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Utah (UT) Variant Overview of the Forest Vegetation Simulator

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Authors and Contributors:

The FVS staff has maintained model documentation for this variant in the form of a variant overview since its release in 1983. The original author was Gary Dixon. In 2008, the previous document was replaced with this updated variant overview. Gary Dixon, Christopher Dixon, Robert Havis, Chad Keyser, Stephanie Rebain, Erin Smith-Mateja, and Don Vandendriesche were involved with this update. Don Vandendriesche cross-checked information contained in this variant overview 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). Utah (UT) Variant Overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 57p.

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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)	408 – Fish Lake National Forest	
Plant Association Code	0 (unknown)	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation	83 (8300 feet)	
Latitude / Longitude	Latitude	Longitude
All location codes	40	112
Site Species	LP	
Site Index	46	
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 Utah (UT) variant was developed in 1983. It covers all the forested areas in Utah, the part of the Wasatch National Forest extending into southern Wyoming, and the small piece of the Manti-La Sal National Forest extending into west-central Colorado.

Since the variant's development in 1983, many of the functions have been adjusted and improved as more data has become available and as model technology has advanced. This variant was expanded in 2000 from its original 10 species to 14 species with the addition of blue spruce, pinyon pine, western juniper, and a general oak species group. Equations for Engelmann spruce were used for blue spruce, and equations from the Central Rockies variant were used for pinyon pine, western juniper, and oak. In 2010 this variant was expanded from 14 species to 24 species. The general oak species group was eliminated and replaced with Gambel oak using the general oak growth equations; pinyon pine was changed to common pinyon and singleleaf pinyon was added using the common pinyon growth equations; Rocky Mountain juniper and Utah juniper were added and use the western juniper equations; Great Basin bristlecone pine was added and uses bristlecone pine equations from the Central Rockies (CR) variant; narrowleaf cottonwood, Fremont cottonwood, and box elder were added and use cottonwood equations from the CR variant; curl-leaf mountain mahogany was added using equations from the South Central Oregon / Northeastern California (SO) and Utah variants; bigtooth maple was added using bigleaf maple equations from the SO variant and other equations from the Utah variant; 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, and other hardwood using equations for Gambel oak.

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 UT variant covers all the forested areas in Utah, the part of the Wasatch National Forest extending into southern Wyoming, and the small piece of the Manti-La Sal National Forest extending into west-central Colorado. The suggested geographic range of use for the UT variant is shown in figure 2.0.1. The UT variant was not fit to forest types in Nevada, but it is currently the best available variant for that area.

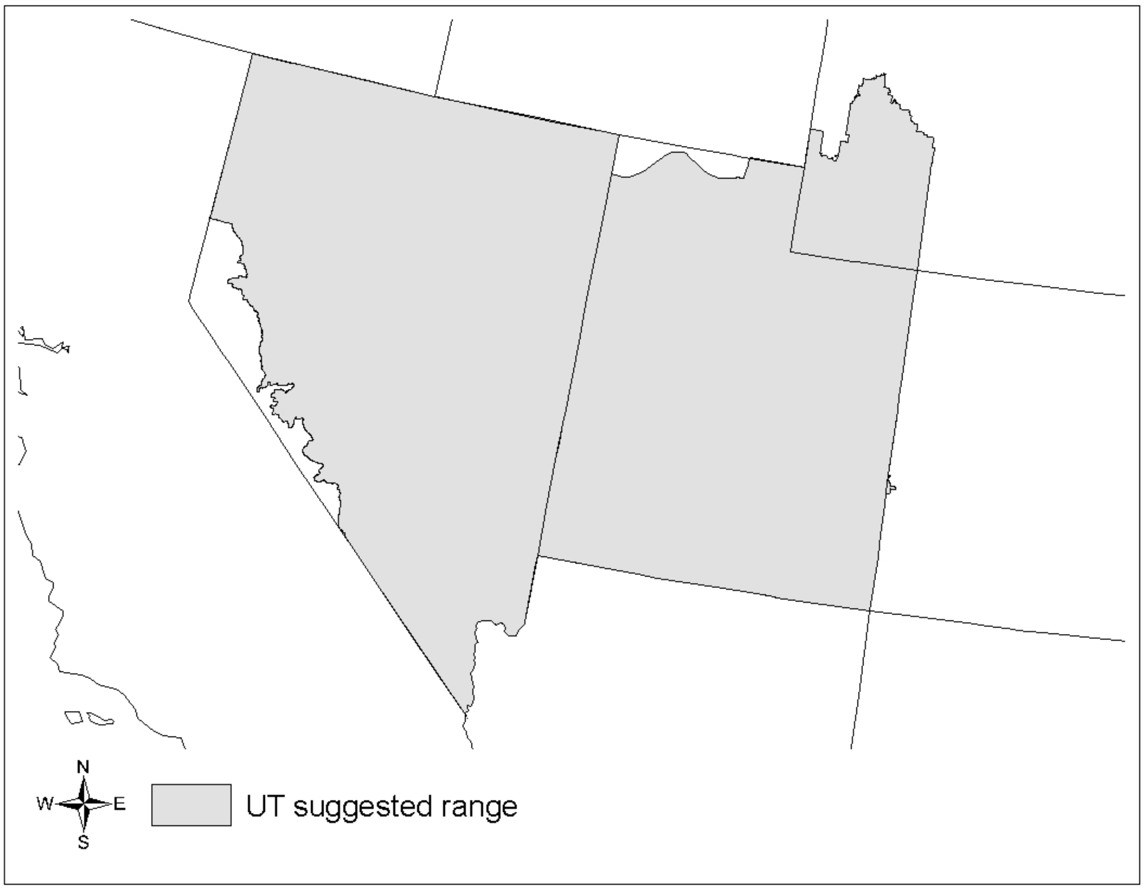

Figure 2.0.1 Suggested geographic range of use for the UT variant.

3.0 Control Variables

FVS users need to specify certain variables used by the UT 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 UT variant, a default forest code of 408 (Fishlake National Forest) will be used. Location codes recognized in the UT variant are shown in tables 3.1.1 and 3.1.2.

Table 3.1.1 Location codes used in the UT variant.

Location Code	Location
401	Ashley National Forest
407	Dixie National Forest
408	Fishlake National Forest
410	Manti-LaSal National Forest
418	Uinta National Forest
419	Wasatch National Forest
404	Cache National Forest (mapped to 419)
409	Humboldt National Forest (mapped to 408)
417	Toiyabe National Forest (mapped to 408)

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

Location Code	Location
7702	Fort Mojave Reservation (mapped to 417)
7711	Fort Mcdermitt Indian Reservation (mapped to 409)
7712	Pyramid Lake Paiute Reservation (mapped to 409)
7714	Summit Lake Reservation (mapped to 409)
7715	Walker River Reservation (mapped to 417)
7716	Yomba Reservation (mapped to 417)
7717	Skull Valley Reservation (mapped to 419)
7718	Uintah And Ouray Reservation (mapped to 401)
7721	Duck Valley Reservation (mapped to 409)
7722	South Fork Reservation (mapped to 409)
7723	Goshute Reservation (mapped to 409)
7728	Kaibab Indian Reservation (mapped to 407)

Location Code	Location
7729	Paiute, (Ut Reservation) (mapped to 407)
7835	Timbi-Sha Shoshone Reservation (mapped to 417)
7920	Ute Mountain Reservation (mapped to 410)
8001	Navajo Nation Reservation (mapped to 410)

3.2 Species Codes

The UT variant recognizes 22 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 UT variant.

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

Table 3.2.1 Species codes used in the UT 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	WF	015	ABCO	*Abies concolor*	white fir
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	PI	106	PIED	*Pinus edulis*	common pinyon
12	WJ	064	JUOC	*Juniperus occidentalis*	western juniper
13	GO	814	QUGA	*Quercus gambelii*	Gambel oak
14	PM	133	PIMO	*Pinus monophylla*	singleleaf pinyon
15	RM	066	JUSC2	*Juniperus scopulorum*	Rocky Mountain juniper
16	UJ	065	JUOS	*Juniperus osteosperma*	Utah juniper

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name[1]	Common Name[1]
17	GB	142	PILO	*Pinus longaeva*	Great Basin bristlecone pine
18	NC	749	POAN3	*Populus angustifolia*	narrowleaf cottonwood
19	FC	748	POFR2	*Populus fremontii*	Fremont cottonwood
20	MC	475	CELE3	*Cercocarpus ledifolius*	curl-leaf mountain mahogany
21	BI	322	ACGR3	*Acer grandidentatum*	bigtooth maple
22	BE	313	ACNE2	*Acer negundo*	boxelder
23	OS	299	2TN		other softwood[2]
24	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 UT variant, habitat type codes are only used in the Fire and Fuels Extension (FFE) to set fuel loading in cases where there are no trees in the first cycle. Habitat type codes recognized in the UT 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 the growth equations for the UT 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 UT variant, the sources shown in table 3.4.1 should be used if possible. The default site species is LP with a site index of 46.

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 + 0.5 for the calculation of *RELSI*. Similarly, if the site index for the stand is greater than the upper site limit, it is set to the upper site limit for the calculation of *RELSI*.

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

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

where:

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

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

Species Code	Reference	BHA or TTA*	Base Age
DF	Brickell (1970) Research Paper INT-75	TTA	50
AS	Edminster, Mowrer, and Shepperd (1985) Research Note RM-453	BHA	80
LP, WB, LM, OS	Alexander, Tackle, and Dahms (1967) Research Paper RM-29	TTA	100**
ES, BS, WF, AF	Alexander (1967) Research Paper RM-32	BHA	100**
PP	Meyer (1961.rev) Tech. Bulletin 630	TTA	100**
PI, WJ, GO, PM, RM, UJ, OH	Any 100-year base age curve	TTA	100
GB, NC, FC, BE	Alexander (1967) Research Paper RM-32	BHA	100
MC, BI	Curtis, R. O., et. al. (1974) Forest Science	BHA	100

***Site index equation 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 equation {3.4.1} in the UT variant.

Species Code	*SITELO*	*SITEHI*
WB	20	50
LM	20	50
DF	30	70
WF	40	80
BS	40	90
AS	30	70
LP	40	85
ES	40	100
AF	50	90
PP	40	80
PI	5	20
WJ	5	15
GO	5	20
PM	5	20
RM	5	15
UJ	5	15
GB	20	60
NC	30	120
FC	30	90
MC	5	15
BI	5	30
BE	15	40
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, 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 UT variant.

Species Code	SDI Maximum*	Mapped to
WB	621	
LM	409	
DF	570	
WF	634	Engelmann spruce
BS	620	
AS	562	
LP	679	
ES	620	
AF	602	
PP	446	
PI	348	
WJ	272	
GO	652	
PM	358	
RM	411	
UJ	497	whitebark pine
GB	621	black cottonwood
NC	452	black cottonwood
FC	452	
MC	501	
BI	619	
BE	344	limber pine
OS	409	Gamble oak
OH	652	

*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 to estimate diameter growth on trees smaller than a given threshold diameter for some species. In the UT variant, height-diameter relationships for all species except curl-leaf mountain mahogany and bigtooth maple 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 curl-leaf mountain mahogany and bigtooth maple. 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 UT variant.

Species Code	Default B_1	B_2
WB	4.1920	-5.1651
LM	4.1920	-5.1651
DF	4.5879	-8.9277
WF	4.3008	-6.8139
BS	4.5293	-7.7725
AS	4.4421	-6.5405
LP	4.3767	-6.1281
ES	4.5293	-7.7725
AF	4.4717	-6.7387
PP	4.6024	-11.4693
PI	3.2000	-5.0000
WJ	3.2000	-5.0000

Species Code	Default B_1	B_2
GO	3.2000	-5.0000
PM	3.2000	-5.0000
RM	3.2000	-5.0000
UJ	3.2000	-5.0000
GB	4.1920	-5.1651
NC	4.4421	-6.5405
FC	4.4421	-6.5405
MC	5.1520	-13.5760
BI	4.7000	-6.3260
BE	4.4421	-6.5405
OS	4.2597	-9.3949
OH	3.2000	-5.0000

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 UT 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
$P_2 = 1709.7229$	$P_2 = 76.5170$
$P_3 = 5.8887$	$P_3 = 2.2107$
$P_4 = -0.2286$	$P_4 = -0.6365$

{4.1.3} $DBH < 5.0$": $HT = 0.0994 + 4.9767 * DBH$

(note: 4.1.3 is used for trees with DBH < 5.0", 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 (b1 and b2) 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 $DBH \geq 1.0$

where:

BRATIO is species-specific bark ratio (bounded to $0.80 \leq BRATIO \leq 0.99$)
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 Coefficients for the bark ratio equation {4.2.1} in the UT variant.

Species Code	b_1	b_2	Equation Number
WB	0.9625	-0.1141	{4.2.3}
LM	0.9625	-0.1141	{4.2.3}
DF	0.867	0.	{4.2.2}
WF	0.890	0.	{4.2.2}
BS	0.9502	-0.2528	{4.2.3}
AS	0.950	0.	{4.2.2}
LP	0.9625	-0.1141	{4.2.3}
ES	0.9502	-0.2528	{4.2.3}
AF	0.890	0.	{4.2.2}
PP	0.8967	-0.4448	{4.2.3}
PI	0.9002	-0.3089	{4.2.1}
WJ	0.9002	-0.3089	{4.2.1}
GO	0.93789	-0.24096	{4.2.3}
PM	0.9002	-0.3089	{4.2.1}
RM	0.9002	-0.3089	{4.2.1}
UJ	0.9002	-0.3089	{4.2.1}
GB	0.9625	-0.1141	{4.2.3}
NC	0.892	-0.086	{4.2.3}
FC	0.892	-0.086	{4.2.3}
MC	0.9	0.	{4.2.2}
BI	0.94782	0.0836	{4.2.3}
BE	0.892	-0.086	{4.2.3}
OS	0.9625	-0.1141	{4.2.3}
OH	0.93789	-0.24096	{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 UT variant, crown ratios missing in the input data are predicted using different equations depending on tree species and size. For all species except Great Basin bristlecone pine, narrowleaf cottonwood, Fremont cottonwood, and boxelder, 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} $CR = ((X - 1) * 10 + 1) / 100$

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 UT variant.

Coefficient	Species Code					
	WB, LM	DF, WF, BS, ES, AF	AS	LP, GO, OH	PP	PI, WJ, PM, RM, UJ, OS
R_1	-1.66949	-0.426688	-0.426688	-1.66949	-1.66949	-2.19723
R_2	-0.209765	-0.093105	-0.093105	-0.209765	-0.209765	0
R_3	0	0.022409	0.022409	0	0	0
R_4	0.003359	0.002633	0.002633	0.003359	0.003359	0
R_5	0.011032	0	0	0.011032	0.011032	0
R_6	0	-0.045532	-0.045532	0	0	0
R_7	0.017727	0	0	0.017727	0.017727	0
R_8	-0.000053	0.000022	0.000022	-0.000053	-0.000053	0
R_9	0.014098	-0.013115	-0.013115	0.014098	0.014098	0
SD	0.5	0.6957	0.931	0.6124*	0.4942	0.2

* 0.5 for GO and OH

For all species except common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah Juniper, Great Basin bristlecone pine, narrowleaf cottonwood, Fremont cottonwood, boxelder, 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 4.3.2

Table 4.3.1.2 Coefficients for the Weibull parameter equations {4.3.6} and {4.3.7} in the UT 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

Species Code	Model Coefficients						
	a_0	b_0	b_1	c_0	c_1	d_0	d_1
WF	1	-0.89553	1.07728	1.74621	0.29052	7.65751	-0.03513
BS	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	1	-0.82631	1.06217	-1.02873	0.80143	6.19911	-0.02216
MC	0	-0.23830	1.18016	3.04000	0	4.62512	-0.01604
BI	0	-0.23830	1.18016	3.04000	0	4.62512	-0.01604
OS	1	-0.26595	0.98326	-1.60411	1.60411	7.92810	-0.06298

Narrowleaf cottonwood, Fremont cottonwood, and boxelder live and dead trees of all sizes are assigned a crown ratio using equation {4.3.1.8} and {4.3.1.10}. Great Basin bristlecone pine live and dead trees of all sizes are assigned a crown ratio using equations {4.3.1.9} and {4.3.1.10}. Common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, and other hardwood trees 1.0 inch diameter and larger use equations {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, Fremont cottonwood, and boxelder; equations {4.3.1.9} and {4.3.1.10} for Great Basin bristlecone pine, common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, and other hardwood; 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 $0.2 \le CR \le 0.9$)
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 UT 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} – {4.4.4}, 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

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

{4.4.2} Bechtold (2004); Equation 02

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

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

{4.4.3} Crookston (2005); Equation 05

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

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

{4.4.4} Donnelly (1996); Equation 06

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

where:

BF	is a species-specific coefficient based on forest code (*BF* = 1.0 in the UT 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} – {4.4.4} in the UT variant.

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
WB	10105	2.2354	0.6668	-0.11658	0.16927	0	0
LM	11301	4.0181	0.8528	0	0	0	0
DF	20205	6.0227	0.54361	-0.20669	0.20395	-0.00644	-0.00378
WF	01505	5.0312	0.53680	-0.18957	0.16199	0.04385	-0.00651
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	0.8198	-0.36992	0.17722	-0.01202	-0.00882
ES	09305	6.7575	0.55048	-0.25204	0.19002	0	-0.00313
AF	01905	5.8827	0.51479	-0.21501	0.17916	0.03277	-0.00828
PP	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
PI	10602	-5.4647	1.9660	-0.0395	0.0427	0	-0.0259
WJ	06405	5.1486	0.73636	-0.46927	0.39114	-0.05429	0
GO	81402	0.3309	0.8918	0	0.0510	0	0
PM	10602	-5.4647	1.9660	-0.0395	0.0427	0	-0.0259
RM	06405	5.1486	0.73636	-0.46927	0.39114	-0.05429	0
UJ	06405	5.1486	0.73636	-0.46927	0.39114	-0.05429	0
GB	10201	7.4251	0.8991	0	0	0	0
NC	74902	4.1687	1.5355	0	0	0	0.1275
FC	74902	4.1687	1.5355	0	0	0	0.1275
MC	47502	4.0105	0.8611	0	0	0	-0.0431
BI	31206	7.5183	0.4461	0	0	0	0
BE	74902	4.1687	1.5355	0	0	0	0.1275
OS	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
OH	81402	0.3309	0.8918	0	0.0510	0	0

*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} – {4.4.4} in the UT 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
WF	01505	1.0	2	75	n/a	n/a	35
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	12205	1.0	13	75	n/a	n/a	50
PI	10602	5.0	n/a	n/a	-40	11	25
WJ	06405	1.0	n/a	n/a	n/a	n/a	36
GO	81402	5.0	n/a	n/a	n/a	n/a	19
PM	10602	5.0	n/a	n/a	-40	11	25
RM	06405	1.0	n/a	n/a	n/a	n/a	36
UJ	06405	1.0	n/a	n/a	n/a	n/a	36
GB	10201	5.0	n/a	n/a	n/a	n/a	25
NC	74902	5.0	n/a	n/a	-26	-2	35
FC	74902	5.0	n/a	n/a	-26	-2	35
MC	47502	5.0	n/a	n/a	-37	27	29
BI	31206	1.0	n/a	n/a	n/a	n/a	30
BE	74902	5.0	n/a	n/a	-26	-2	35
OS	12205	1.0	13	75	n/a	n/a	50
OH	81402	5.0	n/a	n/a	n/a	n/a	19

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

4.5 Crown Competition Factor

The UT 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 curl-leaf mountain mahogany and bigtooth maple. These two species use equation {4.5.2}. Coefficients for all species are shown in table 4.5.1.

{4.5.1} Used for all species other than 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 ≤ 0.1”:CCF_t = 0.001

{4.5.2} 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 Great Basin bristlecone pine, narrowleaf cottonwood, Fremont cottonwood, and boxelder; 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} – {4.5.2} in the UT variant.

Species Code	Model Coefficients				
	R_1	R_2	R_3	R_4	R_5
WB	0.01925	0.01676	0.00365	0.009187	1.7600
LM	0.01925	0.01676	0.00365	0.009187	1.7600
DF	0.11	0.0333	0.00259	0.017299	1.5571
WF	0.04	0.0270	0.00405	0.015248	1.7333
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	0.01676	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
PI	0.01925	0.01676	0.00365	0.009187	1.7600
WJ	0.01925	0.01676	0.00365	0.009187	1.7600
GO	0.03	0.0215	0.00363	0.011109	1.7250
PM	0.01925	0.01676	0.00365	0.009187	1.7600
RM	0.01925	0.01676	0.00365	0.009187	1.7600
UJ	0.01925	0.01676	0.00365	0.009187	1.7600
GB	0.01925	0.01676	0.00365	0.009187	1.7600
NC	0.03	0.0215	0.00363	0.011109	1.7250
FC	0.03	0.0215	0.00363	0.011109	1.7250
MC	0.0204	0.0246	0.0074	0	0
BI	0.0204	0.0246	0.0074	0	0
BE	0.03	0.0215	0.00363	0.011109	1.7250
OS	0.01925	0.01676	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 UT variant the threshold diameter is set to: 1.0" for narrowleaf cottonwood, Fremont cottonwood, and boxelder; 99.0" for common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, Great Basin bristlecone pine, curl-leaf mountain mahogany, bigtooth maple and other hardwood; 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 10-year height growth (*HTG*) for small trees based on site index, and is then modified to account for density effects and tree vigor.

Potential height growth for whitebark pine, limber pine, Douglas-fir, white fir, blue spruce, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine and other softwood is estimated using equation {4.6.1.1}.

{4.6.1.1} $POTHTG = (SI / 5.0)$

Potential height growth for common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, Great Basin bristlecone pine, narrowleaf cottonwood, Fremont cottonwood, curl-leaf mountain mahogany, bigtooth maple boxelder, and other hardwood is estimated using equation {4.6.1.2}.

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

where:

POTHTG	is potential height growth
SI	is species site index on a 50-year age basis
SJ	is species site index on a base-age basis
H	is tree height

Potential height growth is then adjusted based on stand density (*PCTRED*) as computed with equation {4.6.1.3}, and crown ratio (*VIGOR*) as shown in equations {4.6.1.4} and {4.6.1.5}. Common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, Great Basin bristlecone pine, and other hardwood use equation {4.6.1.5} to estimate *VIGOR*. Height growth is then estimated using equation 4.6.1.6 for all species except quaking aspen.

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

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

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

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

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

where:

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

Height growth for small quaking aspen is obtained from a height-age curve from Shepperd (1995). Shepperd's original curve seemed to overestimate height growth when compared with field data from the geographic range of the UT variant, so the UT variant reduces the estimated height growth by 25 percent (as shown in equation {4.6.1.7}). 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 converted from centimeters to feet. An estimate of the tree's current age is obtained at the start of a projection using the tree's height and solving equation {4.6.1.7} for age.

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

$RSIMOD = 0.5 * (1 + ((SJ – 30) / 40))$

where:

HTG	is estimated height growth for the cycle
A	is tree age
RSIMOD	is a growth modifier based on relative site index
SJ	is species site index on a base-age basis bounded $30 < SJ$ for this calculation

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

Height growth 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 {4.6.1.8}, and applied as shown in equation {4.6.1.9}. The range of diameters for each species is shown in table 4.6.1.1.

{4.6.1.8}

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

{4.6.1.9} 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 and diameter growth bounds by species in the UT variant.

Species Code	X_{min}	X_{max}	DG_{max}
WB	2.0	4.0	2.8
LM	2.0	4.0	2.8
DF	2.0	4.0	2.4
WF	2.0	4.0	3.6
BS	2.0	4.0	3.6
AS	2.0	4.0	2.5
LP	1.0	5.0	3.5
ES	2.0	4.0	3.6
AF	2.0	6.0	3.6
PP	2.0	6.0	2.8
PI*	90.0	99.0	2.0
WJ*	90.0	99.0	2.0
GO*	90.0	99.0	2.0
PM*	90.0	99.0	2.0
RM*	90.0	99.0	2.0
UJ*	90.0	99.0	2.0
GB*	99.0	199.0	2.0
NC	0.5	2.0	2.5
FC	0.5	2.0	2.5
MC*	90.0	99.0	2.0
BI*	90.0	99.0	2.0
BE	0.5	2.0	2.5
OS	2.0	6.0	2.8
OH*	90.0	99.0	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. For whitebark pine, limber pine, Douglas-fir, white fir, blue spruce, quaking aspen, lodgepole pine, Engelmann spruce, subalpine fir, narrowleaf cottonwood, Fremont cottonwood, boxelder, and other softwood, these two predicted diameters are estimated using the species-specific height-diameter relationships discussed in section 4.1. By definition, diameter growth is zero for trees less than 4.5 feet tall.

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

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

Common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, Great Basin bristlecone pine, and other hardwood use equation {4.6.2.2} as previously described.

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

where:

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

Curl-leaf mountain mahogany and bigtooth maple use the Curtis-Arney method by default and is shown in equations {4.6.2.3}. Equation {4.6.2.3} is used when calibration of the height-diameter equation is turned off, or when it's turned on and does not occur. If calibration of the height-diameter curve is turned on and does occur, then equation {4.6.2.4} is used to estimate diameter growth directly.

{4.6.2.3} Curtis-Arney method

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

{4.6.2.4} $DG = 0.1 * HTG$

where:

HAT3	$= 4.5 + a * \exp(-b * (3.0 \wedge c))$
DBH	is tree diameter at breast height
HT	is tree height
DG	is estimated tree diameter growth

HTG is estimated tree height growth
a, b, c are species-specific coefficients shown as P_2, P_3, and P_4 in section 4.1

For all species the estimate of diameter growth is adjusted to account for user defined small-tree diameter growth adjustments, and then bounded using equation {4.6.2.5} and coefficients shown in table 4.6.1.2.

{4.6.2.5} $DG \leq (FINT/10) * DG_{max}$

where:

DG is estimated tree diameter growth
FINT is projection cycle length
DG_{max} is the species specific maximum 10-year diameter growth from table 4.6.1.2

4.7 Large Tree Growth Relationships

Trees are considered "large trees" for FVS modeling purposes when they are equal to or greater than some threshold diameter. This threshold diameter is set to: 1.0" for narrowleaf cottonwood, Fremont cottonwood, and boxelder; 99.0" for common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, Great Basin bristlecone pine, curl-leaf mountain mahogany, bigtooth maple and other hardwood; 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). Instead of predicting diameter increment directly, most variants predict the natural log of the periodic change in squared inside-bark diameter (ln(*DDS*)) (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 UT variant predicts diameter growth for whitebark pine, limber pine, Douglas-fir, white fir, blue spruce, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, and other softwood using equation {4.7.1.1}. Coefficients for this equation are shown in tables 4.7.1.1 – 4.7.1.3.

{4.7.1.1} $\ln(DDS) = b_1 + (b_2 * SI) + (b_3 * \sin(ASP - 0.7854) * SL) + (b_4 * \cos(ASP - 0.7854) * SL) + (b_5 * SL) + (b_6 * SL^2) + (b_7 * \ln(DBH)) + (b_8 * (BAL / 100)) + (b_9 * CR) + (b_{10} * CR^2) + (b_{11} * DBH^2) + (b_{12} * PCCF) + (b_{13} * (CCF / 100))$

$\ln(DDS) = \ln(DDS) * 0.95$ (for blue spruce only)

where:

DDS is the predicted periodic change in squared inside-bark diameter

SI is species site index on a 50-year age basis
ASP is stand aspect
SL is stand slope
DBH is tree diameter at breast height
BAL is total basal area in trees larger than the subject tree
CR is a tree's live crown ratio (compacted) expressed as a proportion
PCCF is crown competition factor on the inventory point where the tree is established
CCF is stand crown competition factor
b_1 is a location-specific coefficient shown in Table 4.7.1.1
b_2 is a coefficient based on site index mapped class shown in table 4.7.1.2
b_3- b_{13} are species-specific coefficients shown in tables 4.7.1.3

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

Location Code	Species Code						
	WB, LM, OS	DF	WF	BS, ES	LP	AF	PP
401 – Ashley	1.911884	0.192136	-0.061856	0.011943	-0.256987	-0.467188	-0.13235
407 – Dixie	1.911884	-0.064516	-0.130667	0.011943	-0.256987	-0.638653	-0.460129
408 – Fishlake 409 – Humbolt 417 – Toiyabe	1.911884	-0.064516	-0.314746	0.011943	-0.256987	-0.467188	-0.460129
410 – Manti LaSal	1.911884	-0.064516	-0.314746	0.265071	-0.256987	-0.467188	-0.302309
418 – Uinta	1.911884	0.477698	0.421806	-0.094861	-0.425846	-0.467188	-0.302309
419 – Wasatch 404 – Cache	1.911884	0.589169	0.421806	0.796948	0.530457	0.116430	-0.302309

Table 4.7.1.2 b_2 coefficients by species and site index species for equation {4.7.1.1} in the UT variant.

Site Index Species	Species Code						
	WB, LM, OS	DF	WF	BS, ES	LP	AF	PP
WB, LM, LP, PI, WJ, GO, PM, RM, UJ, GB, NC, FC, MC, BI, BE, OH	0.001766	0.010968	0.017663	0.015133	0.021764	0.004468	0.019282
DF	0.001766	0.006827	0.005327	0.021085	0.021764	0.004468	0.019282
AF	0.001766	0.010968	0.017663	0.021085	0.021764	0.008147	0.019282
BS, ES	0.001766	0.006827	0.017663	0.021085	0.027956	0.008147	0.019282
AS	0.00176	0.01096	0.01766	0.02108	0.02795	-	0.019282

	6	8	3	5	6	0.015283	
WF	0.001766	0.010968	0.017663	0.021085	0.027956	0.008147	0.049804
PP, OS	0.001766	0.010968	0.005327	0.021085	0.027956	0.008147	0.02943

Table 4.7.1.3 Coefficients (b_3- b_{13}) for equation {4.7.1.1} in the UT variant.

Coefficient	Species Code						
	WB, LM, OS	**DF**	**WF**	**BS, ES**	**LP**	**AF**	**PP**
b_3	-0.017520	0.022753	-0.082731	-0.122483	0.128610	-0.192975	-0.287654
b_4	-0.609774	0.015235	0.012704	-0.198194	-0.168522	-0.232267	-0.411292
b_5	-2.057060	-0.532905	-1.133123	0.240433	0.120589	0.383578	0.016965
b_6	2.113263	-0.086518	1.931351	0	-0.266226	-0.333955	2.282665
b_7	0.213947	0.479631	0.827167	0.587579	0.587503	0.833096	0.733305
b_8	-0.358634	-0.707380	-0.010478	-0.399357	-0.192073	-0.182808	-0.320124
b_9	1.523464	3.182592	-0.207507	0.331129	2.148640	1.422919	1.315804
b_{10}	0	-1.310144	1.578941	0.816301	-0.598897	0.225676	0.238917
b_{11}*	-0.000654	0	-0.000018	0	0	-0.000167	-0.0005345
b_{12}	0	-0.001613	-0.000428	0	-0.000467	-0.000200	-0.002576
b_{13}**	-0.199592	0	-0.098821	-0.043414	-0.407523	0	0

*The value of b_{11} is set to –0.0006363 for PP if the location code is 407 (Dixie)
**The value of b_{13} is set to –0.154870 for ES if the site index for the site species is greater than 39

Large-tree diameter growth for quaking aspen is predicted using equation set {4.7.1.2}. 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.

{4.7.1.2} $POTGR = (0.4755 – 0.0000038336 * DBH^{4.1488}) + (0.04510 * CR * DBH^{0.67266})$

$MOD = 1.0 – \exp(-FOFR * GOFAD * ((310-BA)/310)^{0.5})$
$FOFR = 1.07528 * (1.0 – \exp(–1.89022 * DBH / QMD))$
$GOFAD = 0.21963 * (QMD + 1.0)^{0.73355}$
$PREDGR = POTGR * MOD * (0.48630 + 0.01258 * SJ)$

where:

POTGR	is potential diameter growth bounded to be $\geq$ 0.01
DBH	is tree diameter at breast height
CR	is crown ratio expressed as a percent divided by 10
MOD	is a modifier based on tree diameter and stand density
FOFR	is the relative density modifier
GOFAD	is the average diameter modifier
BA	is total stand basal area bounded to be $\leq$ 305
QMD	is stand quadratic mean diameter

PREDGR is predicted diameter growth
SJ is the quaking aspen site index on a base age 80 basis

Large-tree diameter growth for narrowleaf cottonwood, Fremont cottonwood, and boxelder is estimated using equation {4.7.1.3}. Diameter at the end of the growth cycle (DF) 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.

{4.7.1.3} $DF = (1.55986 + 1.01825 * DBH - 0.29342 * \ln(TBA) + 0.00672 * SJ - 0.00073 * BAU / BA) * 1.05$

$DG = (DF - DBH) * BRATIO * DSTAG$
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 common pinyon, western juniper, Gambel Oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, Great Basin bristlecone pine, curl-leaf mountain mahogany, bigtooth maple, and other hardwood.

4.7.2 Large Tree Height Growth

Species in the UT variant use different types of equations depending on species. Eleven species use the Johnson's SBB (1949) method (Schreuder and Hafley, 1977). These species are whitebark pine, limber pine, Douglas-fir, white fir, blue spruce, quaking aspen, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, 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 and table 4.7.2.2. 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} $Z = [C_4 + C_6 * FBY2 – C_7 * (C_3 + C_5 * FBY1)] * (1 – C_7\text{^}2)\text{^}\text{-}0.5$

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

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, or species and site class shown in table 4.7.2.2

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 UT variant.

	Species Code				
Coefficient by *CR class**	**WB, LM, OS**	**WF**	**AS**	**LP**	**PP**
C_1 ($CR \leq 24$)	37	50	30	30	55
C_1 ($25 \leq CR \leq 74$)	45	50	30	35	60
C_1 ($75 \leq CR \leq 100$)	45	50	35	30	50
C_2 ($CR \leq 24$)	85	97	85	80	95
C_2 ($25 \leq CR \leq 74$)	100	97	85	93	115
C_2 ($75 \leq CR \leq 100$)	90	100	85	80	95
C_3 ($CR \leq 24$)	1.77836	1.54	2.00995	1.85047	1.35731
C_3 ($25 \leq CR \leq 74$)	1.66674	1.25483	2.00995	1.49353	1.01274
C_3 ($75 \leq CR \leq 100$)	1.6477	1.54368	1.80388	0.85472	0.53723
C_4 ($CR \leq 24$)	-0.51147	0.26509	0.03288	-0.2558	0.03681
C_4 ($25 \leq CR \leq 74$)	0.25626	0.162	0.03288	0.08644	0.07372
C_4 ($75 \leq CR \leq 100$)	0.30546	-0.23177	-0.07682	0.14709	-0.1006
C_5 ($CR \leq 24$)	1.88795	1.41204	1.81059	1.6717	1.22927
C_5 ($25 \leq CR \leq 74$)	1.45477	1.23576	1.81059	1.6115	1.30149
C_5 ($75 \leq CR \leq 100$)	1.35015	1.46073	1.70032	1.3151	1.06347
C_6 ($CR \leq 24$)	1.20654	1.25972	1.28612	1.5366	0.98859
C_6 ($25 \leq CR \leq 74$)	1.11251	1.22028	1.28612	1.57042	1.10133
C_6 ($75 \leq CR \leq 100$)	0.94823	1.11638	1.29148	1.22489	0.87482
C_7 ($CR \leq 24$)	0.57697	0.7448	0.72051	0.72508	0.86025
C_7 ($25 \leq CR \leq 74$)	0.67375	0.84747	0.72051	0.73267	0.83541

Coefficient by *CR** class	Species Code				
	WB, LM, OS	WF	AS	LP	PP
C_7 (75≤*CR*≤100)	0.70453	0.7941	0.72343	0.8383	0.86191
C_8 (*CR*≤ 24)	3.57635	2.01391	3.00551	2.82825	3.13888
C_8 (25≤*CR*≤74)	2.17942	2.09323	3.00551	1.89981	2.01632
C_8 (75≤*CR*≤100)	2.4648	3.69006	2.91519	1.59182	1.90485
C_9 (*CR*≤ 24)	0.90283	0.83486	1.01433	0.78883	1.06969
C_9 (25≤*CR*≤74)	0.88103	0.85822	1.01433	0.75184	0.98724
C_9 (75≤*CR*≤100)	1.00316	1.03903	0.95244	0.90003	1.04777

**CR* represents percent crown ratio

Table 4.7.2.2 Coefficients in the large tree height growth model, by site index, for species using the Johnson's SBB height distribution in the UT variant.

Coefficient by *SI** class	Species Code		
	DF	BS, ES	AF
C_1 (*SI*≤ 20)	50	50	35
C_1 (21≤*SI*≤30)	60	50	40
C_1 (31≤*SI*≤40)	55	60	40
C_1 (41≤*SI*≤50)	50	45	40
C_1 (50≤*SI*)	38	45	40
C_2 (*SI*≤ 20)	95	105	75
C_2 (21≤*SI*≤30)	110	105	95
C_2 (31≤*SI*≤40)	105	120	100
C_2 (41≤*SI*≤50)	110	120	110
C_2 (50≤*SI*)	110	125	115
C_3 (*SI*≤ 20)	1.03766	1.84149	2.60522
C_3 (21≤*SI*≤30)	1.63201	1.2124	1.95832
C_3 (31≤*SI*≤40)	1.3179	1.42571	1.64996
C_3 (41≤*SI*≤50)	1.00167	1.54101	1.21724
C_3 (50≤*SI*)	0.38147	0.403	1.19929
C_4 (*SI*≤ 20)	-0.10314	0.43562	0.33274
C_4 (21≤*SI*≤30)	0.32350	-0.15047	0.38168
C_4 (31≤*SI*≤40)	-0.36654	-0.18256	-0.03653
C_4 (41≤*SI*≤50)	-0.55765	0.20997	-0.03316
C_4 (50≤*SI*)	-0.67042	-0.81957	0.01214
C_5 (*SI*≤ 20)	1.16073	1.50911	1.88966
C_5 (21≤*SI*≤30)	1.30538	1.30622	1.53254
C_5 (31≤*SI*≤40)	1.38496	1.33875	1.52713
C_5 (41≤*SI*≤50)	1.37084	1.38766	1.30125
C_5 (50≤*SI*)	1.13209	1.15151	1.20833
C_6 (*SI*≤ 20)	1.02648	1.27174	1.50108
C_6 (21≤*SI*≤30)	1.33112	1.12217	1.40855

Coefficient by *SI class**	**Species Code**		
	DF	**BS, ES**	**AF**
C_6 (31≤*SI*≤40)	1.18264	1.10993	1.24917
C_6 (41≤*SI*≤50)	1.29851	1.22927	1.11284
C_6 (50≤*SI*)	0.9219	0.85881	0.9818
C_7 (*SI*≤ 20)	0.83396	0.83183	0.78085
C_7 (21≤*SI*≤30)	0.8187	0.82399	0.77849
C_7 (31≤*SI*≤40)	0.83039	0.8263	0.82371
C_7 (41≤*SI*≤50)	0.78167	0.89085	0.88781
C_7 (50≤*SI*)	0.83348	0.80328	0.89815
C_8 (*SI*≤ 20)	2.56902	2.36779	3.10664
C_8 (21≤*SI*≤30)	2.13984	2.78522	2.25099
C_8 (31≤*SI*≤40)	3.43941	3.40712	3.0564
C_8 (41≤*SI*≤50)	2.80787	2.57529	2.72071
C_8 (50≤*SI*)	2.92151	3.78573	2.9587
C_9 (*SI*≤ 20)	0.94303	0.98709	0.98298
C_9 (21≤*SI*≤30)	0.80286	0.95913	0.84702
C_9 (31≤*SI*≤40)	0.97246	0.99665	1.007
C_9 (41≤*SI*≤50)	0.82521	1.00564	1.03812
C_9 (50≤*SI*)	1.02351	1.07705	1.10539

**SI* represents site index for the species

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 4.7.2.3.

{4.7.2.2} $ZBIAS = C_{10} + C_{11} * (EL - 20)$ for $80 \leq EL \leq 105$

$ZBIAS = 0$ for stand elevations outside this range; or when $ZBIAS < 0$ and $(Z - ZBIAS) \geq 2$

where:

Z is the estimated SBB distribution parameter
ZBIAS is the known bias in the estimate of Z
EL is the elevation of the stand expressed in hundreds of feet

Table 4.7.2.3 Coefficients for the large tree height growth model bias correction in the UT 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

Equation {4.7.2.3} is used to eliminate known bias in the estimate of Z.

{4.7.2.3} Z = Z + (0.1 – 0.10273 * (Z – ZBIAS) + 0.00273 * (Z – ZBIAS)^2) if Z < 0; set Z = 0

If the *Z* value is 2.0 or less, it is adjusted for all younger aged trees using equation {4.7.2.4}. 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.

{4.7.2.4} *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 {4.7.2.5}, and finally, 10-year height growth is calculated by subtraction using equation {4.7.2.6} and adjusted to the cycle length.

{4.7.2.5} *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)]

{4.7.2.6} 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 species

Whitebark pine, limber pine, white fir, quaking aspen, lodgepole pine, ponderosa pine, other softwood are based on crown ratio class and shown in table 4.7.2.1 Douglas-fir, blue spruce, Engelmann spruce, subalpine fir are based on site index class and shown in table 4.7.2.2

Large tree height growth for narrowleaf cottonwood, Fremont cottonwood, and boxelder 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 {4.7.2.7} 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 {4.7.2.8} 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 {4.7.2.9} 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.

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

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

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

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 {4.7.2.10}. If the tree age is less than 30 years, then the height estimate is modified using equation {4.7.2.11}.

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

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

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 {4.7.2.12}.

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

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 common pinyon, western juniper, Gambel oak, singleleaf pinyon, Rocky Mountain juniper, Utah juniper, Great Basin bristlecone pine, curl-leaf mountain mahogany, bigtooth maple, and other hardwood is estimated using small tree height growth equations discussed in section 4.6.1 for all sizes of trees.

5.0 Mortality Model

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

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

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

{5.0.2} $RIP = 1 – (1 – RI)^Y$

where:

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

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

Species Code	p_0	p_1
WB	6.5112	-0.0052485
LM	6.5112	-0.0052485
DF	7.2985	-0.0129121
WF	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	5.5877	-0.005348
PI	5.1677	-0.0077681
WJ	5.1677	-0.0077681
GO	5.1677	-0.0077681
PM	5.1677	-0.0077681

Species Code	p_0	p_1
RM	5.1677	-0.0077681
UJ	5.1677	-0.0077681
GB	5.1677	-0.0077681
NC	5.9617	-0.0052485
FC	5.9617	-0.0052485
MC	5.9617	-0.0340128
BI	5.5877	-0.005348
BE	5.9617	-0.0052485
OS	5.1677	-0.0077681
OH	5.1677	-0.0077681

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 equations {5.0.3}. 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 equations {5.0.4} and {5.0.5}.

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

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

{5.0.4} Used for Great Basin bristlecone pine, narrowleaf cottonwood, Fremont cottonwood, and boxelder:

$MORT = MR * (1 - (CR / 100)) * MWT * 0.1$

{5.0.5} 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
CR	is the subject tree's crown ratio expressed as a percent
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 equations {5.0.4} and {5.0.5} in the UT variant.

Species Code	*MWT*
WB	0.80
LM	0.70
DF	0.55
WF	0.50
BS	0.50
AS	1.00
LP	0.90
ES	0.50
AF	0.60
PP	0.85
PI	0.70
WJ	0.70
GO	0.70
PM	0.70
RM	0.70
UJ	0.70
GB	0.90
NC	0.90
FC	0.90
MC	1.10
BI	0.70
BE	0.90
OS	0.75
OH	0.70

6.0 Regeneration

The UT 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 UT variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
WB	No	0.4	1	9
LM	No	0.4	1	9
DF	No	0.3	1	10
WF	No	0.3	0.5	7
BS	No	0.3	0.5	7
AS	Yes	0.2	6	16
LP	No	0.4	1	10
ES	No	0.3	0.5	7
AF	No	0.3	0.5	7
PP	No	0.5	1	10
PI	No	0.4	0.5	6
WJ	No	0.3	0.5	6
GO	Yes	0.3	0.5	10
PM	No	0.4	0.5	6
RM	No	0.3	0.5	6
UJ	No	0.3	0.5	6
GB	No	0.4	0.5	9
NC	Yes	0.3	3	16
FC	Yes	0.3	3	16
MC	No	0.2	0.5	6
BI	Yes	0.2	0.5	6
BE	Yes	0.3	3	16
OS	No	0.2	0.5	9
OH	No	0.3	0.5	10

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

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

{6.0.1} For stump sprouting hardwood species

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

{6.0.2} For root suckering hardwood species

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

{6.0.3} $TPA_s = TPA_i * PS$

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

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 UT variant.

Species Code	Sprouting Probability	Number of Sprout Records	Source
AS	{6.0.4}	2	Keyser 2001
GO	0.8	{6.0.1}	Simonin 2000
NC	0.8	{6.0.2}	Simonin 2001
FC	0.8	{6.0.2}	Taylor 2000
BI	0.7	1	Tollefson 2006
BE	0.6 for DBH < 15", 0.3 for DBH >	1	Maeglin and Ohman 1973 Eyre 1980

	15"		

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 UT 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 UT variant are shown in tables 7.0.1-7.0.3.

Table 7.0.1 Volume merchantability standards for the UT 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

* Board foot volume is not calculated for common pinyon, western juniper, Gambel oak, singleleaf pinyon, Utah juniper, or curl-leaf mountain mahogany when using the default volume equations. Additionally, no volumes of any kind are calculated for Rocky Mountain juniper.

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

Common Name	Location Code	Equation Number	Reference
whitebark pine	All	400MATW108	Rustagi and Loveless Profile Models
limber pine	All	400MATW108	Rustagi and Loveless Profile Models
Douglas-fir	All	400MATW202	Rustagi and Loveless Profile Models
white fir	All	400MATW015	Rustagi and Loveless Profile Models
blue spruce	407, 408	407FW2W093	Flewelling's 2-Point Profile Model
blue spruce	401, 410, 418, 419	400MATW093	Rustagi and Loveless Profile Models
quaking aspen	All	400MATW746	Rustagi and Loveless Profile Models
lodgepole pine	All	400MATW108	Rustagi and Loveless Profile Models
Engelmann spruce	401, 410, 418, 419	400MATW093	Rustagi and Loveless Profile

Common Name	Location Code	Equation Number	Reference
			Models
Engelmann spruce	407, 408	407FW2W093	Flewelling's 2-Point Profile Model
subalpine fir	All	400MATW019	Rustagi and Loveless Profile Models
ponderosa pine	401	401MATW122	Rustagi and Loveless Profile Models
ponderosa pine	407, 408, 410, 418, 419	402MATW122	Rustagi and Loveless Profile Models
common pinyon	All	400DVEW106	Chojnacky Equations
western juniper	All	400DVEW064	Chojnacky Equations
Gambel oak	All	300DVEW800	Chojnacky Equations
singleleaf pinyon	All	400DVEW133	Chojnacky Equations
Rocky Mountain juniper	All	400DVEW066	Chojnacky Equations
Utah juniper	All	400DVEW065	Chojnacky Equations
Great Basin bristlecone pine	All	400MATW108	Rustagi and Loveless Profile Models
narrowleaf cottonwood	All	400MATW108	Rustagi and Loveless Profile Models
Fremont cottonwood	All	400MATW108	Rustagi and Loveless Profile Models
curl-leaf mountain mahogany	All	400DVEW475	Chojnacky Equations
bigtooth maple	All	400MATW108	Rustagi and Loveless Profile Models
boxelder	All	400MATW108	Rustagi and Loveless Profile Models
other softwood	All	400MATW108	Rustagi and Loveless Profile Models
other hardwood	All	400DVEW998	Chojnacky Equations

Table 7.0.3 Citations by Volume Model

Model Name	Citation
Chojnacky Equations	David Chojnacky 1985. Pinyon-Juniper Volume Equations for the Central Rocky Mountain States. Intermountain Research Station Research Paper INT-339.
Flewelling's 2-Point Profile Model	Unpublished. Based on work presented by Flewelling and Raynes. 1993. Variable-shape stem-profile predictions for western hemlock. Canadian Journal of Forest Research Vol 23. Part I and Part II.
Rustagi and and Loveless	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 UT 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 UT 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 UT variant.

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
1	050	limber pine/Idaho fescue	PIFL2/FEID
2	060	limber pine/curl-leaf mountain mahogany	PIFL2/CELE3
3	070	limber pine/common juniper	PIFL2/JUCO6
4	080	limber pine/spike fescue	PIFL2/LEKI2
5	090	limber pine	PIFL2
6	100	ponderosa pine	PIPO
7	120	ponderosa pine/western needlegrass	PIPO/ACOCO
8	130	ponderosa pine/bluebunch wheatgrass	PIPO/PSSPS
9	140	ponderosa pine/Idaho fescue	PIPO/FEID
10	150	ponderosa pine/western snowberry	PIPO/SYOC h.t.
11	160	ponderosa pine/antelope bitterbrush	PIPO/PUTR2
12	161	ponderosa pine/antelope bitterbrush-bluebunch wheatgrass	PIPO/PUTR2-PSSPS
13	162	ponderosa pine/antelope bitterbrush-Idaho fescue	PIPO/PUTR2-FEID
14	170	ponderosa pine/common snowberry	PIPO/SYAL
15	190	ponderosa pine/mallow ninebark	PIPO/PHMA5
16	195	ponderosa pine/mountain snowberry	PIPO/SYOR2
17	41045	limber pine/creeping barberry	PIFL2/MARE11
18	41115	ponderosa pine/Geyer's sedge	PIPO/CAGE2
19	41141	ponderosa pine/Idaho fescue-Idaho fescue	PIPO/FEID-FEID
20	41143	ponderosa pine/Idaho fescue/greenleaf manzanita	PIPO/FEID/ARPA6
21	41144	ponderosa pine/Idaho fescue/big sagebrush	PIPO/FEID/ARTR2
22	41376	Douglas-fir/sweetcicely/Oregon boxleaf	PSME/OSBE/PAMY
23	41406	blue spruce/bluebunch wheatgrass	PIPU/PSSPS
24	41416	Engelmann spruce/dwarf bilberry	PIEN/VACA13
25	41708	subalpine fir/sicletop lousewort/Douglas-fir	ABLA/PERA/PSME
26	41709	subalpine fir/sicletop lousewort-sicletop lousewort	ABLA/PERA-PERA
27	41715	subalpine fir/creeping barberry-gooseberry currant	ABLA/MARE11-RIMO2
28	41716	subalpine fir/creeping barberry-common juniper	ABLA/MARE11-JUCO6
29	41717	subalpine fir/creeping barberry/Douglas-fir	ABLA/MARE11/PSME

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
30	41725	subalpine fir/grouse whortleberry/broadlef arnica	ABLA/VASC/ARLA8
31	41726	subalpine fir/grouse whortleberry/Geyer's sedge	ABLA/VASC/CAGE2
32	41813	subalpine fir/gooseberry currant/Fendler's meadow-rue	ABLA/RIMO2/THFE
33	41814	subalpine fir/gooseberry currant/lodgepole pine	ABLA/RIMO2/PICO
34	41815	subalpine fir/gooseberry currant/spike trisetum	ABLA/RIMO2/TRSP2
35	41862	white fir/sweetcicely	ABCO/OSBE
36	41864	white fir/creeping barberry/mountain snowberry	ABCO/MARE11/SYOR2
37	41915	lodgepole pine/bluejoint	PICO/CACA4
38	41956	lodgepole pine/kinnikinnick	PICO/ARUV
39	41957	lodgepole pine/creeping barberry	PICO/MARE11
40	41970	lodgepole pine/Ross' sedge	PICO/CARO5
41	41107	ponderosa pine/greenleaf manzanita	PIPO/ARPA6
42	41108	ponderosa pine/curl-leaf mountain mahogany	PIPO/CELE3
43	41109	ponderosa pine/black sagebrush	PIPO/ARNO4
44	41111	ponderosa pine/Gamble oak	PIPO/QUGA
45	41112	ponderosa pine/Gamble oak-mountain snowberry	PIPO/QUGA-SYOR2
46	41113	ponderosa pine/Gamble oak-Gamble oak	PIPO/QUGA-QUGA
47	41114	ponderosa pine/mountain muhly	PIPO/MUMO
48	41365	Douglas-fir/greenleaf manzanita	PSME/ARPA6
49	41366	Douglas-fir/alderleaf mountain mahogany	PSME/CEMO2
50	41367	Douglas-fir/Gamble oak	PSME/QUGA
51	41382	Douglas-fir/creeping barberry/ponderosa pine	PSME/MARE11/PIPO
52	41408	blue spruce/field horsetail	PIPU/EQAR
53	41409	blue spruce/common juniper	PIPU/JUCO6
54	41746	subalpine fir/Columbian monkshood	ABLA/ACCO4
55	41747	subalpine fir/whortleberry	ABLA/VAMY2
56	41816	subalpine fir/gooseberry currant/aspen bluebells	ABLA/RIMO2/MEAR6
57	41866	white fir/creeping barberry-common juniper	ABCO/MARE11-JUCO6
58	41867	white fir/mountain snowberry	ABCO/SYOR2
59	41868	white fir/common juniper	ABCO/JUCO6
60	41869	white fir/Gamble oak	ABCO/QUGA
61	41871	white fir/greenleaf manzanita	ABCO/ARPA6
62	41872	white fir/curl-leaf mountain mahogany	ABCO/CELE3
63	41873	white fir/Rocky Mountain maple	ABCO/ACGL

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
64	42001	quaking aspen/California false hellebore	POTR5/VECA2
65	42002	quaking aspen/western brackenfern	POTR5/PTAQ
66	42003	quaking aspen/mule-ears	POTR5/WYAM
67	42004	quaking aspen/Thurber's fescue	POTR5/FETH
68	42005	quaking aspen/tall forb	POTR5/2FORB
69	42006	quaking aspen/pinegrass	POTR5/CARU
70	42007	quaking aspen/Fendler's meadow-rue	POTR5/THFE
71	42008	quaking aspen/California brome	POTR5/BRCA5
72	42009	quaking aspen/Ross' sedge	POTR5/CARO5
73	42010	quaking aspen/needle and thread	POTR5/HECOC8
74	42011	quaking aspen/timber milkvetch	POTR5/ASMI9
75	42012	quaking aspen/Kentucky bluegrass	POTR5/POPR
76	42040	quaking aspen/thimbleberry	POTR5/RUPA
77	42041	quaking aspen/red elderberry	POTR5/SARA2
78	42042	quaking aspen/russet buffaloberry	POTR5/SHCA
79	42043	quaking aspen/mountain snowberry	POTR5/SYOR2
80	42044	quaking aspen/mountain snowberry/tall forb phase	POTR5/SYOR2/2FORB
81	42045	quaking aspen/mountain snowberry/pinegrass	POTR5/SYOR2/CARU
82	42046	quaking aspen/mountain snowberry/Fendler's meadow-rue	POTR5/SYOR2/THFE
83	42047	quaking aspen/mountain snowberry/Thurber's fescue	POTR5/SYOR2/FETH
84	42048	quaking aspen/mountain snowberry/Ross' sedge	POTR5/SYOR2/CARO5
85	42049	quaking aspen/mountain snowberry/mule-ears	POTR5/SYOR2/WYAM
86	42050	quaking aspen/mountain snowberry/California brome	POTR5/SYOR2/BRCA5
87	42051	quaking aspen/mountain snowberry/Kentucky bluegrass	POTR5/SYOR2/POPR
88	42052	quaking aspen/common juniper	POTR5/JUCO6
89	42053	quaking aspen/common juniper/Geyer's sedge	POTR5/JUCO6/CAGE2
90	42054	quaking aspen/common juniper/silvery lupine	POTR5/JUCO6/LUAR3
91	42055	quaking aspen/common juniper/timber milkvetch	POTR5/JUCO6/ASMI9
92	42056	quaking aspen/big sagebrush	POTR5/ARTR2
93	42080	quaking aspen/Scouler's willow	POTR5/SASC
94	42081	quaking aspen/Saskatoon serviceberry-mountain snowberry	POTR5/AMAL2-SYOR2
95	42082	quaking aspen/Saskatoon serviceberry-mountain snowberry/tall forb	POTR5/AMAL2-SYOR2/2FORB

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
96	42083	quaking aspen/Saskatoon serviceberry-mountain snowberry/Fendler's meadow-rue	POTR5/AMAL2-SYOR2/THFE
97	42084	quaking aspen/Saskatoon serviceberry-mountain snowberry/pinegrass	POTR5/AMAL2-SYOR2/CARU
98	42085	quaking aspen/Saskatoon serviceberry-mountain snowberry/California brome	POTR5/AMAL2-SYOR2/BRCA5
99	42086	quaking aspen/Saskatoon serviceberry-roundleaf snowberry	POTR5/AMAL2-SYRO
100	42087	quaking aspen/Saskatoon serviceberry/western brackenfern	POTR5/AMAL2/PTAQ
101	42088	quaking aspen/Saskatoon serviceberry/tall forb	POTR5/AMAL/2FORB
102	42089	quaking aspen/Saskatoon serviceberry/Fendler's meadow-rue	POTR5/AMAL2/THFE
103	42101	quaking aspen-subalpine fir/tall forb	POTR5-ABLA/2FORB
104	42102	quaking aspen-subalpine fir/Fendler's meadow-rue	POTR5-ABLA/THFE
105	42103	quaking aspen-subalpine fir/Geyer's sedge	POTR5-ABLA/CAGE2
106	42104	quaking aspen-subalpine fir/Ross' sedge	POTR5-ABLA/CARO5
107	42105	quaking aspen-subalpine fir/russet buffaloberry	POTR5-ABLA/SHCA
108	42106	quaking aspen-subalpine fir/mountain snowberry	POTR5-ABLA/SYOR2
109	42107	quaking aspen-subalpine fir/mountain snowberry/tall forb	POTR5-ABLA/SYOR2/2FORB
110	42108	quaking aspen-subalpine fir/mountain snowberry/Fendler's meadow-rue	POTR5-ABLA/SYOR2/THFE
111	42109	quaking aspen-subalpine fir/mountain snowberry/California brome	POTR5-ABLA/SYOR2/BRCA5
112	42110	quaking aspen-subalpine fir/common juniper	POTR5-ABLA/JUCO6
113	42111	quaking aspen-subalpine fir/Saskatoon serviceberry	POTR5-ABLA/AMAL2
114	42201	quaking aspen-lodgepole pine/Fendler's meadow-rue	POTR5-PICO/THFE
115	42202	quaking aspen-lodgepole pine/Geyer's sedge	POTR5-PICO/CAGE2
116	42203	quaking aspen-lodgepole pine/mountain snowberry	POTR5-PICO/SYOR2
117	42204	quaking aspen-lodgepole pine/common juniper	POTR5-PICO/JUCO6
118	42301	quaking aspen-Douglas-fir/pinegrass	POTR5-PSME/CARU
119	42302	quaking aspen-Douglas-fir/mountain snowberry	POTR5-PSME/SYOR2
120	42303	quaking aspen-Douglas-fir/common juniper	POTR5-PSME/JUCO
121	42304	quaking aspen-Douglas-fir/Saskatoon	POTR5-PSME/AMAL2

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
		serviceberry	
122	42401	quaking aspen-white fir/Kentucky bluegrass	POTR5-ABCO/POPR
123	42402	quaking aspen-white fir/mountain snowberry	POTR5-ABCO/SYOR2
124	42403	quaking aspen-white fir/greenleaf manzanita	POTR5-ABCO/ARPA6
125	42500	quaking aspen-blue spruce	POTR5-PIPU
126	42600	quaking aspen-limber pine	POTR5-PIFL2
127	42700	quaking aspen-ponderosa pine	POTR5-PIPO
128	43002	spruce/redosier dogwood	PICEA/COSES
129	43004	spruce/field horsetail	PICEA/EQAR
130	43006	spruce/bluejoint	PICEA/CACA4
131	43012	spruce/fragrant bedstraw	PICEA/GATR3
132	43105	gray alder/northern black currant	ALIN2/RIHU
133	43202	Booth's willow/beaked sedge	SABO2/CARO6
134	43208	Booth's willow/starry false lily of the vally	SABO2/MAST4
135	43225	Geyer's willow/Kentucky bluegrass	SAGE2/POPR
136	43227	Geyer's willow/forb (mesic)	SAGE2/2FORB
137	43241	narrowleaf willow/field horsetail	SAEX/EQAR
138	43271	yellow willow	SALU2
139	43283	mountain willow	SAEA
140	43303	Wolf's willow/Nebraska sedge	SAWO/CANE2
141	43305	Wolf's willow/bluejoint	SAWO/CACA4
142	43307	Wolf's willow/fowl bluegrass	SAWO/POPA2
143	43321	diamondleaf willow	SAPL2
144	43354	redosier dogwood/fragrant bedstraw	COSES/GATR3
145	43400	alderleaf buckthorn	RHAL
146	43552	shrubby cinquefoil/Idaho fescue	DAFL3/FEID
147	43602	silver sagebrush/Idaho fescue	ARCA13/FEID
148	43813	sedge	CAREX
149	43881	fowl bluegrass	POPA2
150	43941	forb (mesic, meadow)	2FORB
151	43003	conifer/field horsetail	2TE/EQAR
152	43005	conifer/bluejoint	2TE/CACA4
153	43007	conifer/blue wildrye	2TE/ELGL
154	43008	conifer/shrubby cinquefoil	2TE/DAFL3
155	43009	conifer/tufted hairgrass	2TE/DECA18
156	43011	conifer/Columbian monkshood	2TE/ACCO4
157	43013	conifer/red baneberry	2TE/ACRU2
158	43041	narrowleaf cottonwood/water birch	POAN3/BEOC2
159	43042	narrowleaf cottonwood/bigtooth maple	POAN3/ACGR3

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
160	43044	narrowleaf cottonwood/Woods' rose	POAN3/ROWO
161	43045	narrowleaf cottonwood/fragrant sumac	POAN3/RHAR4
162	43081	boxelder/redosier dogwood	ACNE2/COSE16
163	43082	boxelder/field horsetail	ACNE2/EQAR
164	43102	gray alder/field horsetail	ALIN2/EQAR
165	43201	Booth's willow/water sedge	SABO2/CAAQ
166	43209	Booth's willow/mesic forb	SABO2/2FORB
167	43210	Booth's willow/mesic graminoid	SABO2/2GRAM
168	43221	Geyer's willow/water sedge	SAGE2/CAAQ
169	43226	Geyer's willow/tufted hairgrass	SAGE2/DECA18
170	43244	narrowleaf willow/mesic graminoid	SAEX/2GRAM
171	43245	narrowleaf willow (barren)	SAEX
172	43281	Bebb willow/mesic graminoid	SABE2/2GRAM
173	43286	arroyo willow (barren)	SALA6
174	43322	diamondleaf willow/water sedge	SAPL2/CAAQ
175	43323	diamondleaf willow/bluejoint	SAPL2/CACA4
176	43324	diamondleaf willow/tufted hairgrass	SAPL2/DECA18
177	43326	grayleaf willow/tufted hairgrass	SAGL/DECA18
178	43601	silver sagebrush/tufted hairgrass	ARCA13/DECA18
179	43603	silver sagebrush/sheep fescue	ARCA13/FEOV
180	43802	Buxbaum's sedge	CABU6
181	43804	woollyfruit sedge	CALA11
182	43806	mud sedge	CALI7
183	43810	russet sedge	CAPH8
184	43851	bluejoint	CACA4
185	43861	timber oatgrass	DAIN
186	43901	white marsh marigold	CALE4
187	43925	broadleaf cattail type	TYLA
188	46001	little sagebrush/bluebunch wheatgrass	ARAR8/PSSPS
189	46002	little sagebrush/Idaho fescue	ARAR8/FEID
190	46003	little sagebrush/Sandberg bluegrass	ARAR8/POSE
191	46011	silver sagebrush/mat muhly	ARCAB3/MURI
192	46021	silver sagebrush/Idaho fescue	ARCAV2/FEID
193	46031	little sagebrush/Idaho fescue	ARARL/FEID
194	46041	black sagebrush/bluebunch wheatgrass	ARNO4/PSSPS
195	46042	black sagebrush/Idaho fescue	ARNO4/FEID
196	46043	black sagebrush/needle and thread	ARNO4/HECOC8
197	46051	scabland sagebrush/Sandberg bluegrass	ARRI2/POSE
198	46061	little sagebrush/Idaho fescue	ARART/FEID

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
199	46101	big sagebrush/mountain brome (subalpine)	ARTRS2/BRCA5
200	46111	big sagebrush/bluebunch wheatgrass	ARTR2/PSSPS
201	46112	big sagebrush/basin wildrye	ARTR2/LECI4
202	46113	big sagebrush/Idaho fescue	ARTR2/FEID
203	46114	big sagebrush/needle and thread grass	ARTR2/HECOC8
204	46131	threetip sagebrush/bluebunch wheatgrass	ARTR4/PSSPS
205	46132	threetip sagebrush/Idaho fescue	ARTR4/FEID
206	46133	threetip sagebrush/needle and thread	ARTR4/HECOC8
207	46151	mountain big sagebrush/bluebunch wheatgrass	ARTRV/PSSPS
208	46152	mountain big sagebrush/basin wildrye	ARTRV/LECI4
209	46153	mountain big sagebrush/Idaho fescue	ARTRV/FEID
210	46154	mountain big sagebrush/needle and thread	ARTRV/HECOC8
211	46155	mountain big sagebrush/Thurber's needlegrass	ARTRV/ACTH7
212	46156	big sagebrush/Geyer's sedge	ARTRS2/CAGE2
213	46157	mountain big sagebrush/mountain snowberry/bluebunch wheatgrass	ARTRV/SYOR2/PSSPS
214	46158	mountain big sagebrush/mountain snowberry/Idaho fescue	ARTRV/SYOR2/FEID
215	46159	mountain big sagebrush/mountain snowberry/Geyer's sedge	ARTRV/SYOR2/CAGE2
216	46171	Wyoming big sagebrush/bluebunch wheatgrass	ARTRW8/PSSPS
217	46172	Wyoming big sagebrush/Sandberg bluegrass	ARTRW8/POSE
218	46173	Wyoming big sagebrush/squirreltail	ARTRW8/ELELE
219	46174	Wyoming big sagebrush/Thurber's needlegrass	ARTRW8/ACTH7
220	46191	big sagebrush/bluebunch wheatgrass	ARTRX/PSSPS
221	46192	big sagebrush/Idaho fescue	ARTRX/FEID
222	46201	antelope bitterbrush/bluebunch wheatgrass	PUTR2/PSSPS
223	46301	curl-leaf mountain mahogany/bluebunch wheatgrass	CELE3/PSSPS
224	47001	Idaho fescue-bluebunch wheatgrass	FEID-PSSPS
225	47011	bluebunch wheatgrass-Sandberg bluegrass	PSSPS-POSE
226	47012	bluebunch wheatgrass-Idaho fescue	PSSPS-FEID
227	47021	sand dropseed-Sandberg bluegrass	SPCR-POSE
228	47025	Fendler threeawn-Sandberg bluegrass	ARPUL-POSE
229	47002	Idaho fescue/prairie Junegrass	FEID/KOMA
230	47003		
231	47004		
232	43001	conifer/redosier dogwood	2TE/COSE16
233	43010	conifer/Kentucky bluegrass	2TE/POPR

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
234	43043	narrowleaf cottonwood/redosier dogwood	POAN3/COSES
235	43046	narrowleaf cottonwoon/Kentucky bluegrass	POAN3/POPR
236	43101	gray alder/redosier dogwood	ALIN2/COSE16
237	43103	gray alder/mesic forb	ALIN2/2FORB
238	43104	gray alder/mesic graminoid	ALIN2/2GRAM
239	43151	water birch/redosier dogwood	BEOC2/COSE16
240	43152	water birch/mesic forb	BEOC2/2FORB
241	43155	water birch/Kentucky bluegrass	BEOC2/POPR
242	43203	Booth's willow/Nebraska sedge	SABO2/CANE2
243	43204	Booth's willow/bluejoint	SABO2/CACA4
244	43205	Booth's willow/field horsetail	SABO2/EQAR
245	43206	Booth's willow/fowl bluegrass	SABO2/POPA2
246	43207	Booth's willow/Kentucky bluegrass	SABO2/POPR
247	43222	Geyer's willow/beaked sedge	SAGE2/CARO6
248	43223	Geyer's willow/bluejoint	SAGE2/CACA4
249	43224	Geyer's willow/fowl bluegrass	SAGE2/POPA2
250	43228	Geyer's willow/mesic graminoid	SAGE2/2GRAM
251	43242	narrowleaf willow/Kentucky bluegrass	SAEX/POPR
252	43243	narrowleaf willow/mesic forb	SAEX/2FORB
253	43301	Wolf's willow/field horsetail	SAWO/EQAR
254	43302	Wolf's willow/beaked sedge	SAWO/CARO6
255	43306	Wolf's willow/tufted hairgrass	SAWO/DECA18
256	43308	Wolf's willow/mesic forb	SAWO/2FORB
257	43353	redosier dogwood/common cowparsnip	COSES/HEMA80
258	43551	shrubby cinquefoil/tufted hairgrass	DAFL3/DECA18
259	43553	shrubby cinquefoil/Kentucky bluegrass	DAFL3/POPR
260	43604	silver sagebrush/Kentucky bluegrass	ARCA13/POPR
261	43801	water sedge	CAAQ
262	43805	woolly sedge	CAPE42
263	43807	smallwing sedge	CAMI7
264	43808	Nebraska sedge	CANE2
265	43809	beaked sedge	CARO6
266	43812	analogue sedge	CASI2
267	43821	common spikerush	ELPA3
268	43822	fewflower spikerush	ELQU2
269	43831	Baltic rush	JUBA
270	43871	tufted hairgrass	DECA18
271	43882	Kentucky bluegrass	POPR
272	43921	tall fringed bluebells	MECI3

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
273	43931	California false hellebore	VECA2
274	41050	limber pine/Idaho fescue	PIFL2/FEID
275	41060	limber pine/curl-leaf mountain mahogany	PIFL2/CELE3
276	41070	limber pine/common juniper	PIFL2/JUCO6
277	41080	limber pine/spike fescue	PIFL2/LEKI2
278	41140	ponderosa pine/Idaho fescue	PIPO/FEID
279	41160	ponderosa pine/antelope bitterbrush	PIPO/PUTR2
280	41195	ponderosa pine/mountain snowberry	PIPO/SYOR2
281	41220	Douglas-fir/Idaho fescue	PSME/FEID
282	41221	Douglas-fir/Idaho fescue-Idaho fescue	PSME/FEID-FEID
283	41260	Douglas-fir/mallow ninebark	PSME/PHMA5
284	41265	Douglas-fir/mallow ninebark/Douglas-fir	PSME/PHMA5/PSME
285	41266	Douglas-fir/mallow ninebark-Oregon boxleaf	PSME/PHMA5-PAMY
286	41280	Douglas-fir/thinleaf huckleberry	PSME/VAME
287	41310	Douglas-fir/common snowberry	PSME/SYAL
288	41313	Douglas-fir/common snowberry-common snowberry	PSME/SYAL-SYAL
289	41320	Douglas-fir/pinegrass	PSME/CARU
290	41323	Douglas-fir/pinegrass-pinegrass	PSME/CARU-CARU
291	41340	Douglas-fir/white spirea	PSME/SPBE2
292	41341	Douglas-fir/white spirea-white spirea	PSME/SPBE2-SPBE2
293	41343	Douglas-fir/white spirea/pinegrass	PSME/SPBE2/CARU
294	41360	Douglas-fir/common juniper	PSME/JUCO6
295	41370	Douglas-fir/heartleaf arnica	PSME/ARCO9
296	41371	Douglas-fir/heartleaf arnica-heartleaf arnica	PSME/ARCO9-ARCO9
297	41372	Douglas-fir/heartleaf arnica/timber milkvetch	PSME/ARCO9/ASMI9
298	41375	Douglas-fir/sweetcicely	PSME/OSBE
299	41380	Douglas-fir/mountain snowberry	PSME/SYOR2
300	41385	Douglas-fir/curl-leaf mountain mahogany	PSME/CELE3
301	41390	Douglas-fir/Rocky Mountain maple	PSME/ACGL
302	41395	Douglas-fir/creeping barberry	PSME/MARE11
303	41396	Douglas-fir/creeping barberry-creeping barberry	PSME/MARE11-MARE11
304	41397	Douglas-fir/creeping barberry-mountain snowberry	PSME/MARE11-SYOR2
305	41398	Douglas-fir/creeping barberry/Geyer's sedge	PSME/MARE11/CAGE2
306	41399	Douglas-fir/creeping barberry/common juniper	PSME/MARE11/JUCO6
307	41407	blue spruce/creeping barberry	PIPU/MARE11
308	41410	Engelmann spruce/field horsetail	PIEN/EQAR

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
309	41415	Engelmann spruce/white marsh marigold	PIEN/CALE4
310	41440	Engelmann spruce/fragrant bedstraw	PIEN/GATR3
311	41485	Engelmann spruce/grouse whortleberry	PIEN/VASC
312	41490	Engelmann spruce/softleaf sedge	PIEN/CADI6
313	41493	Engelmann spruce/revolute hypnum moss	PIEN/HYRE70
314	41497	Engelmann spruce/gooseberry current	PIEN/RIMO2
315	41601	subalpine fir/red baneberry	ABLA/ACRU2
316	41603	subalpine fir/mallow ninebark	ABLA/PHMA5
317	41635	subalpine fir/claspleaf twistedstalk	ABLA/STAM2
318	41636	subalpine fir/claspleaf twistedstalk-claspleaf twistedstalk phase	ABLA/STAM2-STAM2
319	41640	subalpine fir/dwarf bilberry	ABLA/VACA13
320	41645	subalpine fir/Rocky Mountain maple	ABLA/ACGL
321	41650	subalpine fir/bluejoint	ABLA/CACA4
322	41651	subalpine fir/bluejoint-bluejoint	ABLA/CACA4-CACA4
323	41654	subalpine fir/bluejoint/dwarf bilberry	ABLA/CACA4/VACA13
324	41655	subalpine fir/bluejoint/western Labrador tea	ABLA/CACA4/LEGL
325	41660	subalpine fir/twinflower	ABLA/LIBO3
326	41661	subalpine fir/twinflower-twinflower	ABLA/LIBO3-LIBO3
327	41663	subalpine fir/twinflower/grouse whortleberry	ABLA/LIBO3/VASC
328	41670	subalpine fir/rusty menziesia	ABLA/MEFE
329	41671	subalpine fir/rusty menziesia-rusty menziesia	ABLA/MEFE-MEFE
330	41690	subalpine fir/common beargrass	ABLA/XETE
331	41691	subalpine fir/common beargrass/thinleaf huckleberry	ABLA/XETE/VAME
332	41692	subalpine fir/common beargrass/grouse whortleberry	ABLA/XETE/VASC
333	41702	subalpine fir/creeping barberry-creeping barberry	ABLA/MARE11-MARE11
334	41703	subalpine fir/creeping barberry	ABLA/MARE11
335	41705	subalpine fir/white spirea	ABLA/SPBE2
336	41706	subalpine fir/creeping barberry/Engelmann spruce	ABLA/MARE11/PIEN
337	41707	subalpine fir/sicletop lousewort	ABLA/PERA
338	41714	subalpine fir/creeping barberry/limber pine	ABLA/MARE11/PIFL2
339	41720	subalpine fir/thinleaf huckleberry	ABLA/VAME
340	41721	subalpine fir/thinleaf huckleberry/grouse whortleberry	ABLA/VAME/VASC
341	41723	subalpine fir/thinleaf huckleberry-thinleaf huckleberry	ABLA/VAME-VAME

FVS Seq Num	Habitat Type Codes	Habitat type Type Name	Abbreviation
342	41730	subalpine fir/grouse whortleberry	ABLA/VASC
343	41731	subalpine fir/grouse whortleberry/pinegrass	ABLA/VASC/CARU
344	41732	subalpine fir/grouse whortleberry-grouse whortleberry	ABLA/VASC-VASC
345	41734	subalpine fir/grouse whortleberry/whitebark pine	ABLA/VASC/PIAL
346	41745	subalpine fir/common juniper	ABLA/JUCO6
347	41750	subalpine fir/pinegrass	ABLA/CARU
348	41760	subalpine fir/sweetcicely	ABLA/OSBE
349	41780	subalpine fir/heartleaf arnica	ABLA/ARCO9
350	41790	subalpine fir/Geyer's sedge	ABLA/CAGE2
351	41791	subalpine fir/Geyer's sedge-Geyer'ssedge	ABLA/CAGE2-CAGE2
352	41795	subalpine fir/Ross' sedge	ABLA/CARO5
353	41810	subalpine fir/gooseberry currant	ABLA/RIMO2
354	41811	subalpine fir/gooseberry currant-gooseberry currant	ABLA/RIMO2-RIMO2
355	41830	subalpine fir/Hitchcock's smooth woodrush	ABLA/LUGLH
356	41831	subalpine fir/Hitchcock's smooth woodrush/grouse whortleberry	ABLA/LUGLH/VASC
357	41861	white fir/mallow ninebark	ABCO/PHMA5
358	41863	white fir/creeping barberry	ABCO/MARE11
359	41865	white fir/creeping barberry-creeping barberry	ABCO/MARE11-MARE11
360	41920	lodgepole pine/dwarf bilberry	PICO/VACA13
361	41940	lodgepole pine/grouse whortleberry	PICO/VASC
362	41955	lodgepole pine/Geyer's sedge	PICO/CAGE2
363	41960	lodgepole pine/common juniper	PICO/JUCO6

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