf mountain mahogany. This feature can be turned off using the NOHTDREG keyword.

{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 height-diameter relationship equation in the TT variant.

Species Code	Default B_1	B_2
WB	4.1920	-5.1651
LM	4.1920	-5.1651
DF	4.5175	-6.5129
PM	3.2	-5.0
BS	4.5822	-6.4818
AS	4.4625	-5.2223
LP	4.4625	-5.2223
ES	4.5822	-6.4818
AF	4.3603	-5.2148
PP	4.993	-12.430
UJ	3.2	-5.0
RM	3.2	-5.0

Species Code	Default B_1	B_2
BI	4.7	-6.3260
MM	4.4421	-6.5405
NC	4.4421	-6.5405
MC	5.1520	-13.5760
OS	4.1920	-5.1651
OH	4.4421	-6.5405

The default height-diameter relationship for bigtooth maple and curl-leaf mountain mahogany uses the Curtis-Arney functional form as shown in equation {4.1.2} (Curtis 1967, Arney 1985). If the input data contains at least three measured heights for a species, then FVS can switch to a logistic height-diameter equation {4.1.1} for trees with a *DBH* of 5.0" or greater that is calibrated to the input data. If the logistic equation is being used then trees of these two species less than 5.0" DBH use equation 4.1.3. For bigtooth maple and curl-leaf mountain mahogany in the TT variant, this switch to using the logistic equations doesn't happen by default, but can be turned on with the NOHTDREG keyword by entering "1" in field 2.

{4.1.2} Curtis-Arney functional form

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

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

where:

curl-leaf mountain mahogany	bigtooth maple
$P_2 = 1709.7229$	$P_2 = 76.5170$
$P_3 = 5.8887$	$P_3 = 2.2107$
$P_4 = -0.2286$	$P_4 = -0.6365$

{4.1.4} $HT = 0.0994 + 4.9767 * DBH$ $\qquad DBH < 5.0''$

(note: 4.1.4 is used in conjuntion with 4.1.1 for trees with $DBH \geq 5.0''$ when the logistic equations are being used for bigtooth maple or curl-leaf mountain mahogany)

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 equations are shown in {4.2.1} - {4.2.4} with equations number and coefficients (b_1 and b_2) by species shown in table 4.2.1.

{4.2.1} $BRATIO = b_1 + b_2 * (1/DBH)$ where $1.0 \leq DBH \leq 19.0$

{4.2.2} $BRATIO = b_1$

{4.2.3} $BRATIO = b_1 + b_2 * (1.0/DBH)$ where $DBH \geq 1.0$

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

where:

BRATIO	is species-specific bark ratio (bounded to $0.80 \leq BRATIO \leq 0.97$ for PP; bounded to $0.80 \leq BRATIO \leq 0.99$ for all other species)
DBH	is tree diameter outside bark at breast height
DIB	is tree diameter inside bark at breast height
b_1 - b_2	are species-specific coefficients shown in table 4.2.1

Table 4.2.1 Coefficient for bark ratio equation {4.2.1} in the TT variant.

Species Code	b_1	b_2	Equation Number
WB	0.969	0.	{4.2.2}
LM	0.969	0.	{4.2.2}
DF	0.867	0.	{4.2.2}
PM	0.9002	-0.3089	{4.2.1}
BS	0.956	0.	{4.2.2}
AS	0.969	0.	{4.2.2}
LP	0.969	0.	{4.2.2}
ES	0.956	0.	{4.2.2}
AF	0.937	0.	{4.2.2}
PP	0.80943	1.01687	{4.2.4}
UJ	0.9002	-0.3089	{4.2.1}
RM	0.9002	-0.3089	{4.2.1}
BI	0.94782	0.0836	{4.2.3}
MM	0.950	0.	{4.2.2}
NC	0.892	-0.086	{4.2.3}
MC	0.9	0.	{4.2.2}
OS	0.969	0.	{4.2.2}
OH	0.892	-0.086	{4.2.3}

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 TT variant, crown ratios missing in the input data are predicted using different equations depending on tree species and size. For all species except narrowleaf cottonwood and other hardwood, live trees less than 1.0" in diameter and dead trees of all sizes use equation {4.3.1.1} and one of the equations listed below,{4.3.1.2} or {4.3.1.3}, to compute crown ratio. Curlleaf mountain mahogany and bigtooth maple use crown ratio equation {4.3.1.3}, whereas all others not listed above use crown ratio equation {4.3.1.2}. Equation coefficients are found in table 4.3.1.1.

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

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

{4.3.1.3} $CR = ((X-1.0) * 10 + 1) / 100$

where:

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

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

Coefficient	Species Code						
	WB, LM	DF, BS, ES, AF, NC, OH	AS, MM	LP	PM, UJ, RM, OS	PP	BI, MC
R_1	-1.669490	-0.426688	-0.426688	-1.669490	-2.19723	-0.17561	5.0
R_2	-0.209765	-0.093105	-0.093105	-0.209765	0	-0.33847	0
R_3	0	0.022409	0.022409	0	0	0.05699	0
R_4	0.003359	0.002633	0.002633	0.003359	0	0.00692	0
R_5	0.011032	0	0	0.011032	0	0	0
R_6	0	-0.045532	-0.045532	0	0	0	0
R_7	0.017727	0	0	0.017727	0	0	0
R_8	-0..000053	0.000022	0.000022	-0.000053	0	0	0
R_9	0.014098	-0.013115	-0.013115	0.014098	0	0	0
SD	0.5	0.6957	0.9310	0.6124	0.2	0.8866	0.5

For all species, except singleleaf pinyon, Utah juniper, Rocky Mountain juniper, narrowleaf cottonwood, and other hardwood, a Weibull-based crown model developed by Dixon (1985) as described in Dixon (2002) is used to predict crown ratio for all live trees 1.0" in diameter or larger. To estimate crown ratio using this methodology, the average stand crown ratio is estimated from stand density index using equation {4.3.1.4}. Weibull parameters are then estimated from the average stand crown ratio using equations in equation set {4.3.1.5}. Individual tree crown ratio is then set from the Weibull distribution, equation {4.3.1.6} based on a tree's relative position in the diameter distribution and multiplied by a scale factor, shown in equation {4.3.1.7}, which accounts for stand density. Crowns estimated from the Weibull distribution are bounded to be between the 5 and 95 percentile points of the specified Weibull distribution. Equation coefficients for each species are shown in table 4.3.1.2.

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

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

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

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

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

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

where:

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

a_0, b_{0-1}, c_{0-1}, and d_{0-1} are species-specific coefficients shown in table 4.3.1.2

Table 4.3.1.2 Coefficients for the Weibull parameter equation {4.3.4} in the TT variant.

Species Code	Model Coefficients						
	a_0	b_0	b_1	c_0	c_1	d_0	d_1
WB	1	-0.82631	1.06217	3.31429	0	6.19911	-0.02216
LM	1	-0.82631	1.06217	3.31429	0	6.19911	-0.02216
DF	1	-0.24217	0.96529	-7.94832	1.93832	7.46296	-0.02944
ES	1	-0.90648	1.08122	3.48889	0	6.81087	-0.01037
AS	0	-0.08414	1.14765	2.77500	0	4.01678	-0.01516
LP	0	0.17162	1.07338	3.15000	0	6.00567	-0.03520

ES	1	-0.90648	1.08122	3.48889	0	6.81087	-0.01037
AF	1	-0.89553	1.07728	1.74621	0.29052	7.65751	-0.03513
PP	0	0.24916	1.04831	4.36	0	6.41166	-0.02041
BI	0	-0.23830	1.18016	3.04	0	4.62512	-0.01604
MM	0	-0.08414	1.14765	2.77500	0	4.01678	-0.01516
MC	0	-0.23830	1.18016	3.04	0	4.62512	-0.01604
OS	1	-0.26595	0.98326	-7.00555	1.60411	7.92810	-0.06298

Narrowleaf cottonwood and other hardwood live and dead trees of all sizes are assigned a crown ratio using equations {4.3.1.8} and {4.3.1.10}. Singleleaf pinyon, Utah juniper, and Rocky Mountain juniper live and dead trees 1.0 inch in diameter and larger are assigned a crown ratio using equation {4.3.1.9} and {4.3.1.10}.

{4.3.1.8} $CL = 5.17281 + 0.32552 * HT – 0.01675 * BA$

{4.3.1.9} $CL = -0.59373 + 0.67703 * HT$

{4.3.1.10} $CR = (CL / HT)$

where:

BA is total stand basal area in square feet/acre
HT is total tree height in feet
CL is crown length in feet (bounded between 1.0 and *HT*)
CR is tree crown ratio expressed as a proportion of total tree height

4.3.2 Crown Ratio Change

Crown ratio change is estimated after growth, mortality and regeneration are estimated during a projection cycle. Crown ratio change is the difference between the crown ratio at the beginning of the cycle and the predicted crown ratio at the end of the cycle. Crown ratio predicted at the end of the projection cycle is estimated for live tree records using equations {4.3.1.8} and {4.3.10} for narrowleaf cottonwood and other hardwood; equations {4.3.1.9} and {4.3.1.10} for singleleaf pinyon, Utah juniper, and Rocky Mountain juniper; and the Weibull distribution, equations {4.3.1.4}-{4.3.1.7}, for all other species. Crown change is checked to make sure it doesn't exceed the change possible if all height growth produces new crown. Crown change is further bounded to 1% per year for the length of the cycle to avoid drastic changes in crown ratio. Equations {4.3.1.1} – {4.3.1.3} are not used when estimating crown ratio change.

4.3.3 Crown Ratio for Newly Established Trees

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

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

where:

CR is crown ratio expressed as a proportion (bounded to $0.2 \leq CR \leq 0.9$)

PCCF	is crown competition factor on the inventory point where the tree is established
RAN	is a small random component

4.4 Crown Width Relationships

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

{4.4.1} Bechtold (2004); Equation 01

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

{4.4.2} Bechtold (2004); Equation 02

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

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

{4.4.3} Crookston (2003); Equation 03

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

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

{4.4.4} Crookston (2005); Equation 05

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

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

{4.4.5} 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 TT variant)
CW	is tree maximum crown width
CL	is tree crown length
CR	is tree 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} - {4.4.5} in the TT variant.

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
WB	10105	2.2354	0.66680	-0.11658	0.16927	0	0
LM	11301	4.0181	0.8528	0	0	0	0
DF	20205	6.0227	0.54361	-0.20669	0.20395	-0.00644	-0.00378
PM	10602	-5.4647	1.9660	-0.0395	0.0427	0	-0.0259
BS	09305	6.7575	0.55048	-0.25204	0.19002	0	-0.00313
AS	74605	4.7961	0.64167	-0.18695	0.18581	0	0
LP	10805	6.6941	0.81980	-0.36992	0.17722	-0.01202	-0.00882
ES	09305	6.7575	0.55048	-0.25204	0.19002	0	-0.00313
AF	01905	5.8827	0.51479	-0.21501	0.17916	0.03277	-0.00828
PP	12203	1.02687	1.49085	0.1862	0.68272	-0.28242	0
UJ	06405	5.1486	0.73636	-0.46927	0.39114	-0.05429	0
RM	06405	5.1486	0.73636	-0.46927	0.39114	-0.05429	0
BI	31206	7.5183	0.4461	0	0	0	0
MM	32102	5.9765	0.8648	0	0.0675	0	0
NC	74902	4.1687	1.5355	0	0	0	0.1275
MC	47502	4.0105	0.8611	0	0	0	-0.0431
OS	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
OH	74902	4.1687	1.5355	0	0	0	0.1275

*Equation number is a combination of the species FIA code (###) and source (##).
**DBH limited to a maximum of 25" for calculation of crown width

Table 4.4.2 *MinD* values and data bounds for equations {4.4.1} - {4.4.5} in the TT 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
LM	11301	5.0	n/a	n/a	n/a	n/a	25
DF	20205	1.0	1	75	n/a	n/a	80
PM	10602	5.0	n/a	n/a	-40	11	25
BS	09305	1.0	1	85	n/a	n/a	40
AS	74605	1.0	n/a	n/a	n/a	n/a	45
LP	10805	1.0	1	79	n/a	n/a	40

ES	09305	1.0	1	85	n/a	n/a	40
AF	01905	1.0	10	85	n/a	n/a	30
PP	12203	2.0	n/a	n/a	n/a	n/a	46
UJ	06405	1.0	n/a	n/a	n/a	n/a	36
RM	06405	1.0	n/a	n/a	n/a	n/a	36
BI	31206	1.0	n/a	n/a	n/a	n/a	30
MM	32102	5.0	n/a	n/a	n/a	n/a	39
NC	74902	5.0	n/a	n/a	-26	-2	35
MC	47502	5.0	n/a	n/a	-37	27	29
OS	12205	1.0	13	75	n/a	n/a	50
OH	74902	5.0	n/a	n/a	-26	-2	35

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

4.5 Crown Competition Factor

The TT variant uses crown competition factor (*CCF*) as a predictor variable in some growth relationships. Crown competition factor (Krajicek and others 1961) is a relative measurement of stand density that is based on tree diameters. Individual tree CCF_t values estimate the percentage of an acre that would be covered by the tree's crown if the tree were open-grown. Stand *CCF* is the summation of individual tree (CCF_t) values. A stand *CCF* value of 100 theoretically indicates that tree crowns will just touch in an unthinned, evenly spaced stand. Crown competition factor for an individual tree is calculated using equation {4.5.1} for all species except ponderosa pine, bigtooth maple, and curl-leaf mountain mahogany. Ponderosa pine uses equations {4.5.2}. Bigtooth maple and curl-leaf mountain mahogany species use equations {4.5.3}. Coefficients for all species are shown in Table 4.5.1.

All species other than bigtooth maple and curl-leaf mountain mahogany:

{4.5.1} Used for all species except ponderosa pine, bigtooth maple, and curl-leaf mountain mahogany

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

{4.5.2} Used for ponderosa pine:

$DBH \geq DBRK$: $CCF_t = R_1 + (R_2 * DBH) + (R_3 * DBH^2)$
$DBH < DBRK$: $CCF_t = R_4 * DBH^{R_5}$

{4.5.3} Used for curl-leaf mountain mahogany and bigtooth maple:

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

where:

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

DBRK is 10" for ponderosa pine, narrowleaf cottonwood, and other hardwood; 1.0" for all other species

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

Table 4.5.1 Coefficients *CCF* equations {4.5.1} – {4.5.3} in the TT variant.

Species Code	Model Coefficients				
	R_1	R_2	R_3	R_4	R_5
WB	0.01925	0.0168	0.00365	0.009187	1.7600
LM	0.01925	0.0168	0.00365	0.009187	1.7600
DF	0.11	0.0333	0.00259	0.017299	1.5571
PM	0.01925	0.01676	0.00365	0.009187	1.7600
BS	0.03	0.0173	0.00259	0.007875	1.7360
AS	0.03	0.0238	0.00490	0.008915	1.7800
LP	0.01925	0.0168	0.00365	0.009187	1.7600
ES	0.03	0.0173	0.00259	0.007875	1.7360
AF	0.03	0.0216	0.00405	0.011402	1.7560
PP	0.03	0.0180	0.00281	0.007813	1.7680
UJ	0.01925	0.01676	0.00365	0.009187	1.7600
RM	0.01925	0.01676	0.00365	0.009187	1.7600
BI	0.0204	0.0246	0.0074	0	0
MM	0.03	0.0238	0.00490	0.008915	1.7800
NC	0.03	0.0215	0.00363	0.011109	1.7250
MC	0.0204	0.0246	0.0074	0	0
OS	0.01925	0.0168	0.00365	0.009187	1.7600
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. In the TT variant the threshold diameter is set to: 1.0" for narrowleaf cottonwood and other hardwood; 99.0" for singleleaf pinyon, Utah juniper, Rocky Mountain juniper, bigtooth maple, and curl-leaf mountain mahogany; and 3.0" for all other species.

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

4.6.1 Small Tree Height Growth

The small-tree height increment model predicts either 5-year, or 10-year, height growth (*HTG*) depending on species. Height growth estimates are then scaled to the appropriate cycle length.

Small tree 5-year height growth in the TT variant is estimated as a function of crown ratio and point crown competition factor for whitebark pine, limber pine, Douglas-fir, blue spruce, lodgepole pine, Engelmann spruce, subalpine fir, and other softwood. Height growth is estimated using equation {4.6.1.1} and coefficients shown in table 4.6.1.1.

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

$STDEV = HTG * (c_5 + (c_6 * CR))$

where:

HTG is estimated 5-year height growth
STDEV is estimated standard deviation for the height growth estimate
ZRAND is a random number, bounded $-2 \leq ZRAND \leq 2$
TPCCF is crown competition factor based on sample point statistics (bounded to $25 \leq TPCCF \leq 300$)
CR is a tree's live crown ratio (compacted) expressed as a percent
$c_1 - c_6$ are species-specific coefficients for equation {4.6.1.1} shown in table 4.6.1.1

Table 4.6.1.1 Coefficients ($c_1 - c_6$) for equation {4.6.1.1} in the TT variant.

Species Code	Model Coefficients					
	c_1	c_2	c_3	c_4	c_5	c_6
WB	1.17527	-0.42124	-2.56002	-0.58642	1.08720	-0.00230
LM	1.17527	-0.42124	-2.56002	-0.58642	1.08720	-0.00230
DF	-4.35709	0.67307	-2.49682	-0.51938	1.13785	-0.00185
BS	-0.55052	-0.02858	-2.26007	-0.67115	1.09730	-0.00130
LP	-0.90086	0.16996	-1.50963	-0.61825	1.00749	-0.00435
ES	-0.55052	-0.02858	-2.26007	-0.67115	1.09730	-0.00130
AF	-4.35709	0.67307	-2.49682	-0.51938	1.13785	-0.00185
OS	1.17527	-0.42124	-2.56002	-0.58642	1.08720	-0.00230

Small tree 10-year height growth for quaking aspen and Rocky Mountain maple is obtained from a height-age curve from Shepperd (1995). Because Shepperd's original curve seemed to overestimate height growth, the TT variant reduces the estimated height growth by 25 percent (shown in equation {4.6.1.2}). A height is estimated from the tree's current age, and then its current age plus 10 years. Height growth is the difference between these two height estimates, and converted from centimeters to feet. An estimate of the tree's current age may be entered during data input, is obtained at the start of a projection using the tree's height and solving equation {4.6.1.2} for age, or known for trees established using the regeneration establishment model in FVS.

{4.6.1.2} $HTG = ([((26.9825 * (A+10)\text{^}1.1752) - (26.9825 * A\text{^}1.1752)) / (2.54 * 12)] + 0.1*ZRAND)$

$* 0.75 * RSIMOD$

$RSIMOD = 0.5 * (1 + (SI - 30)/40)$ for quaking aspen, bounded $0 \leq RSIMOD \leq 1$

$RSIMOD = 0.5 * (1 + (SI - 5)/25)$ for Rocky Mountain maple, bounded $0 \leq RSIMOD \leq 1$

where:

HTG is estimated 10-year tree height growth in feet
A is tree age
ZRAND is a random number, bounded $-2 \leq ZRAND \leq 2$

SI is species site index

Small tree potential 10-year height growth for singleleaf pinyon, Utah juniper, Rocky Mountain juniper, bigtooth maple, narrowleaf cottonwood, curl-leaf mountain mahogany, and other hardwood is estimated using equation {4.6.1.3}.

{4.6.1.3} $POTHTG = ((SJ / 5.0) * (SJ * 1.5 - H) / (SJ * 1.5)) * 0.83$

where:

POTHTG is potential 10-year height growth
SJ is species site index on a base-age basis
H is tree height at the beginning of the projection cycle

Potential height growth is then adjusted based on stand density (*PCTRED*) as computed with equation {4.6.1.4}, and crown ratio (*VIGOR*) as shown in equations {4.6.1.5} and {4.6.1.6}. Bigtooth maple, Rocky Mountain maple, narrowleaf cottonwood, curl-leaf mountain mahogany, and other hardwood use equation {4.6.1.5} to estimate *VIGOR*; singleleaf pinyon, Utah juniper, and Rocky Mountain juniper use equation {4.6.1.6}. Height growth is then estimated using equation 4.6.1.7 or 4.6.1.8.

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

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

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

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

{4.6.1.7} $HTG = POTHTG * PCTRED * VIGOR + 0.1 * ZRAND$

Used for singleleaf pinyon, Utah juniper, Rocky Mountain juniper, bigtooth maple, Rocky

Mountain maple, and curl-leaf mountain mahogany.

{4.6.1.8} $HTG = POTHTG * PCTRED * VIGOR + 0.2 * ZRAND$

Used for narrowleaf cottonwood and other hardwood.

where:

PCTRED is reduction in height growth due to stand density (bounded to $0.01 \leq PCTRED \leq 1$)
HT_{Avg} is average height of the 40 largest diameter trees in the stand
CCF is stand crown competition factor
VIGOR is reduction in height growth due to tree vigor (bounded to $VIGOR \leq 1.0$)
CR is a tree’s live crown ratio (compacted) expressed as a proportion
HTG is estimated height growth for the cycle
POTHTG is potential 10-year height growth
ZRAND is a random number, bounded $-2 \leq ZRAND \leq 0.5$

Small tree 5-year height growth for ponderosa pine (PP) is estimated using equation {4.6.1.9}.

{4.6.1.9} $HTG = 2.764559 - 0.009643 * BA + 0.025303 * CR^2 + 0.1 * ZRAND$

where:

HTG	is estimated 5-year height growth
BA	is total stand basal area
CR	is a tree's live crown ratio class (1 = 0-10 percent, 2 = 11-20 percent, …, 9 = >80 percent)
ZRAND	is a random number, bounded $-2 \leq ZRAND \leq 0.5$

For all species, 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 {4.6.1.10}, and applied as shown in equation {4.6.1.11}. The range of diameters for each species is shown in table 4.6.1.2.

{4.6.1.10}

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

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

where:

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

Table 4.6.1.2 Diameter bounds by species in the TT variant.

Species Code	X_{min}	X_{max}
WB	1.5	3.0
LM	1.5	3.0
DF	1.5	3.0
PM*	90.0	99.0

Species Code	X_{min}	X_{max}
BS	1.5	3.0
AS	1.5	3.0
LP	1.5	3.0
ES	1.5	3.0
AF	1.5	3.0
PP	2.0	5.0
UJ*	90.0	99.0
RM*	90.0	99.0
BI*	90.0	99.0
MM	2.0	4.0
NC	0.5	2.0
MC*	90.0	99.0
OS	1.5	3.0
OH	0.5	2.0

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

4.6.2 Small Tree Diameter Growth

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

For whitebark pine, limber pine, Douglas-fir, blue spruce, quaking aspen, lodgepole pine, Engelmann spruce, subalpine fir, and other softwood in the TT variant, these two small-tree diameters are estimated using equation {4.6.2.1} or {4.6.2.2}, and coefficients for these equations are 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 TT variant.

Species	Equation	Model Coefficients

Code	Used	b_1	b_2	b_3	b_4
WB	{4.6.2.1}	0.000231	-0.00005	0.001711	0.17023
LM	{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
BS	{4.6.2.2}	0.04125	0.17486	-0.002371	-0.00070
AS	{4.6.2.2}	-0.41227	0.16944	0.003191	-0.00220
LP	{4.6.2.2}	-0.41227	0.16944	0.003191	-0.00220
ES	{4.6.2.2}	0.04125	0.17486	-0.002371	-0.00070
AF	{4.6.2.2}	-0.15906	0.15323	0	0
OS	{4.6.2.1}	0.000231	-0.00005	0.001711	0.17023

For Rocky Mountain maple, narrowleaf cottonwood, and other hardwood these two small-tree diameters are estimated using the species-specific height-diameter relationships discussed in section 4.1.

Singleleaf pinyon, Utah juniper, and Rocky Mountain juniper use equation {4.6.2.3} as previously described.

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

where:

DBH is tree diameter at root collar
HT is tree height
SI is species site index on a base-age basis

Bigtooth maple and curl-leaf mountain mahogany use the Curtis-Arney method by default and is shown in equation {4.6.2.4}. If height calibration is specified with the NOHTDREG keyword, the logistic equations discussed in section 4.1 are used to estimate small tree diameter growth.

{4.6.2.4} Used for Bigtooth maple and curl-leaf mountain mahogany

$HT > HAT3$: $DBH = \exp(\ln((\ln(HT - 4.5) - \ln(a))/-b) / c)$
$HT \leq HAT3$: $DBH = ((HT - 4.51) * 2.7) / (4.5 + a * \exp(-b * (3.0 ^\wedge c)) - 4.51) + 0.3$

where:

HAT3 $= 4.5 + a * \exp(-b * (3.0 ^\wedge c))$
DBH is tree diameter at breast height
HT is tree height
a, b, c are species-specific coefficients shown as P_2, P_3, and P_4 in section 4.1

For ponderosa pine (PP) these two small-tree diameters are estimated using equation {4.6.2.5}.

{4.6.2.5} $DBH = \exp(-1.10700 + 0.830144 * HT)$

where:

DBH is tree diameter at breast height
HT is tree height

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. In the TT variant the threshold diameter is set to: 1.0" for narrowleaf cottonwood and other hardwood; 99.0" for singleleaf pinyon, Utah juniper, Rocky Mountain juniper, bigtooth maple, and curl-leaf mountain mahogany; and 3.0" for all other species.

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

4.7.1 Large Tree Diameter Growth

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

The TT variant predicts diameter growth for whitebark pine, limber pine, Douglas-fir, blue spruce, lodgepole pine, Engelmann spruce, subalpine fir ponderosa pine and other softwood using equation {4.7.1.1}. Ponderosa pine coefficients are from an equation fit for the Payette National Forest in the Central Idaho variant. Coefficients for these equations are shown in tables 4.7.1.1 – 4.7.1.6. Diameter growth equations for other species in the TT variant are shown later in this section.

{4.7.1.1} $\ln(DDS) = b_1 + (b_2 * SI) + (b_3 * \sin(ASP) * SL) + (b_4 * \cos(ASP) * SL) + (b_5 * SL) + (b_6 * SL^2) + (b_7 * \ln(DBH)) + (b_8 * BAL / 100) + (b_9 * CR) + (b_{10} * CR^2) + (b_{11} * DBH^2) + b_{12} * (CCF / 100)) + b_{13} + (b_{14} * PBAL / \ln(DBH + 1)) + (b_{15} * \ln(BA))$

where:

DDS is squared inside-bark diameter
SI is species site index
ASP is a species-specific variable for stand aspect ((ASP = stand aspect) for ponderosa pine; (ASP = stand aspect – 0.7854) for all other species)
SL is stand slope
DBH is tree diameter at breast height
BAL is total basal area in trees larger than the subject tree
PBAL is total basal area in trees larger than the subject tree on the inventory point where the tree is located
CR is a tree's live crown ratio (compacted) expressed as a proportion
CCF is stand crown competition factor
BA is total stand basal area
b_1 is a location-specific coefficient shown in table 4.7.1.2

b_2 is a coefficient based on site index species shown in table 4.7.1.3
b_3- b_{10}, b_{14}, b_{15} are species-specific coefficients shown in tables 4.7.1.1
b_{11} is a location-specific coefficient shown in table 4.7.1.4
b_{12} is a coefficient based on site index class shown in table 4.7.1.5
b_{13} is a coefficient based on habitat type class shown in table 4.7.1.6

Table 4.7.1.1 Coefficients (b_3- b_{10}, b_{14}, b_{15}) for equation {4.7.1.1} in the TT variant.

	Species Code					
Coefficient	**WB, LM, OS**	**DF**	**LP**	**BS, ES**	**AF**	**PP**
b_3	-0.017520	0.076614	-0.036871	0.102053	0.052805	0.076531
b_4	-0.609774	-0.268610	-0.075306	-0.698103	-0.17839	0.127311
b_5	-2.057060	-0.711260	-0.129291	1.335928	0.784185	0.024336
b_6	2.113263	0	0	-1.481349	-1.504007	- 0.781480
b_7	0.213947	0.533965	0.563751	0.378802	0.648535	0.822203
b_8	-0.358634	-0.574858	-0.469671	-0.490005	-0.312129	0
b_9	1.523464	1.931900	2.164346	1.098353	0.137638	1.768935
b_{10}	0	-0.894368	-0.625799	0	1.0665429	- 0.176164
b_{14}	0	0	0	0	0	- 0.006065
b_{15}	0	0	0	0	0	- 0.257322

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

	Species Code					
Location Code	**WB, LM, OS**	**DF**	**LP**	**BS, ES**	**AF**	**PP**
403 – Bridger	1.911884	1.084994	0.494205	1.543251	0.921658	1.879603
405 – Caribou	1.911884	1.084994	0.494205	1.543251	0.921658	1.879603
415 – Targhee	1.568742	0.796640	0.502908	0.943003	0.807282	1.879603
416 – Teton	2.001195	1.042871	0.502908	0.792165	0.914279	1.879603

Table 4.7.1.3 b_2 coefficients by site index species for equation {4.7.1.1} in the TT variant.

Site Index Species	Species Code					
	WB, LM, OS	DF	LP	BS, ES	AF	PP
WB, LM, PM, LP, PP, UJ, RM, BI, MM, NC, MC, OS, OH	0.001766	0.011597	0.009756	0.011389	0.003955	0
DF	0.001766	0.011597	0.009756	0.011389	0.003955	0
BS, ES, AF	0.001766	0.011597	0.009756	0.011389	0.003955	0
--	0.001766	0.011597	0.014334	0.019985	0.006310	0
AS	0.001766	0.011597	0.014334	0.019985	0.006310	0

Table 4.7.1.4 b_{11} coefficients by location code for equation {4.7.1.1} in the TT variant.

Location Code	Species Code					
	WB, LM, OS	DF	LP	BS, ES	AF	PP
403 – Bridger	-0.0006538	-0.0001997	0	-0.0001056	-0.0002152	-0.0004163
405 – Caribou	-0.0006538	-0.0001997	0	-0.0001056	-0.0002152	-0.0004163
415 – Targhee	-0.0006538	-0.0001997	-0.0009803	-0.0001056	-0.0002152	-0.0004163
416 – Teton	-0.0006538	-0.0001997	-0.0016416	-0.0001056	-0.0002567	-0.0004163

Table 4.7.1.5 b_{12} coefficients by site index class for equation {4.7.1.1} in the TT variant.

Site Index Class	Species Code					
	WB, LM, OS	DF	LP	BS, ES	AF	PP
1 (SI<30)	-0.199592	-0.641932	-0.206752	-0.045495	-0.186614	0
2 (30≤SI≤39)	-0.199592	-0.141370	-0.206752	-0.045495	-0.186614	0
3 (40≤SI≤49)	-0.199592	-0.141370	-0.206752	-0.204852	-0.186614	0
4 (50≤SI≤59)	-0.199592	-0.141370	-0.206752	-0.311383	-0.023236	0
5 (60≤SI)	-0.199592	-0.141370	-0.206752	-0.311383	-0.023236	0

Table 4.7.1.6 b_{13} coefficients by habitat type class for equation {4.7.1.2} in the TT variant. Mapping of habitat type classes is shown in Appendix A.

Habitat Type Class	Species Code
	PP
0	0.
1	0.006074
2	0.181590
3	-0.196098
4	-0.055780
5	0.133907

Large-tree diameter growth for quaking aspen and Rocky Mountain maple are predicted using 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.

{4.7.1.3} Used for quaking aspen and Rocky Mountain maple

$POTGR = (0.4755 - 0.0000038336 * DBH^{4.1488}) + (0.0451 * CR * DBH^{0.67266})$
$MOD = 1.0 - \exp(-FOFR * GOFAD * ((310-BA)/310)^{0.5})$
$FOFR = 1.07528 * (1.0 - \exp(-1.89022 * DBH / QMD))$
$GOFAD = 0.21963 * (QMD + 1.0)^{0.73355}$
$PREDGR = POTGR * MOD * (.48630 + 0.01258 * SI)$

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

Large-tree diameter growth for narrowleaf cottonwood and other hardwood is predicted using equation set {4.7.1.4}. 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.

{4.7.1.4} Used for narrowleaf cottonwood and other hardwood

$DF = (1.55986 + 1.01825 * DBH - 0.29342 * \ln(TBA) + 0.00672 * SJ - 0.00073 * BAU / BA) * 1.05$
$DG = (DF - DBH) * BRATIO * DSTAG$
DSTAG = 1 when RELSDI is less than or equal to 0.7 or the stagnation indicator has not been turned
on using field 7 of the SDIMAX keyword.
DSTAG = 3.33333 * (1 – RELSDI) when RELSDI is greater than 0.7 and the stagnation indicator has
been turned on using field 7 of the SDIMAX keyword.

where:

DF	is tree diameter at breast height at the end of the cycle
DBH	is tree diameter at breast height at the beginning of the cycle
BA	is total stand basal area at the beginning of the cycle

TBA	is total stand basal area at the beginning of the cycle (bounded to be $\geq$ 5)
BAU	is total stand basal area at the beginning of the cycle in diameter classes larger than the diameter class the tree being projected is in
SJ	is species-specific site index on a base-age basis
DG	is tree diameter growth
BRATIO	is species-specific bark ratio
DSTAG	is a growth multiplier to account for stand stagnation
RELSDI	is a current stand density index divided by the maximum stand density index for the stand (bounded to be less than or equal to 0.85)

Equations presented in section 4.6 are used for trees of all sizes for singleleaf pinyon, Utah juniper, Rocky Mountain juniper, bigtooth maple, and curl-leaf mountain mahogany.

4.7.2 Large Tree Height Growth

Species in the TT variant use different types of equations depending on species. Ten species use Johnson's SBB (1949) method (Schreuder and Hafley, 1977). These species are whitebark pine, limber pine, Douglas-fir, blue spruce, quaking aspen, lodgepole pine, Engelmann spruce, subalpine fir, Rocky Mountain maple, and other softwood. Using this method, height growth is obtained by subtracting current height from the estimated future height. Parameters of the SBB distribution cannot be calculated 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 4.7.2.1. In this case, height growth is set to 0.1. Otherwise, the SBB distribution "*Z*" parameter is estimated using equation {4.7.2.1}.

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

$FBY1 = \ln[Y1/(1 - Y1)]$
$FBY2 = \ln[Y2/(1 - Y2)]$
$Y1 = (DBH – 0.1) / C_1$
$Y2 = (HT – 4.5) / C_2$

where:

HT	is tree height
DBH	is tree diameter at breast height
Z	is a parameter in the SBB distribution
Y1*, Y2*	are temporary variables in the calculation of Z
FBY1, FBY2	are temporary variables in the calculation of Z
$C_1 – C_7$	are coefficients based on species and crown ratio class shown in table 4.7.2.1

Table 4.7.2.1 Coefficients in the large tree height growth model, by crown ratio, for species using the Johnson's SBB height distribution in the TT variant.

Coefficient by	Species Code							
***CR** class**	**WB**	**LM**	**DF**	**AS, MM**	**LP**	**BS, ES**	**AF**	**OS**
C_1 (*CR*$\leq$ 24)	37	37	60	30	30	50	20	37
C_1 (25$\leq$*CR*$\leq$74)	45	45	70	30	45	50	35	45
C_1 (75$\leq$*CR*$\leq$100)	45	45	70	35	35	50	50	45
C_2 (*CR*$\leq$ 24)	85	85	105	85	105	145	95	85

C_2 (25≤*CR*≤74)	100	100	120	85	110	145	110	100
C_2 (75≤*CR*≤100)	90	90	130	85	90	140	130	90
C_3 (*CR*≤ 24)	1.77836	1.77836	2.43099	2.00995	2.00207	1.23692	0.90779	1.77836
C_3 (25≤*CR*≤74)	1.66674	1.66674	1.85710	2.00995	2.50885	1.23692	1.36713	1.66674
C_3 (75≤*CR*≤100)	1.64770	1.64770	1.51547	1.80388	1.31478	0.94647	1.63172	1.64770
C_4 (*CR*≤ 24)	-0.51147	-0.51147	0.20403	0.03288	-0.25204	0.30499	0.33845	-0.51147
C_4 (25≤*CR*≤74)	0.25626	0.25626	-0.10692	0.03288	0.09740	0.30499	0.35062	0.25626
C_4 (75≤*CR*≤100)	0.30546	0.30546	0.30923	-0.07682	0.21254	0.31838	0.60577	0.30546
C_5 (*CR*≤ 24)	1.88795	1.88795	1.28447	1.81059	2.04453	1.19486	1.06402	1.88795
C_5 (25≤*CR*≤74)	1.45477	1.45477	1.40067	1.81059	1.85457	1.19486	1.25426	1.45477
C_5 (75≤*CR*≤100)	1.35015	1.35015	1.30655	1.70032	1.29774	1.04318	1.29877	1.35015
C_6 (*CR*≤ 24)	1.20654	1.20654	0.99886	1.28612	1.62734	1.09838	0.81823	1.20654
C_6 (25≤*CR*≤74)	1.11251	1.11251	1.16053	1.28612	1.48205	1.09838	1.05571	1.11251
C_6 (75≤*CR*≤100)	0.94823	0.94823	1.23707	1.29148	1.09363	0.95444	1.16988	0.94823
C_7 (*CR*≤ 24)	0.57697	0.57697	0.79629	0.72051	0.72514	0.90058	0.97688	0.57697
C_7 (25≤*CR*≤74)	0.67375	0.67375	0.78576	0.72051	0.77851	0.90058	0.90342	0.67375
C_7 (75≤*CR*≤100)	0.70453	0.70453	0.86427	0.72343	0.85692	0.91934	0.90860	0.70453
C_8 (*CR*≤ 24)	3.57635	3.57635	5.66171	3.00551	2.84910	2.08863	1.95458	3.57635
C_8 (25≤*CR*≤74)	2.17942	2.17942	3.85554	3.00551	3.49791	2.08863	2.31128	2.17942
C_8 (75≤*CR*≤100)	2.46480	2.46480	2.24521	2.91519	2.30681	1.78262	2.11592	2.46480
C_9 (*CR*≤ 24)	0.90283	0.90283	1.02398	1.01433	0.91104	0.97969	1.27034	0.90283
C_9 (25≤*CR*≤74)	0.88103	0.88103	0.94853	1.01433	0.97420	0.97969	1.07333	0.88103
C_9 (75≤*CR*≤100)	1.00316	1.00316	0.91281	0.95244	1.01686	1.00481	1.00870	1.00316

**CR* represents percent crown ratio

Bias in the estimate of Z for Douglas-fir, blue spruce, lodgepole pine, Engelmann spruce, and subalpine fir is estimated using the set of equations shown in {4.7.2.2} and coefficients shown in table 4.7.2.2.

{4.7.2.2} $ZBIAS = C_{10} + C_{11} * EL$ for $55 \leq EL \leq 80$

where:

ZBIAS = 0 for stand elevations outside this range; or when ZBIAS < 0 and (Z – ZBIAS) > 2
EL is the elevation of the stand expressed in hundreds of feet

Table 4.7.2.2 Coefficients for the large tree height growth model bias correction in the TT variant.

Species Code	C_{10}	C_{11}
DF	-0.86001	0.01051
BS	-0.84735	0.01102
LP	0.40153	-0.0078
ES	-0.84735	0.01102
AF	0.89035	-0.01331

Quaking aspen and Rocky Mountain maple use equation {4.7.2.3} to eliminate known bias.

{4.7.2.3} ZBIAS = 0.1 – 0.10273 * Z + 0.00273 * Z^2 (bounded ZBIAS $\geq$ 0)

Equation set {4.7.2.4} is used to eliminate known bias in the estimate of Z.

{4.7.2.4} Z = Z – ZBIAS for Douglas-fir, blue spruce, lodgepole pine, Engelmann spruce and subalpine fir

Z = Z + ZBIAS for quaking aspen and Rocky Mountain maple

If the *Z* value is 2.0 or less, it is adjusted for all younger aged trees using equation {4.7.2.5}. This adjustment is done for trees with an estimated age between 11 and 39 years and a diameter less than 9.0 inches. After this calculation, the value of *Z* is bounded to be 2.0 or less for trees meeting these criteria.

{4.7.2.5} *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
CLOSUR	is an adjustment based on crown closure
K	is an adjustment for trees with long crowns

Estimated height 10 years later is calculated using equation {4.7.2.6}, and finally, 10-year height growth is calculated by subtraction using equation {4.7.2.7} and adjusted to the cycle length.

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

PSI = C_8 * [(*D10* – 0.1) / (0.1 + C_1– *D10*)]^C_9 * [exp(*K*)]
K = *Z* * [(1 - C_7^2)^(0.5 / C6)]

{4.7.2.7} Height growth:

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

where:

H10	is estimated height of the tree in ten years
HT	is height of the tree at the beginning of the cycle
D10	is estimated diameter at breast height of the tree in ten years
POTHTG	is potential height growth
C_1 – C_9	are regression coefficients based on crown ratio class shown in table 4.7.2.1

Large tree height growth for Ponderosa pine is estimated using equation set {4.7.2.8}.

{4.7.2.8} *HTG* = exp(*X*) + 0.4809 (bounded *HTG* $\geq$ 0.1)

$X = 2.76195 + 0.62144 * \ln(DG) – 0.00013358 * HT^2 – 0.5657 * \ln(D) + 0.23315 * \ln(HT)$

where:

HTG	is estimated height growth
HT	is tree height at the beginning of the cycle
D	is tree diameter at breast height at the beginning of the cycle
DG	is estimated tree diameter growth for the current cycle

Large tree height growth for narrowleaf cottonwood and other hardwood is estimated using equations from the Spruce-fir model type of the Central Rockies variant. The equations predict height growth from site index curves for even-aged stands and height growth from a regression equation for uneven-aged stands. These estimates get blended when certain conditions are met, and in some instances a growth reduction due to stand stagnation may be applied. A stand is considered uneven-aged if the range in ages between the 5th percentile and 95th percentile trees in the basal area distribution exceeds 40 years.

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

The final height growth estimate for a tree depends on whether the stand is even-aged or uneven-aged, total stand basal area, the tree's position in the stand, and whether the stand is considered as stagnated. Equation {4.7.2.9} is used when the stand is even-aged, or the total stand basal area is less than 70 square feet, or when the stand is uneven-aged with total stand basal area at least 70 square feet and the tree's percentile in the basal area distribution is at least 40. Equation {4.7.2.10} is used when the stand is uneven-aged with stand basal area at least 70 square feet and the tree's percentile in the basal area distribution is less than 40. Equation {4.7.2.11} is used when the stand is uneven-aged with stand basal area at least 70 square feet and the tree's percentile in the basal area distribution is at least 10 but no larger than 40.

{4.7.2.9} $HTG = [((HHE2 - HHE1) * ADJUST) + (ZZRAN * 0.1)] * [(DSTAG + 1) * 0.5]$

{4.7.2.10} $HTG = [(HHU2 - HHU1) + (ZZRAN * 0.1)] * [(DSTAG + 1) * 0.5]$

{4.7.2.11} $HTG = [(XWT * ((HHE2 - HHE1) * ADJUST) + (1 - XWT) * (HHU2 - HHU1)) + (ZZRAN * 0.1)] * [(DSTAG + 1) * 0.5]$

where:

HTG	is estimated 10-year height growth
HHE1	is estimated tree height at the beginning of the cycle using the even-aged equations

HHE2	is estimated tree height 10-years in the future using the even-aged equations
HHU1	is estimated tree height at the beginning of the cycle using the uneven-aged equations
HHU2	is estimated tree height 10-years in the future using the uneven-aged equations
ADJUST	is an adjustment based on site index (*ADJUST* = 0.78 + 0.0023 * site index)
ZZRAN	is a random number in the range $-2 \leq ZZRAN \leq 2$
DSTAG	is an adjustment for stagnated stand conditions
XWT	is a weight used to blend even-aged and uneven-aged height growth estimates (*XWT* = ((*PCT* - 10) * (10 / 3)) / 100
PCT	is the tree's percentile in the basal area distribution

Even-aged height is estimated using Alexander's (1967) site curves for Engelmann spruce and sub-alpine fir. Height is estimated using equation {4.7.2.12}. If the tree age is less than 30 years, then the height estimate is modified using equation {4.7.2.13}.

{4.7.2.12} $HTE = (4.5 + (2.75780 * SJ \wedge 0.83312) * [1 – \exp(-0.015701 * AGETEM)] \wedge (22.71944 * SJ \wedge -0.63557)) * FACTOR$

{4.7.2.13} $HTE = 4.5 + [(HTE – 4.5) / AGETEM] * A$

where:

HTE	is the even-aged height estimate
A	is breast-height tree age
SJ	is species site index on a base-age basis
AGETEM	is the tree's breast-height age, bounded $AGETEM \geq 30$
FACTOR	is an adjustment based on the ratio of stand basal area in trees larger than the diameter class for the subject tree to total stand basal area (*FACTOR* = (1 – (*BAU* / *BA*)) bounded $0.728 \leq FACTOR \leq 1.0$)
BAU	is total basal area in trees in larger diameter classes than the subject tree
BA	is total stand basal area

The estimate for uneven-aged stands is similarly obtained from equations that predict a tree's future height based on stand and tree variables, equation {4.7.2.14}.

{4.7.2.14} $HTU = 4.5 + (-2.04 + 1.4534 * SJ) * [(1 – \exp(-0.058112 * DBH)) \wedge (1.8944 * (BA \wedge -0.192979)]$

where:

HTU	is the uneven-aged height estimate
SJ	is species site index on a base-age basis
DBH	is tree diameter at breast height
BA	is total stand basal area, bounded to be ≥ 10

Height growth for singleleaf pinyon, Utah juniper, Rocky Mountain juniper, bigtooth maple, and curl-leaf mountain mahogany is estimated using small tree height growth equations discussed in section 4.6.1 for all sizes of trees.

5.0 Mortality Model

The TT variant uses a blend of the SDI-based mortality model as described in Section 7.3.2 of Essential FVS: A User's Guide to the Forest Vegetation Simulator (Dixon 2002, referred to as EFVS) and the original Prognosis type mortality model described in Section7.3.1. The SDI-based mortality model is comprised of two steps: 1) determining the amount of stand mortality (section 7.3.2.1 of EFVS) and 2) dispersing stand mortality to individual tree records (section7.3.2.2 of EFVS). In determining the amount of stand mortality, the summation of individual tree background mortality rates is used when stand density is below the minimum level for density dependent mortality (default is 55% of maximum SDI), while stand level density-related mortality rates are used when stands are above this minimum level.

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

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

{5.0.2} $RIP = 1 – (1 – RI)^Y$

where:

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

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

Species Code	p_0	p_1
WB	6.5112	-0.0052485
LM	6.5112	-0.0052485
DF	7.2985	-0.0129121
PM	5.1677	-0.0077681
BS	9.6943	-0.0127328
AS	5.1677	-0.0077681
LP	5.9617	-0.0340128
ES	9.6943	-0.0127328
AF	5.1677	-0.0077681
PP	0.21180	0
UJ	5.1677	-0.0077681
RM	5,1677	-0.0077681
BI	5.5877	-0.005348

Species Code	p_0	p_1
MM	5.1677	-0.0077681
NC	5.9617	-0.0052485
MC	5.9617	-0.0340128
OS	5.1677	-0.0077681
OH	5.9617	-0.0052485

Ponderosa pine in the TT variant uses the Prognosis-type mortality model (Hamilton 1986). The first part of the mortality rate estimate predicts individual tree mortality based on habitat type, species, diameter, diameter increment, estimated potential diameter increment, stand basal area, and a tree's diameter relative to the average stand diameter. The second part of the mortality rate estimate is dependent on the proximity of stand basal area to the site maximum and the rate of basal area increment. The final mortality rate applied to a tree record is a weighted average of these two predictions.

The equation used to calculate the first part of mortality for ponderosa pine is shown in equation {5.0.3} and this is then adjusted to the length of the cycle using a compound interest formula as shown in equation {5.0.4}. The coefficient used for equation {5.0.3} is shown in table 5.0.1 Diameter growth in equation {5.0.3} is estimated using equation {5.0.5} Values for the diameter growth index (*I*) represent ponderosa pine habitat types on the Payette National Forest.

{5.0.3} $RI = [1 / (1 + \exp(p_0 + 2.76253 + 0.2223 * \sqrt{DBH} + -0.0460508 * \sqrt{BA} + 11.2007 * DG + 0.2463 * RDBH + ((-0.55442 + 6.0713 * DG) / DBH)))]$

{5.0.4} $RIP = 1 - (1 - RI)^{\wedge}Y$

{5.0.5} $DG = 0.20 + (0.05 * I)$

where:

RI	is the proportion of the tree record attributed to mortality
DBH	is tree diameter at breast height
BA	is total stand basal area
Y	is length of the current projection cycle in years
DG	is diameter growth for the cycle
I	is a diameter growth index value determined by habitat type and location code $I = 12$ for trees with $DBH > 5.0$" $I = 41$ for trees with $DBH \leq 5.0$"
BAMAX	is maximum basal area expected for the species
SDI_{max}	is maximum stand density index
p_0	is a species-specific coefficient shown in table 5.0.1

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

Once the amount of stand mortality is determined based on either the summation of background mortality rates or density-related mortality rates, mortality is dispersed to individual tree records in relation to a tree's percentile in the basal area distribution (*PCT*) using equation {5.0.6}. This value is then adjusted by a species-specific mortality modifier (representing the species' tolerance), and for some species a crown ratio modifier, to obtain a final mortality rate as shown in equation {5.0.7}. The mortality modifier for ponderosa pine is from ponderosa pine in the Utah variant.

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

{5.0.6} $MR = 0.84525 - (0.01074 * PCT) + (0.0000002 * PCT3)$

{5.0.7} Final mortality rate

Used for narrowleaf cottonwood and other hardwood: $MORT = MR * (1 - (CR / 100)) * MWT * 0.1$

Used for all other species: $MORT = MR * MWT * 0.1$

where:

MR is the proportion of the tree record attributed to mortality (bounded: $0.01 \leq MR \leq 1$)
PCT is the subject tree's percentile in the basal area distribution of the stand
MORT is the final mortality rate of the tree record
MWT is a mortality weight value based on a species' tolerance shown in table 5.2.1

Table 5.2.1 *MWT* values for the mortality equation {5.0.7} in the TT variant.

Species Code	*MWT*
WB	0.8
LM	0.7
DF	0.55
PM	0.7
BS	0.5
AS	1.0
LP	0.9
ES	0.5
AF	0.6
PP	0.85
UJ	0.7
RM	0.7
BI	0.7
MM	1.0

NC	0.9
MC	1.1
OS	0.75
OH	0.90

6.0 Regeneration

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

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

Table 6.0.1 Regeneration parameters by species in the TT variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
WB	No	0.4	1.0	23.0
LM	No	0.3	1.0	27.0
DF	No	0.3	1.0	21.0
PM	No	0.4	0.5	6.0
BS	No	0.3	0.5	18.0
AS	Yes	0.2	6.0	20.0
LP	No	0.4	1.0	24.0
ES	No	0.3	0.5	18.0
AF	No	0.3	0.5	18.0
PP	No	0.5	1.0	17.0
UJ	No	0.3	0.5	6.0
RM	No	0.3	0.5	6.0
BI	Yes	0.2	0.5	6.0
MM	Yes	0.2	6.0	16.0
NC	Yes	0.3	3.0	16.0
MC	No	0.2	0.5	6.0
OS	No	0.2	0.5	22.0
OH	No	0.3	3.0	16.0

The number of sprout records created for each sprouting species is found in table 6.0.2. For root suckering hardwood species, logic rule {6.0.1} is used to determine the number of sprout records. 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 TT variant.

Species Code	Sprouting Probability	Number of Sprout Records	Source
AS	{6.0.3}	2	Keyser 2001
BI	0.7	1	Tollefson 2006
MM	0.7	1	Anderson 2001
NC	0.9	{6.0.1}	Simonin 2001

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

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

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

7.0 Volume

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

Table 7.0.1 Volume merchantability standards for the TT variant.

Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	7.0 / 6.0 inches	8.0 / 6.0 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	7.0 / 6.0 inches	8.0 / 6.0 inches
Stump Height	1.0 foot	1.0 foot

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

Common Name	Location Code	Equation Number	Reference
whitbark pine	403,405,415,416	400MATW108	Rustagi and Loveless Profile Models
limber pine	403,405,415,416	400MATW108	Rustagi and Loveless Profile Models
Douglas-fir	403,415,416	400MATW202	Rustagi and Loveless Profile Models
Douglas-fir	405	405MATW202	Rustagi and Loveless Profile Models
singleleaf pine	403,405,415,416	400DVEW133	Chojnacky Equations
blue spruce	403,405,415,416	400MATW093	Rustagi and Loveless Profile Models
quaking aspen	403,405,415,416	400MATW746	Rustagi and Loveless Profile Models
lodgepole pine	403,405,415,416	400MATW108	Rustagi and Loveless Profile Models
Engelmann spruce	403,405,415,41	400MATW09	Rustagi and Loveless Profile

Common Name	Location Code	Equation Number	Reference
	6	3	Models
subalpine fir	403,415,416	400MATW019	Rustagi and Loveless Profile Models
subalpine fir	405	405MATW019	Rustagi and Loveless Profile Models
ponderosa pine	403,405,415,416	400MATW122	Rustagi and Loveless Profile Models
Utah juniper	403,405,415,416	400DVEW065	Chojnacky Equations
Rocky mountain juniper	403,405,415,416	400DVEW066	Chojnacky Equations
bigtooth maple	403,405,415,416	400MATW108	Rustagi and Loveless Profile Models
Rocky mountain maple	403,405,415,416	400MATW108	Rustagi and Loveless Profile Models
narrowleaf cottonwood	403,405,415,416	400MATW108	Rustagi and Loveless Profile Models
curl-leaf mountain mahogany	403,405,415,416	400DVEW475	Chojnacky Equations
other softwood	403,405,415,416	400MATW108	Rustagi and Loveless Profile Models
other hardwood	403,405,415,416	400DVEW998	Chojnacky Equations

Table 7.0.3 Citations by Volume Model

Model Name	Citation
Chojnacky Equations	Chojnacky, David 1985. Pinyon-Juniper Volume Equations for the Central Rocky Mountain States. Intermountain Research Station Research Paper INT-339.
Rustagi and and Loveless Profile Models	Rustagi, K.R. and Loveless, R.S.,Jr., 1991. Compatible variable-form volume and stem-profile equations for Douglas-fir. Can. J. For. Res. 21:143-151.

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 TT 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 TT variant through the participation and contribution of various organizations led by Forest Health Protection. These models are currently maintained by the Forest Management Service Center and regional Forest Health Protection specialists. Additional details regarding each model may be found in chapter 8 of the Essential FVS Users Guide (Dixon 2002).

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11.0 Appendices

11.1 Appendix A: Habitat Type Codes

Table 11.1.1 Habitat Type Codes recognized in the TT variant and corresponding habitat type class.

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
1	050	limber pine/Idaho fescue	PIFL2/FEID	1
2	060	limber pine/curl-leaf mountain mahogany	PIFL2/CELE3	1
3	070	limber pine/common juniper	PIFL2/JUCO6	1
4	080	limber pine/spike fescue	PIFL2/LEKI2	1
5	090	limber pine	PIFL2	1
6	100	ponderosa pine	PIPO	1
7	120	ponderosa pine/western needlegrass	PIPO/ACOCO	1
8	130	ponderosa pine/bluebunch wheatgrass	PIPO/PSSPS	1
9	140	ponderosa pine/Idaho fescue	PIPO/FEID	1
10	150	ponderosa pine/western snowberry	PIPO/SYOC h.t.	1
11	160	ponderosa pine/antelope bitterbrush	PIPO/PUTR2	1
12	161	ponderosa pine/antelope bitterbrush-bluebunch wheatgrass	PIPO/PUTR2-PSSPS	1
13	162	ponderosa pine/antelope bitterbrush-Idaho fescue	PIPO/PUTR2-FEID	1
14	170	ponderosa pine/common snowberry	PIPO/SYAL	1
15	190	ponderosa pine/mallow ninebark	PIPO/PHMA5	2
16	195	ponderosa pine/mountain snowberry	PIPO/SYOR2	2
17	41045	limber pine/creeping barberry	PIFL2/MARE11	1
18	41115	ponderosa pine/Geyer's sedge	PIPO/CAGE2	1
19	41141	ponderosa pine/Idaho fescue-Idaho fescue	PIPO/FEID-FEID	1
20	41143	ponderosa pine/Idaho fescue/greenleaf manzanita	PIPO/FEID/ARPA6	1
21	41144	ponderosa pine/Idaho fescue/big sagebrush	PIPO/FEID/ARTR2	1
22	41376	Douglas-fir/sweetcicely/Oregon boxleaf	PSME/OSBE/PAMY	4

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
23	41406	blue spruce/bluebunch wheatgrass	PIPU/PSSPS	0
24	41416	Engelmann spruce/dwarf bilberry	PIEN/VACA13	0
25	41708	subalpine fir/sicletop lousewort/Douglas-fir	ABLA/PERA/PSME	0
26	41709	subalpine fir/sicletop lousewort-sicletop lousewort	ABLA/PERA-PERA	0
27	41715	subalpine fir/creeping barberry-gooseberry currant	ABLA/MARE11-RIMO2	0
28	41716	subalpine fir/creeping barberry-common juniper	ABLA/MARE11-JUCO6	0
29	41717	subalpine fir/creeping barberry/Douglas-fir	ABLA/MARE11/PSME	0
30	41725	subalpine fir/grouse whortleberry/broadlef arnica	ABLA/VASC/ARLA8	0
31	41726	subalpine fir/grouse whortleberry/Geyer's sedge	ABLA/VASC/CAGE2	0
32	41813	subalpine fir/gooseberry currant/Fendler's meadow-rue	ABLA/RIMO2/THFE	0
33	41814	subalpine fir/gooseberry currant/lodgepole pine	ABLA/RIMO2/PICO	0
34	41815	subalpine fir/gooseberry currant/spike trisetum	ABLA/RIMO2/TRSP2	0
35	41862	white fir/sweetcicely	ABCO/OSBE	0
36	41864	white fir/creeping barberry/mountain snowberry	ABCO/MARE11/SYOR2	0
37	41915	lodgepole pine/bluejoint	PICO/CACA4	0
38	41956	lodgepole pine/kinnikinnick	PICO/ARUV	0
39	41957	lodgepole pine/creeping barberry	PICO/MARE11	0
40	41970	lodgepole pine/Ross' sedge	PICO/CARO5	0
41	41107	ponderosa pine/greenleaf manzanita	PIPO/ARPA6	1
42	41108	ponderosa pine/curl-leaf mountain mahogany	PIPO/CELE3	1
43	41109	ponderosa pine/black sagebrush	PIPO/ARNO4	1
44	41111	ponderosa pine/Gamble oak	PIPO/QUGA	1
45	41112	ponderosa pine/Gamble oak-mountain snowberry	PIPO/QUGA-SYOR2	1
46	41113	ponderosa pine/Gamble oak-Gamble oak	PIPO/QUGA-QUGA	1
47	41114	ponderosa pine/mountain muhly	PIPO/MUMO	1

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
48	41365	Douglas-fir/greenleaf manzanita	PSME/ARPA6	4
49	41366	Douglas-fir/alderleaf mountain mahogany	PSME/CEMO2	4
50	41367	Douglas-fir/Gamble oak	PSME/QUGA	4
51	41382	Douglas-fir/creeping barberry/ponderosa pine	PSME/MARE11/PIPO	4
52	41408	blue spruce/field horsetail	PIPU/EQAR	0
53	41409	blue spruce/common juniper	PIPU/JUCO6	0
54	41746	subalpine fir/Columbian monkshood	ABLA/ACCO4	0
55	41747	subalpine fir/whortleberry	ABLA/VAMY2	0
56	41816	subalpine fir/gooseberry currant/aspen bluebells	ABLA/RIMO2/MEAR6	0
57	41866	white fir/creeping barberry-common juniper	ABCO/MARE11-JUCO6	0
58	41867	white fir/mountain snowberry	ABCO/SYOR2	0
59	41868	white fir/common juniper	ABCO/JUCO6	0
60	41869	white fir/Gamble oak	ABCO/QUGA	0
61	41871	white fir/greenleaf manzanita	ABCO/ARPA6	0
62	41872	white fir/curl-leaf mountain mahogany	ABCO/CELE3	0
63	41873	white fir/Rocky Mountain maple	ABCO/ACGL	0
64	42001	quaking aspen/California false hellebore	POTR5/VECA2	0
65	42002	quaking aspen/western brackenfern	POTR5/PTAQ	0
66	42003	quaking aspen/mule-ears	POTR5/WYAM	0
67	42004	quaking aspen/Thurber's fescue	POTR5/FETH	0
68	42005	quaking aspen/tall forb	POTR5/2FORB	0
69	42006	quaking aspen/pinegrass	POTR5/CARU	0
70	42007	quaking aspen/Fendler's meadow-rue	POTR5/THFE	0
71	42008	quaking aspen/California brome	POTR5/BRCA5	0
72	42009	quaking aspen/Ross' sedge	POTR5/CARO5	0
73	42010	quaking aspen/needle and thread	POTR5/HECOC8	0
74	42011	quaking aspen/timber milkvetch	POTR5/ASMI9	0
75	42012	quaking aspen/Kentucky bluegrass	POTR5/POPR	0
76	42040	quaking aspen/thimbleberry	POTR5/RUPA	0
77	42041	quaking aspen/red elderberry	POTR5/SARA2	0
78	42042	quaking aspen/russet buffaloberry	POTR5/SHCA	0
79	42043	quaking aspen/mountain snowberry	POTR5/SYOR2	0
80	42044	quaking aspen/mountain	POTR5/SYOR2/2FORB	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
		snowberry/tall forb phase		
81	42045	quaking aspen/mountain snowberry/pinegrass	POTR5/SYOR2/CARU	0
82	42046	quaking aspen/mountain snowberry/Fendler's meadow-rue	POTR5/SYOR2/THFE	0
83	42047	quaking aspen/mountain snowberry/Thurber's fescue	POTR5/SYOR2/FETH	0
84	42048	quaking aspen/mountain snowberry/Ross' sedge	POTR5/SYOR2/CARO5	0
85	42049	quaking aspen/mountain snowberry/mule-ears	POTR5/SYOR2/WYAM	0
86	42050	quaking aspen/mountain snowberry/California brome	POTR5/SYOR2/BRCA5	0
87	42051	quaking aspen/mountain snowberry/Kentucky bluegrass	POTR5/SYOR2/POPR	0
88	42052	quaking aspen/common juniper	POTR5/JUCO6	0
89	42053	quaking aspen/common juniper/Geyer's sedge	POTR5/JUCO6/CAGE2	0
90	42054	quaking aspen/common juniper/silvery lupine	POTR5/JUCO6/LUAR3	0
91	42055	quaking aspen/common juniper/timber milkvetch	POTR5/JUCO6/ASMI9	0
92	42056	quaking aspen/big sagebrush	POTR5/ARTR2	0
93	42080	quaking aspen/Scouler's willow	POTR5/SASC	0
94	42081	quaking aspen/Saskatoon serviceberry-mountain snowberry	POTR5/AMAL2-SYOR2	0
95	42082	quaking aspen/Saskatoon serviceberry-mountain snowberry/tall forb	POTR5/AMAL2-SYOR2/2FORB	0
96	42083	quaking aspen/Saskatoon serviceberry-mountain snowberry/Fendler's meadow-rue	POTR5/AMAL2-SYOR2/THFE	0
97	42084	quaking aspen/Saskatoon serviceberry-mountain snowberry/pinegrass	POTR5/AMAL2-SYOR2/CARU	0
98	42085	quaking aspen/Saskatoon serviceberry-mountain snowberry/California brome	POTR5/AMAL2-SYOR2/BRCA5	0
99	42086	quaking aspen/Saskatoon serviceberry-roundleaf snowberry	POTR5/AMAL2-SYRO	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
100	42087	quaking aspen/Saskatoon serviceberry/western brackenfern	POTR5/AMAL2/PTAQ	0
101	42088	quaking aspen/Saskatoon serviceberry/tall forb	POTR5/AMAL/2FORB	0
102	42089	quaking aspen/Saskatoon serviceberry/Fendler's meadow-rue	POTR5/AMAL2/THFE	0
103	42101	quaking aspen-subalpine fir/tall forb	POTR5-ABLA/2FORB	0
104	42102	quaking aspen-subalpine fir/Fendler's meadow-rue	POTR5-ABLA/THFE	0
105	42103	quaking aspen-subalpine fir/Geyer's sedge	POTR5-ABLA/CAGE2	0
106	42104	quaking aspen-subalpine fir/Ross' sedge	POTR5-ABLA/CARO5	0
107	42105	quaking aspen-subalpine fir/russet buffaloberry	POTR5-ABLA/SHCA	0
108	42106	quaking aspen-subalpine fir/mountain snowberry	POTR5-ABLA/SYOR2	0
109	42107	quaking aspen-subalpine fir/mountain snowberry/tall forb	POTR5-ABLA/SYOR2/2FORB	0
110	42108	quaking aspen-subalpine fir/mountain snowberry/Fendler's meadow-rue	POTR5-ABLA/SYOR2/THFE	0
111	42109	quaking aspen-subalpine fir/mountain snowberry/California brome	POTR5-ABLA/SYOR2/BRCA5	0
112	42110	quaking aspen-subalpine fir/common juniper	POTR5-ABLA/JUCO6	0
113	42111	quaking aspen-subalpine fir/Saskatoon serviceberry	POTR5-ABLA/AMAL2	0
114	42201	quaking aspen-lodgepole pine/Fendler's meadow-rue	POTR5-PICO/THFE	0
115	42202	quaking aspen-lodgepole pine/Geyer's sedge	POTR5-PICO/CAGE2	0
116	42203	quaking aspen-lodgepole pine/mountain snowberry	POTR5-PICO/SYOR2	0
117	42204	quaking aspen-lodgepole pine/common juniper	POTR5-PICO/JUCO6	0
118	42301	quaking aspen-Douglas-fir/pinegrass	POTR5-PSME/CARU	0
119	42302	quaking aspen-Douglas-fir/mountain snowberry	POTR5-PSME/SYOR2	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
120	42303	quaking aspen-Douglas-fir/common juniper	POTR5-PSME/JUCO	0
121	42304	quaking aspen-Douglas-fir/Saskatoon serviceberry	POTR5-PSME/AMAL2	0
122	42401	quaking aspen-white fir/Kentucky bluegrass	POTR5-ABCO/POPR	0
123	42402	quaking aspen-white fir/mountain snowberry	POTR5-ABCO/SYOR2	0
124	42403	quaking aspen-white fir/greenleaf manzanita	POTR5-ABCO/ARPA6	0
125	42500	quaking aspen-blue spruce	POTR5-PIPU	0
126	42600	quaking aspen-limber pine	POTR5-PIFL2	0
127	42700	quaking aspen-ponderosa pine	POTR5-PIPO	0
128	43002	spruce/redosier dogwood	PICEA/COSES	0
129	43004	spruce/field horsetail	PICEA/EQAR	0
130	43006	spruce/bluejoint	PICEA/CACA4	0
131	43012	spruce/fragrant bedstraw	PICEA/GATR3	0
132	43105	gray alder/northern black currant	ALIN2/RIHU	0
133	43202	Booth's willow/beaked sedge	SABO2/CARO6	0
134	43208	Booth's willow/starry false lily of the vally	SABO2/MAST4	0
135	43225	Geyer's willow/Kentucky bluegrass	SAGE2/POPR	0
136	43227	Geyer's willow/forb (mesic)	SAGE2/2FORB	0
137	43241	narrowleaf willow/field horsetail	SAEX/EQAR	0
138	43271	yellow willow	SALU2	0
139	43283	mountain willow	SAEA	0
140	43303	Wolf's willow/Nebraska sedge	SAWO/CANE2	0
141	43305	Wolf's willow/bluejoint	SAWO/CACA4	0
142	43307	Wolf's willow/fowl bluegrass	SAWO/POPA2	0
143	43321	diamondleaf willow	SAPL2	0
144	43354	redosier dogwood/fragrant bedstraw	COSES/GATR3	0
145	43400	alderleaf buckthorn	RHAL	0
146	43552	shrubby cinquefoil/Idaho fescue	DAFL3/FEID	0
147	43602	silver sagebrush/Idaho fescue	ARCA13/FEID	0
148	43813	sedge	CAREX	0
149	43881	fowl bluegrass	POPA2	0
150	43941	forb (mesic, meadow)	2FORB	0
151	43003	conifer/field horsetail	2TE/EQAR	0
152	43005	conifer/bluejoint	2TE/CACA4	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
153	43007	conifer/blue wildrye	2TE/ELGL	0
154	43008	conifer/shrubby cinquefoil	2TE/DAFL3	0
155	43009	conifer/tufted hairgrass	2TE/DECA18	0
156	43011	conifer/Columbian monkshood	2TE/ACCO4	0
157	43013	conifer/red baneberry	2TE/ACRU2	0
158	43041	narrowleaf cottonwood/water birch	POAN3/BEOC2	0
159	43042	narrowleaf cottonwood/bigtooth maple	POAN3/ACGR3	0
160	43044	narrowleaf cottonwood/Woods' rose	POAN3/ROWO	0
161	43045	narrowleaf cottonwood/fragrant sumac	POAN3/RHAR4	0
162	43081	boxelder/redosier dogwood	ACNE2/COSE16	0
163	43082	boxelder/field horsetail	ACNE2/EQAR	0
164	43102	gray alder/field horsetail	ALIN2/EQAR	0
165	43201	Booth's willow/water sedge	SABO2/CAAQ	0
166	43209	Booth's willow/mesic forb	SABO2/2FORB	0
167	43210	Booth's willow/mesic graminoid	SABO2/2GRAM	0
168	43221	Geyer's willow/water sedge	SAGE2/CAAQ	0
169	43226	Geyer's willow/tufted hairgrass	SAGE2/DECA18	0
170	43244	narrowleaf willow/mesic graminoid	SAEX/2GRAM	0
171	43245	narrowleaf willow (barren)	SAEX	0
172	43281	Bebb willow/mesic graminoid	SABE2/2GRAM	0
173	43286	arroyo willow (barren)	SALA6	0
174	43322	diamondleaf willow/water sedge	SAPL2/CAAQ	0
175	43323	diamondleaf willow/bluejoint	SAPL2/CACA4	0
176	43324	diamondleaf willow/tufted hairgrass	SAPL2/DECA18	0
177	43326	grayleaf willow/tufted hairgrass	SAGL/DECA18	0
178	43601	silver sagebrush/tufted hairgrass	ARCA13/DECA18	0
179	43603	silver sagebrush/sheep fescue	ARCA13/FEOV	0
180	43802	Buxbaum's sedge	CABU6	0
181	43804	woollyfruit sedge	CALA11	0
182	43806	mud sedge	CALI7	0
183	43810	russet sedge	CAPH8	0
184	43851	bluejoint	CACA4	0
185	43861	timber oatgrass	DAIN	0
186	43901	white marsh marigold	CALE4	0
187	43925	broadleaf cattail type	TYLA	0
188	46001	little sagebrush/bluebunch	ARAR8/PSSPS	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
		wheatgrass		
189	46002	little sagebrush/Idaho fescue	ARAR8/FEID	0
190	46003	little sagebrush/Sandberg bluegrass	ARAR8/POSE	0
191	46011	silver sagebrush/mat muhly	ARCAB3/MURI	0
192	46021	silver sagebrush/Idaho fescue	ARCAV2/FEID	0
193	46031	little sagebrush/Idaho fescue	ARARL/FEID	0
194	46041	black sagebrush/bluebunch wheatgrass	ARNO4/PSSPS	0
195	46042	black sagebrush/Idaho fescue	ARNO4/FEID	0
196	46043	black sagebrush/needle and thread	ARNO4/HECOC8	0
197	46051	scabland sagebrush/Sandberg bluegrass	ARRI2/POSE	0
198	46061	little sagebrush/Idaho fescue	ARART/FEID	0
199	46101	big sagebrush/mountain brome (subalpine)	ARTRS2/BRCA5	0
200	46111	big sagebrush/bluebunch wheatgrass	ARTR2/PSSPS	0
201	46112	big sagebrush/basin wildrye	ARTR2/LECI4	0
202	46113	big sagebrush/Idaho fescue	ARTR2/FEID	0
203	46114	big sagebrush/needle and thread grass	ARTR2/HECOC8	0
204	46131	threetip sagebrush/bluebunch wheatgrass	ARTR4/PSSPS	0
205	46132	threetip sagebrush/Idaho fescue	ARTR4/FEID	0
206	46133	threetip sagebrush/needle and thread	ARTR4/HECOC8	0
207	46151	mountain big sagebrush/bluebunch wheatgrass	ARTRV/PSSPS	0
208	46152	mountain big sagebrush/basin wildrye	ARTRV/LECI4	0
209	46153	mountain big sagebrush/Idaho fescue	ARTRV/FEID	0
210	46154	mountain big sagebrush/needle and thread	ARTRV/HECOC8	0
211	46155	mountain big sagebrush/Thurber's needlegrass	ARTRV/ACTH7	0
212	46156	big sagebrush/Geyer's sedge	ARTRS2/CAGE2	0
213	46157	mountain big sagebrush/mountain snowberry/bluebunch wheatgrass	ARTRV/SYOR2/PSSPS	0
214	46158	mountain big sagebrush/mountain	ARTRV/SYOR2/FEID	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
		snowberry/Idaho fescue		
215	46159	mountain big sagebrush/mountain snowberry/Geyer's sedge	ARTRV/SYOR2/CAGE2	0
216	46171	Wyoming big sagebrush/bluebunch wheatgrass	ARTRW8/PSSPS	0
217	46172	Wyoming big sagebrush/Sandberg bluegrass	ARTRW8/POSE	0
218	46173	Wyoming big sagebrush/squirreltail	ARTRW8/ELELE	0
219	46174	Wyoming big sagebrush/Thurber's needlegrass	ARTRW8/ACTH7	0
220	46191	big sagebrush/bluebunch wheatgrass	ARTRX/PSSPS	0
221	46192	big sagebrush/Idaho fescue	ARTRX/FEID	0
222	46201	antelope bitterbrush/bluebunch wheatgrass	PUTR2/PSSPS	0
223	46301	curl-leaf mountain mahogany/bluebunch wheatgrass	CELE3/PSSPS	0
224	47001	Idaho fescue-bluebunch wheatgrass	FEID-PSSPS	0
225	47011	bluebunch wheatgrass-Sandberg bluegrass	PSSPS-POSE	0
226	47012	bluebunch wheatgrass-Idaho fescue	PSSPS-FEID	0
227	47021	sand dropseed-Sandberg bluegrass	SPCR-POSE	0
228	47025	Fendler threeawn-Sandberg bluegrass	ARPUL-POSE	0
229	47002	Idaho fescue/prairie Junegrass	FEID/KOMA	0
230	47003			0
231	47004			0
232	43001	conifer/redosier dogwood	2TE/COSE16	0
233	43010	conifer/Kentucky bluegrass	2TE/POPR	0
234	43043	narrowleaf cottonwood/redosier dogwood	POAN3/COSES	0
235	43046	narrowleaf cottonwoon/Kentucky bluegrass	POAN3/POPR	0
236	43101	gray alder/redosier dogwood	ALIN2/COSE16	0
237	43103	gray alder/mesic forb	ALIN2/2FORB	0
238	43104	gray alder/mesic graminoid	ALIN2/2GRAM	0
239	43151	water birch/redosier dogwood	BEOC2/COSE16	0
240	43152	water birch/mesic forb	BEOC2/2FORB	0
241	43155	water birch/Kentucky bluegrass	BEOC2/POPR	0
242	43203	Booth's willow/Nebraska sedge	SABO2/CANE2	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
243	43204	Booth's willow/bluejoint	SABO2/CACA4	0
244	43205	Booth's willow/field horsetail	SABO2/EQAR	0
245	43206	Booth's willow/fowl bluegrass	SABO2/POPA2	0
246	43207	Booth's willow/Kentucky bluegrass	SABO2/POPR	0
247	43222	Geyer's willow/beaked sedge	SAGE2/CARO6	0
248	43223	Geyer's willow/bluejoint	SAGE2/CACA4	0
249	43224	Geyer's willow/fowl bluegrass	SAGE2/POPA2	0
250	43228	Geyer's willow/mesic graminoid	SAGE2/2GRAM	0
251	43242	narrowleaf willow/Kentucky bluegrass	SAEX/POPR	0
252	43243	narrowleaf willow/mesic forb	SAEX/2FORB	0
253	43301	Wolf's willow/field horsetail	SAWO/EQAR	0
254	43302	Wolf's willow/beaked sedge	SAWO/CARO6	0
255	43306	Wolf's willow/tufted hairgrass	SAWO/DECA18	0
256	43308	Wolf's willow/mesic forb	SAWO/2FORB	0
257	43353	redosier dogwood/common cowparsnip	COSES/HEMA80	0
258	43551	shrubby cinquefoil/tufted hairgrass	DAFL3/DECA18	0
259	43553	shrubby cinquefoil/Kentucky bluegrass	DAFL3/POPR	0
260	43604	silver sagebrush/Kentucky bluegrass	ARCA13/POPR	0
261	43801	water sedge	CAAQ	0
262	43805	woolly sedge	CAPE42	0
263	43807	smallwing sedge	CAMI7	0
264	43808	Nebraska sedge	CANE2	0
265	43809	beaked sedge	CARO6	0
266	43812	analogue sedge	CASI2	0
267	43821	common spikerush	ELPA3	0
268	43822	fewflower spikerush	ELQU2	0
269	43831	Baltic rush	JUBA	0
270	43871	tufted hairgrass	DECA18	0
271	43882	Kentucky bluegrass	POPR	0
272	43921	tall fringed bluebells	MECI3	0
273	43931	California false hellebore	VECA2	0
274	41050	limber pine/Idaho fescue	PIFL2/FEID	1
275	41060	limber pine/curl-leaf mountain mahogany	PIFL2/CELE3	1
276	41070	limber pine/common juniper	PIFL2/JUCO6	1
277	41080	limber pine/spike fescue	PIFL2/LEKI2	1

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
278	41140	ponderosa pine/Idaho fescue	PIPO/FEID	1
279	41160	ponderosa pine/antelope bitterbrush	PIPO/PUTR2	1
280	41195	ponderosa pine/mountain snowberry	PIPO/SYOR2	2
281	41220	Douglas-fir/Idaho fescue	PSME/FEID	3
282	41221	Douglas-fir/Idaho fescue-Idaho fescue	PSME/FEID-FEID	3
283	41260	Douglas-fir/mallow ninebark	PSME/PHMA5	4
284	41265	Douglas-fir/mallow ninebark/Douglas-fir	PSME/PHMA5/PSME	4
285	41266	Douglas-fir/mallow ninebark-Oregon boxleaf	PSME/PHMA5-PAMY	4
286	41280	Douglas-fir/thinleaf huckleberry	PSME/VAME	3
287	41310	Douglas-fir/common snowberry	PSME/SYAL	0
288	41313	Douglas-fir/common snowberry-common snowberry	PSME/SYAL-SYAL	0
289	41320	Douglas-fir/pinegrass	PSME/CARU	0
290	41323	Douglas-fir/pinegrass-pinegrass	PSME/CARU-CARU	0
291	41340	Douglas-fir/white spirea	PSME/SPBE2	4
292	41341	Douglas-fir/white spirea-white spirea	PSME/SPBE2-SPBE2	4
293	41343	Douglas-fir/white spirea/pinegrass	PSME/SPBE2/CARU	4
294	41360	Douglas-fir/common juniper	PSME/JUCO6	0
295	41370	Douglas-fir/heartleaf arnica	PSME/ARCO9	0
296	41371	Douglas-fir/heartleaf arnica-heartleaf arnica	PSME/ARCO9-ARCO9	0
297	41372	Douglas-fir/heartleaf arnica/timber milkvetch	PSME/ARCO9/ASMI9	0
298	41375	Douglas-fir/sweetcicely	PSME/OSBE	0
299	41380	Douglas-fir/mountain snowberry	PSME/SYOR2	0
300	41385	Douglas-fir/curl-leaf mountain mahogany	PSME/CELE3	0
301	41390	Douglas-fir/Rocky Mountain maple	PSME/ACGL	0
302	41395	Douglas-fir/creeping barberry	PSME/MARE11	0
303	41396	Douglas-fir/creeping barberry-creeping barberry	PSME/MARE11-MARE11	0
304	41397	Douglas-fir/creeping barberry-mountain snowberry	PSME/MARE11-SYOR2	0
305	41398	Douglas-fir/creeping	PSME/MARE11/CAGE2	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
		barberry/Geyer's sedge		
306	41399	Douglas-fir/creeping barberry/common juniper	PSME/MARE11/JUCO6	0
307	41407	blue spruce/creeping barberry	PIPU/MARE11	0
308	41410	Engelmann spruce/field horsetail	PIEN/EQAR	0
309	41415	Engelmann spruce/white marsh marigold	PIEN/CALE4	0
310	41440	Engelmann spruce/fragrant bedstraw	PIEN/GATR3	0
311	41485	Engelmann spruce/grouse whortleberry	PIEN/VASC	0
312	41490	Engelmann spruce/softleaf sedge	PIEN/CADI6	0
313	41493	Engelmann spruce/revolute hypnum moss	PIEN/HYRE70	5
314	41497	Engelmann spruce/gooseberry current	PIEN/RIMO2	0
315	41601	subalpine fir/red baneberry	ABLA/ACRU2	0
316	41603	subalpine fir/mallow ninebark	ABLA/PHMA5	0
317	41635	subalpine fir/claspleaf twistedstalk	ABLA/STAM2	0
318	41636	subalpine fir/claspleaf twistedstalk-claspleaf twistedstalk phase	ABLA/STAM2-STAM2	0
319	41640	subalpine fir/dwarf bilberry	ABLA/VACA13	0
320	41645	subalpine fir/Rocky Mountain maple	ABLA/ACGL	0
321	41650	subalpine fir/bluejoint	ABLA/CACA4	0
322	41651	subalpine fir/bluejoint-bluejoint	ABLA/CACA4-CACA4	0
323	41654	subalpine fir/bluejoint/dwarf bilberry	ABLA/CACA4/VACA13	0
324	41655	subalpine fir/bluejoint/western Labrador tea	ABLA/CACA4/LEGL	0
325	41660	subalpine fir/twinflower	ABLA/LIBO3	0
326	41661	subalpine fir/twinflower-twinflower	ABLA/LIBO3-LIBO3	0
327	41663	subalpine fir/twinflower/grouse whortleberry	ABLA/LIBO3/VASC	0
328	41670	subalpine fir/rusty menziesia	ABLA/MEFE	0
329	41671	subalpine fir/rusty menziesia-rusty menziesia	ABLA/MEFE-MEFE	0
330	41690	subalpine fir/common beargrass	ABLA/XETE	0
331	41691	subalpine fir/common beargrass/thinleaf huckleberry	ABLA/XETE/VAME	0
332	41692	subalpine fir/common	ABLA/XETE/VASC	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
		beargrass/grouse whortleberry		
333	41702	subalpine fir/creeping barberry-creeping barberry	ABLA/MARE11-MARE11	0
334	41703	subalpine fir/creeping barberry	ABLA/MARE11	0
335	41705	subalpine fir/white spirea	ABLA/SPBE2	0
336	41706	subalpine fir/creeping barberry/Engelmann spruce	ABLA/MARE11/PIEN	0
337	41707	subalpine fir/sicletop lousewort	ABLA/PERA	0
338	41714	subalpine fir/creeping barberry/limber pine	ABLA/MARE11/PIFL2	0
339	41720	subalpine fir/thinleaf huckleberry	ABLA/VAME	0
340	41721	subalpine fir/thinleaf huckleberry/grouse whortleberry	ABLA/VAME/VASC	0
341	41723	subalpine fir/thinleaf huckleberry-thinleaf huckleberry	ABLA/VAME-VAME	0
342	41730	subalpine fir/grouse whortleberry	ABLA/VASC	0
343	41731	subalpine fir/grouse whortleberry/pinegrass	ABLA/VASC/CARU	0
344	41732	subalpine fir/grouse whortleberry-grouse whortleberry	ABLA/VASC-VASC	0
345	41734	subalpine fir/grouse whortleberry/whitebark pine	ABLA/VASC/PIAL	0
346	41745	subalpine fir/common juniper	ABLA/JUCO6	0
347	41750	subalpine fir/pinegrass	ABLA/CARU	0
348	41760	subalpine fir/sweetcicely	ABLA/OSBE	0
349	41780	subalpine fir/heartleaf arnica	ABLA/ARCO9	0
350	41790	subalpine fir/Geyer's sedge	ABLA/CAGE2	0
351	41791	subalpine fir/Geyer's sedge-Geyer'ssedge	ABLA/CAGE2-CAGE2	0
352	41795	subalpine fir/Ross' sedge	ABLA/CARO5	0
353	41810	subalpine fir/gooseberry currant	ABLA/RIMO2	0
354	41811	subalpine fir/gooseberry currant-gooseberry currant	ABLA/RIMO2-RIMO2	0
355	41830	subalpine fir/Hitchcock's smooth woodrush	ABLA/LUGLH	0
356	41831	subalpine fir/Hitchcock's smooth woodrush/grouse whortleberry	ABLA/LUGLH/VASC	0
357	41861	white fir/mallow ninebark	ABCO/PHMA5	0
358	41863	white fir/creeping barberry	ABCO/MARE11	0
359	41865	white fir/creeping barberry-creeping	ABCO/MARE11-	0

FVS Seq Num	Habitat Type Codes	Habitat Type Name	Abbreviation	Habitat Type Class {4.7.1.2}
		barberry	MARE11	
360	41920	lodgepole pine/dwarf bilberry	PICO/VACA13	0
361	41940	lodgepole pine/grouse whortleberry	PICO/VASC	0
362	41955	lodgepole pine/Geyer's sedge	PICO/CAGE2	0
363	41960	lodgepole pine/common juniper	PICO/JUCO6	0

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