United States
Department of
Agriculture

Forest Service

Forest Management
Service Center

Fort Collins, CO

2021

Revised:

June 2021

Alaska (AK) Variant Overview

Forest Vegetation Simulator

Sitka Ranger District, AK
(Thomas Witherspoon, FS-R10)

Alaska Variant Overview

Forest Vegetation Simulator

Authors and Contributors:

In 2021, the Alaska variant was released to model forested conditions throughout all of Alaska. Mark Castle led the development work. Along the way, Mark was joined by Mike Shettles, Aaron Gagnon, Lance David, and Chad Keyser who helped fit and embed new relationships in this new variant. The Alaska variant replaces the Southeast Alaska and Coastal British Columbia (SEAPROG) variant.

FVS Staff. 2021 (revised June 28, 2021). Alaska (AK) Variant Overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 39p.

Table of Contents

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)	1005 – Tongass National Forest	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation	Based on location code	
Latitude / Longitude	Based on location code	
Site Species	WH	
Site Index	70 feet (breast height age; 100 years)	
Maximum Stand Density Index	Species specific	
Maximum Basal Area	Based on maximum stand density index	
Volume Equations	National Volume Estimator Library	
Location Code	Merchantable Cubic Foot (Minimum DBH / Top Diameter)	Merchantable Board Foot (Minimum DBH / Top Diameter)
713	6.0 / 4.0 inches	9.0 / 6.0 inches
703, 1002, 1003, 1005, 8134, 8135, 8112	9.0 / 7.0 inches	9.0 / 7.0 inches
1004	9.0 / 6.0 inches	9.0 / 6.0 inches
720, 7400, 7401, 7402,7403, 7404, 7405, 7406, 7407, 7408	5.0 / 4.0 inches	9.0 / 6.0 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Basal Area Factor	62.5 BAF	
Small-Tree Fixed Area Plot	1/300th Acre	
Breakpoint DBH	5.0 inches	

1.0 Introduction

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

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

From 2018 to 2021, new relationships were developed for twenty-three species commonly found in the coastal and northern boreal forest types of Alaska. As such, this variant should be used for all forested areas in Alaska, thus replacing the Southeast Alaska (SEAPROG) variant, which is no longer available.

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 AK variant was fit to data representing coastal and boreal forest types of Alaska. Data used in model development came from University of Alaska at Fairbanks Growth and Yield Cooperative (46%), USDA Forest Service, Forest Inventory and Analysis (41%), Tanana Chief's Conference (1%), US Department of Defense (8%), and Alaska State Department of Natural Resources (4%). A data summary is shown in table 2.0.1.

Table 2.0.1 Data summary for trees used in the development of the AK variant.

Species	Number of observations	DBH (mean, st.dev) [min, max]	Total tree height (mean, stdev) [min, max]
Pacific silver fir	12	(8.1, 3.6) [5, 15.6]	(40, 17) [16, 62]
subalpine fir	49	(10.2, 5) [4.1, 23.9]	(48, 20) [14, 102]
Alaska yellow cedar	13980	(9.2, 5.9) [1, 55.7]	(38, 21) [5, 139]
tamarack	142	(2.1, 1.4) [0.5, 7.9]	(16, 8) [7, 47]
white spruce	76904	(5.1, 3.8) [0.3, 41.3]	(34, 20) [5, 123]
black spruce	53147	(2.5, 1.9) [0.5, 21.1]	(18, 11) [5, 77]
Sitka spruce	18968	(11.4, 8.1) [1, 74]	(53, 31) [5, 238]
lodgepole pine	3411	(8.1, 4) [1, 26.6]	(30, 16) [5, 98]
western red cedar	5556	(11.6, 8.1) [1, 72]	(44, 23) [5, 151]
western hemlock	37772	(9.8, 6.8) [1, 58.7]	(48, 28) [5, 214]
mountain hemlock	23377	(9, 5.1) [1, 46.9]	(35, 18) [5, 150]
red alder	707	(7.3, 3.5) [1, 25.7]	(44, 16) [7, 120]

Species	Number of observations	DBH (mean, st.dev) [min, max]	Total tree height (mean, stdev) [min, max]
paper birch	48630	(5.7, 3.6) [0.5, 32.2]	(44, 19) [5, 98]
poplar/cottonwood	6740	(7.8, 6.1) [0.5, 59.2]	(46, 23) [5, 145]
quaking aspen	23960	(5.6, 3) [0.5, 27.6]	(42, 17) [5, 107]
salix	8	(9.7, 2.1) [7.1, 13.4]	(32, 11) [7, 44]

The AK variant covers Alaska coastal and boreal forest types found throughout the state as well as forested areas in coastal British Columbia and the northwestern tip of the Olympic Peninsula in Washington. The suggested geographic range of use for the AK variant is shown in figure 2.0.1.

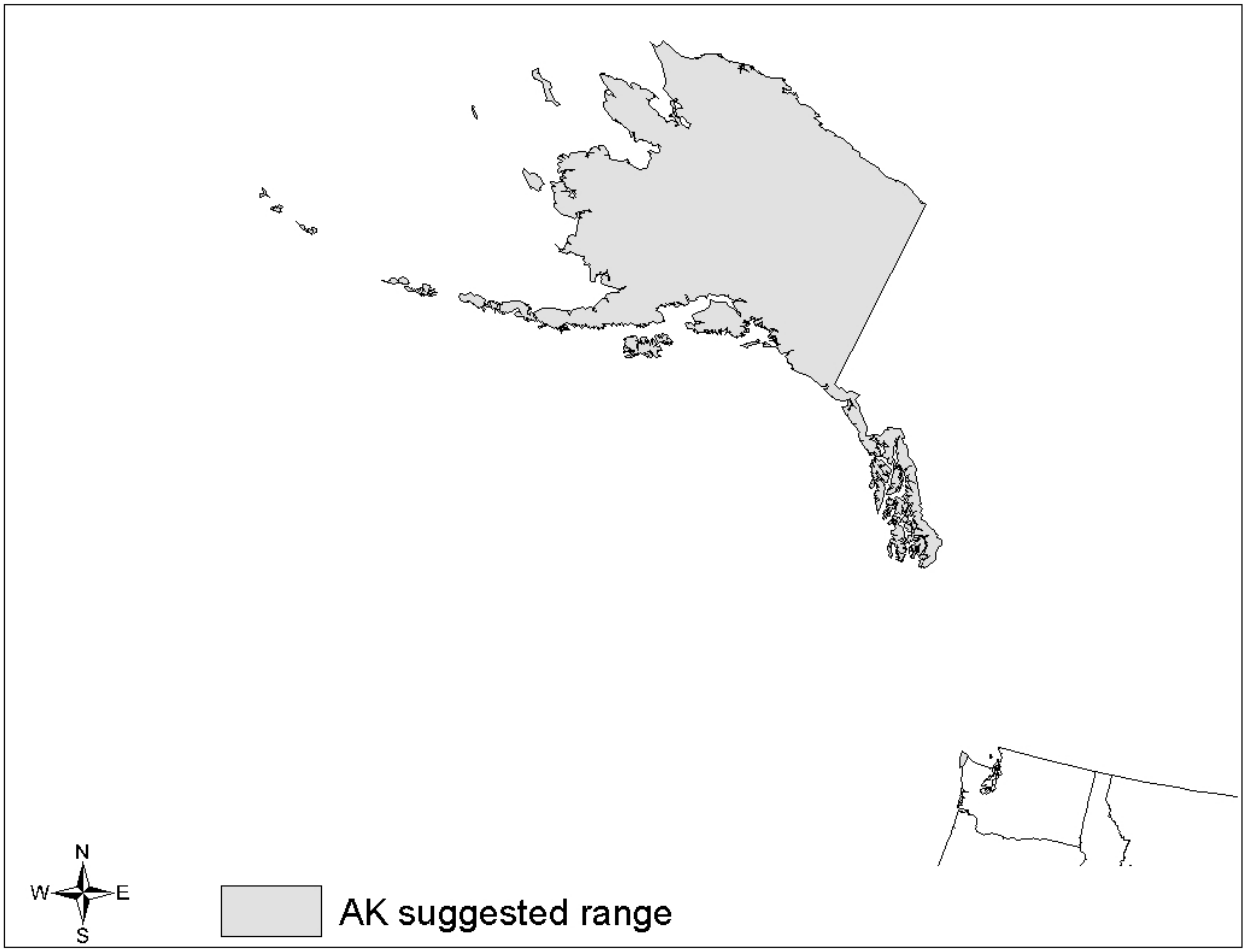

Figure 2.0.1 Suggested geographic range of use for the AK variant.

3.0 Control Variables

FVS users need to specify certain variables used by the AK 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 two digits of the code represents the Forest Service Region number, and the last two digits represent the Forest number/management area 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 AK variant, a default forest code of 1005 (Tongass National Forest) will be used. Location codes recognized in the AK variant are shown in table 3.1.1 and table 3.1.2.

When not entered by the user, the default latitude, longitude, and elevation are set based on the location code.

Table 3.1.1 Location codes used in the AK variant.

Location Code	Location	Latitude	Longitude	Elevation (ft)
1002	Tongass National Forest: Old Stikine Area (mapped to 1005)	55.34	-131.64	100
1003	Tongass National Forest: Old Chatham Area (mapped to 1005)	55.34	-131.64	100
1004	Chugach National Forest	61.22	-149.88	100
1005	Tongass National Forest[1]	55.34	-131.64	100
701	BC/Makah Old Combined code (mapped to 703)	48.53	-123.37	100
703	British Columbia	48.53	-123.37	100
713	Bureau of Land Management	61.22	-149.89	200
720	State of Alaska, Department of Natural Resources	61.22	-149.89	200
7400	Tanana Chiefs Conference (any location)	64.84	-147.71	500

[1]1005 is the code used for the Tongass National Forest. 1005 represented the Ketchikan Area in the SEAPROG variant.

Table 3.1.2 Bureau of Indian Affairs location codes used in the AK variant.

Location Code	Location	Latitude	Longitude	Elevation (ft)
7401	Arctic Village Anvsa	68.13	-145.54	1000
7402	Ahtna	62.14	-145.47	1500
7403	Chugach	61.19	-149.89	100
7404	Cook Inlet	61.21	-149.81	100
7405	Doyon	64.85	-147.72	400
7406	Kongiganak Anvsa	59.99	-162.89	100
7407	Nanwalek Anvsa	59.36	-151.92	200
7408	Selawik Anvsa	66.73	-160.05	100
8112	Quileute Reservation	48.37	-124.61	300
8134	Annette Island	48.00	-124.61	100
8135	Makah Indian Reservation	55.12	-131.57	100

3.2 Species Codes

The AK variant recognizes 23 species. 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 codes identifying species not recognized by the variant will be mapped to the most similar species in the variant. The species mapping crosswalk is available on the variant documentation webpage of the FVS website. Any non-valid species code will default to the "other hardwoods" category.

Either the FVS species number or FVS 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 AK variant.

Table 3.2.1 Species codes used in the AK variant.

Species Number	Species Code	Common Name	FIA Code	PLANTS Symbol	Scientific Name
1	SF	Pacific silver fir	011	ABAM	*Abies amabilis*
2	AF	subalpine fir	019	ABLA	*Abies lasiocarpa*
3	YC	Alaska cedar	042	CANO9	*Callitropsis nootkatensis*
4	TA	tamarack	071	LALA	*Larix laricina*
5	WS	white spruce	094	PIGL	*Picea glauca*
6	LS	Lutz's spruce		PILU	*Picea lutzii*
7	BE	black spruce	095	PIMA	*Picea mariana*
8	SS	Sitka spruce	098	PISI	*Picea sitchensis*
9	LP	lodgepole pine	108	PICO	*Pinus contorta*
10	RC	western redcedar	242	THPL	*Thuja plicata*
11	WH	western hemlock	263	TSHE	*Tsuga heterophylla*
12	MH	mountain hemlock	264	TSME	*Tsuga mertensiana*

Species Number	Species Code	Common Name	FIA Code	PLANTS Symbol	Scientific Name
13	OS	other softwoods	298	2TE	
14	AD	alder species	350	ALNUS	*Alnus*
15	RA	red alder	351	ALRU2	*Alnus rubra*
16	PB	paper birch	375	BEPA	*Betula papyrifera*
17	AB	Alaska birch (resin birch)	376	BENE4	*Betula neoalaskana*
18	BA	balsam poplar	741	POBA2	*Populus balsamifera*
19	AS	quaking aspen	746	POTR5	*Populus tremuloides*
20	CW	black cottonwood	747	POBAT	*Populus balsamifera spp. trichocarpa*
21	WI	willow species	920	SALIX	*Salix*
22	SU	Scouler's willow	928	SASC	*Salix scouleriana*
23	OH	other hardwoods	998	2TD	

3.3 Habitat Type, Plant Association, and Ecological Unit Codes

Habitat type, plant association, and ecological unit codes are not used in the AK variant.

3.4 Site Index

Site index is used in the growth equations and the sprouting routine in the AK 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 AK variant, the sources shown in table 3.4.1 should be used if possible. When site species and site index is not set by the user, the site species/index is set to western hemlock,70.

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}. Lower and upper limits of site indices used in equation {3.4.1} may be found in table 3.4.1.

{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 values
i is the species values for which site index is to be calculated

Table 3.4.1 Recommended site index references and range in the AK variant.

Species Number	Species Code	Source	Source Species[1]	*SITELO*	*SITEHI*	Base Age	Age[2]
1	SF	Hegyi et al. (1981)	balsam (coast)	35	105	100	TTA
2	AF	Hegyi et al. (1981)	balsam (interior)	20	65	100	TTA
3	YC	Hegyi et al. (1981)	yellow cedar	25	75	100	TTA
4	TA	Hegyi et al. (1981)	larch	25	55	100	TTA
5	WS	Hegyi et al. (1981)	spruce	30	85	100	TTA
6	LS	Hegyi et al. (1981)	spruce	30	85	100	TTA
7	BE	Hegyi et al. (1981)	spruce	20	55	50	TTA
8	SS[3]	Hegyi et al. (1981) / Payandeh (1974)	Sitka spruce	40	125	100	TTA
9	LP	Hegyi et al. (1981)	lodgepole pine	15	55	100	TTA
10	RC	Hegyi et al. (1981)	western red cedar (coast)	30	85	100	TTA
11	WH[3]	Hegyi et al. (1981) / Payandeh (1974)	hemlock (coast)	35	105	100	TTA
12	MH[3]	Hegyi et al. (1981) / Payandeh (1974)	hemlock (coast)	20	65	100	TTA
13	OS	Hegyi et al. (1981)	spruce	30	85	100	TTA
14	AD	Hegyi et al. (1981)	red alder	20	50	100	TTA
15	RA	Hegyi et al. (1981)	red alder	75	135	100	TTA
16	PB	Hegyi et al. (1981)	common paper birch	35	75	100	TTA
17	AB	Hegyi et al. (1981)	common paper birch	45	90	100	TTA
18	BA	Hegyi et al. (1981)	balsam poplar/black cottonwood	45	105	100	TTA
19	AS	Hegyi et al. (1981)	aspen	45	85	100	TTA
20	CW	Hegyi et al. (1981)	balsam poplar/black cottonwood	45	105	100	TTA
21	WI	Hegyi et al. (1981)	balsam poplar/black cottonwood	20	50	100	TTA
22	SU	Hegyi et al. (1981)	balsam poplar/black cottonwood	45	70	100	TTA
23	OH	Hegyi et al. (1981)	balsam poplar/black cottonwood	20	50	100	TTA

[1] Hegyi (1981) source equation specified in table 4 of document.

[2] Age is total tree age (TTA).

[3] Western hemlock, mountain hemlock, and Sitka spruce less than 200 years old use Payandeh (1974) equations; western hemlock, mountain hemlock, and Sitka spruce greater than or equal to 200 years old use Hegyi (1981) equations.

3.5 Maximum Density

Stand density index (SDI) relative to maximum stand density index (SDImax) is used throughout the AK variant. Maximum stand density is not allowed to extend past the stand level maximum basal area and maximum SDI. If not set by the user, a default maximum 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 or from user input. Maximum SDI 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 the species-specific SDI maximum
BAMAX	is the user-specified stand basal area maximum
SDIU	is the proportion of theoretical maximum density at which the stand reaches actual maximum density (default 0.85, changed with the SDIMAX keyword)

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

Species Number	Species Code	SDI Maximum*	Mapped to
1	SF	790	
2	AF	602	
3	YC	592	
4	TA	387	
5	WS	412	
6	LS	412	white spruce
7	BE	500	
8	SS	654	
9	LP	679	
10	RC	762	
11	WH	682	
12	MH	687	
13	OS	412	white spruce
14	AD	441	red alder
15	RA	441	
16	PB	466	
17	AB	466	paper birch
18	BA	384	
19	AS	562	
20	CW	452	

Species Number	Species Code	SDI Maximum*	Mapped to
21	WI	447	black willow
22	SU	447	black willow
23	OH	452	black cottonwood

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

4.0 Growth Relationships

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

4.1 Height-Diameter Relationships

Height-diameter relationships in FVS are primarily used to estimate tree heights missing in input data, and occasionally to estimate diameter growth on trees smaller than a given threshold diameter. In the AK variant, FVS will dub in heights by one of two methods. By default, the AK variant will use the Chapman-Richards functional form as shown in equation {4.1.1} (Rijal et al., 2012).

If the input data contains at least three measured heights for a species, then FVS can switch to a logistic height-diameter equation {4.1.2} (Wykoff, et.al 1982) that may be calibrated to the input data. FVS will not automatically use equation {4.1.2} even if you have enough height values in the input data. To override this default, the user must use the NOHTDREG keyword to turn calibration on. Coefficients for equations {4.1.1} and {4.1.2} are given in table 4.1.1.

{4.1.1} $HT = 4.5 + AX_1 * (1 - \exp(BX_1 * DBH))\text{^}CX_1$

{4.1.2} $HT = 4.5 + \exp(AX + BX / (DBH + 1.0))$

where:

HT is tree height
DBH is tree diameter at breast height
AX_1, BX_1, CX_1 are species-specific coefficients shown in table 4.1.1
AX, BX are species-specific coefficients shown in table 4.1.2

Table 4.1.1 Default coefficients for equations {4.1.1} and {4.2.2} in the AK variant.

Species Code	Coefficients				
	AX_1	**BX_1**	**CX_1**	**AX**	**BX**
SF	173.578068	-0.034704	1.06697	5.047089	-12.629014
AF	173.578068	-0.034704	1.06697	5.047089	-12.629014
YC	118.005962	-0.04487	1.090783	4.683932	-10.690737
TA	68.53457	-0.149647	1.335243	4.350320	-5.776563
WS	115.991446	-0.068079	1.059224	4.633182	-6.81926
LS	115.991446	-0.068079	1.059224	4.633182	-6.81926
BE	68.534570	-0.149647	1.335243	4.350320	-5.776563
SS	173.578068	-0.034704	1.06697	5.047089	-12.629014
LP	71.730424	-0.096667	1.589409	4.513771	-10.853785
RC	105.741099	-0.051922	1.134463	4.716522	-11.426736
WH	141.210402	-0.054102	1.248358	5.007972	-12.085418
MH	108.158839	-0.054874	1.309823	4.701229	-12.133655
OS	115.991446	-0.068079	1.059224	4.633182	-6.81926

Species Code	Coefficients				
	AX_1	BX_1	CX_1	AX	BX
AD	115.115222	-0.04711	0.795143	4.622461	-6.696442
RA	131.581959	-0.03474	0.783043	4.542755	-6.654068
PB	59.019982	-0.330044	1.482009	4.393426	-3.968868
AB	59.019982	-0.330044	1.482009	4.393426	-3.968868
BA	115.115222	-0.04711	0.795143	4.622461	-6.696442
AS	69.442183	-0.181461	1.179203	4.479633	-5.03023
CW	115.115222	-0.04711	0.795143	4.622461	-6.696442
WI	115.115222	-0.04711	0.795143	4.622461	-6.696442
SU	115.115222	-0.04711	0.795143	4.622461	-6.696442
OH	115.115222	-0.04711	0.795143	4.622461	-6.696442

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 used in the AK variant to calculate bark ratio are shown below {4.2.1 – 4.2.3}. Coefficients for the equations are shown in table 4.2.1. Table 4.2.1 also designates which equation is associated with each of the species present in the AK variant.

{4.2.1} $DBT = a * DBH ^{\wedge} b$

$BRATIO = (DBH – DBT) / DBH$

{4.2.2} $BRATIO = (a + (b * DBH)) / DBH$

{4.2.3} $DIB = a * DBH ^{\wedge} b$

$BRATIO = DIB / DBH$

where:

BRATIO is species-specific bark ratio
DBH is tree diameter at breast height
DBT is double bark thickness
DIB is diameter inside bark

Table 4.2.1 Coefficients and equations for bark ratio equations {4.2.1} – {4.2.3} in the AK variant.

Species Code	Equation Number	a	b
SF	4.2.1	0.186	0.45417
AF	4.2.1	0.186	0.45417
YC	4.2.1	0.186	0.45417
TA	4.2.3	0.796645	1.060823
WS	4.2.3	0.839825	1.039951
LS	4.2.3	0.839825	1.039951
BE	4.2.3	0.796645	1.060823

Species Code	Equation Number	a	b
SS	4.2.1	0.843047	1.030798
LP	4.2.1	0.186	0.45417
RC	4.2.1	0.186	0.45417
WH	4.2.1	0.186	0.45417
MH	4.2.3	0.743935	1.048186
OS	4.2.3	0.839825	1.039951
AD	4.2.2	0.075256	0.94373
RA	4.2.2	0.075256	0.94373
PB	4.2.3	0.899145	1.011965
AB	4.2.3	0.899145	1.011965
BA	4.2.3	0.792559	1.028571
AS	4.2.3	0.921204	0.996669
CW	4.2.3	0.784468	1.035819
WI	4.2.3	0.784468	1.035819
SU	4.2.3	0.784468	1.035819
OH	4.2.3	0.784468	1.035819

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 AK variant, crown ratios missing in the input data are dubbed using equations {4.3.1.1} - {4.3.1.2}.

{4.3.1.1} $X = B_1 + B_2 * \ln(H*12/D) + B_3 * RDEN + B_4 * D/QMDPLT + N(0,SD)$

{4.3.1.2} $CR = 1 / (1 + \exp(X))$

where:

D	is tree diameter at breast height
HT	is tree height
RDEN	is relative density of the stand (Zeide SDI / maximum SDI) on inventory point
QMDPLOT	is quadratic mean diameter of trees on inventory point
N(0,SD)	is a random increment from normal distribution with mean 0 and standard deviation of SD which is only applied to trees less than 1.0” DBH and dead trees.
CR	is crown ratio expressed as a proportion (bounded to $0.05 \leq CR \leq 0.95$)
$B_1 - B_4$	are species-specific coefficients shown in table 4.3.1.1

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

Species Code	Coefficients				
	B_1	B_2	B_3	B_4	SD
SF	-2.818788	0.623633	0.952948	-0.174337	0.1719
AF	-2.818788	0.623633	0.952948	-0.174337	0.1719
YC	0.655733	-0.064716	0.439411	-0.174337	0.159
TA	6.469047	-1.495754	0.913909	-0.051268	0.1645
WS	-4.02647	0.655230	0.914077	-0.051268	0.1542
LS	-4.02647	0.655230	0.914077	-0.051268	0.1542
BE	-2.781735	0.438826	0.970251	-0.051268	0.1894
SS	-2.818788	0.623633	0.952948	-0.174337	0.1719
LP	-0.425173	0.295262	0.732675	-0.174337	0.1568
RC	-0.449694	0.104368	0.557638	-0.174337	0.1811
WH	-0.364665	0.116994	0.573079	-0.174337	0.1582
MH	-0.47458	0.141604	0.590263	-0.174337	0.155
OS	-4.026470	0.655230	0.914077	-0.051268	0.1542
AD	0.977291	-0.314026	0.848483	-0.051268	0.1447
RA	-2.799049	0.660530	0.987503	-0.174337	0.1447
PB	-1.268650	0.147556	1.092390	-0.051268	0.144
AB	-1.268650	0.147556	1.092390	-0.051268	0.144
BA	0.977291	-0.314026	0.848483	-0.051268	0.1605
AS	0.802511	-0.143680	1.023227	-0.051268	0.1356
CW	0.977291	-0.314026	0.848483	-0.051268	0.1605
WI	-2.406592	0.347417	0.952753	-0.051268	0.0938
SU	-2.406592	0.347417	0.952753	-0.051268	0.0938
OH	0.977291	-0.314026	0.848483	-0.051268	0.1605

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 (across all species) using equations {4.3.1.1} - {4.3.1.2}. 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 decrease and 3% per year increase for the length of the cycle to avoid drastic changes in crown ratio.

4.3.3 Crown Ratio for Newly Established Trees

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

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

where:

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

4.4 Crown Width Relationships

The AK 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 cover (*PCC*) calculations in the model.

Crown width is calculated using equations {4.4.1} – {4.4.3}, 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} Crookston (2005); Equation 05

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

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

{4.4.2} Donnelly (1996); Equation 06

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

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

{4.4.3} Castle (2019); Equation 08

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

where:

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

Table 4.4.1 Coefficients for crown width equations {4.4.1} – {4.4.3} in the AK variant.

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
SF	01105	4.4799	0.45976	-0.10425	0.11866	0.06762	-0.00715
AF	01905	5.8827	0.51479	-0.21501	0.17916	0.03277	-0.00828
YC	04205	3.3756	0.45445	-0.11523	0.22547	0.08756	-0.00894
TA	09508	3.391358	0.638945	-0.395285	0.264254	0	0

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
WS	09408	8.515316	0.630576	-0.867757	0.477791	0.10021	-0.015034
LS	09408	8.515316	0.630576	-0.867757	0.477791	0.10021	-0.015034
BE	09508	3.391358	0.638945	-0.395285	0.264254	0	0
SS	09805	8.48	0.70692	-0.38812	0.17127	0	0
LP	10805	6.6941	0.81980	-0.36992	0.17722	-0.01202	-0.00882
RC	24205	6.2382	0.29517	-0.10673	0.23219	0.05341	-0.00787
WH	26305	6.0384	0.51581	-0.21349	0.17468	0.06143	-0.00571
MH	26405	3.7854	0.54684	-0.12954	0.16151	0.03047	-0.00561
OS	09408	8.515316	0.630576	-0.867757	0.477791	0.10021	-0.015034
AD	74708	0.790658	0.551987	0.446434	0	0	-0.048415
RA	35106	7.0806	0.4771	0	0	0	0
PB	37508	2.725006	0.53601	0	0.196372	-0.015305	0
AB	37508	2.725006	0.53601	0	0.196372	-0.015305	0
BA	74708	0.790658	0.551987	0.446434	0	0	-0.048415
AS	74608	2.386015	0.63014	-0.147121	0.274356	0	0
CW	74708	0.790658	0.551987	0.446434	0	0	-0.048415
WI	74708	0.790658	0.551987	0.446434	0	0	-0.048415
SU	74708	0.790658	0.551987	0.446434	0	0	-0.048415
OH	74708	0.790658	0.551987	0.446434	0	0	-0.048415

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

Table 4.4.2 *MinD* values and data bounds for equations {4.4.1}-{4.4.3} in the AK variant.

Species Code	Equation Number*	*MinD*	*EL* min	*EL* max	*CW* max
SF	01105	1.0	4	72	33
AF	01905	1.0	10	85	30
YC	04205	1.0	16	62	59
TA	09508	n/a	n/a	n/a	16
WS	09408	n/a	1	85	40
LS	09408	n/a	1	85	40
BE	09508	n/a	n/a	n/a	16
SS	09805	1.0	n/a	n/a	50
LP	10805	1.0	1	79	40
RC	24205	1.0	1	72	45
WH	26305	1.0	1	72	54
MH	26405	n/a	n/a	n/a	45
OS	09408	n/a	1	85	40
AD	74708	1.0	n/a	n/a	35
RA	35106	1.0	n/a	n/a	35
PB	37508	n/a	n/a	n/a	53
AB	37508	n/a	n/a	n/a	53

Species Code	Equation Number*	*MinD*	*EL* min	*EL* max	*CW* max
BA	74708	n/a	n/a	n/a	56
AS	74608	n/a	n/a	n/a	48
CW	74708	n/a	n/a	n/a	56
WI	74708	n/a	n/a	n/a	56
SU	74708	n/a	n/a	n/a	56
OH	74708	n/a	n/a	n/a	56

4.5 Crown Competition Factor

The AK 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 equations 4.5.1- 4.5.4:

{4.5.1} $MCW = b_1 + b_2 * DBH$

{4.5.2} $MCW = b_1 + DBH\text{^}b_2 * 3.28$

{4.5.3} $MCA = Pi * (MCW/2)\text{^}2$

{4.5.4} $DBH > 0.1$ $CCF_t = (MCA/43560) * 100 * P$

$DBH \leq 0.1$ $CCF_t = 0.001 * P$

where:

MCW	open grown crown width for an individual tree
DBH	is tree diameter at breast height
MCA	crown area for an individual tree
Pi	constant of 3.14159
CCF_t	is crown competition factor for an individual tree
P	trees per acre representation of an individual tree
$b_1 - b_2$	are species-specific coefficients shown in table 4.5.1

Table 4.5.1 Coefficients for the *MCW* equations {4.5.1} – {4.5.2} in the AK variant.

Species Code	Equation number	Reference Species	Model Coefficients	
			b_1	b_2
SF	4.5.1	white and grand fir, Paine and Hann 1982	6.1880	1.0069
AF	4.5.1	white and grand fir, Paine and Hann 1982	6.1880	1.0069
YC	4.5.1	western redcedar, Smith 1966	4.0	1.6
TA	4.5.2	black spruce, Russell and Weiskittel 2011	0.535	0.742
WS	4.5.2	white spruce, Russell and Weiskittel 2011	1.50	0.496
LS	4.5.2	white spruce, Russell and Weiskittel 2011	1.50	0.496

Species Code	Equation number	Reference Species	Model Coefficients	
			b_1	b_2
BE	4.5.2	black spruce, Russell and Weiskittel 2011	0.535	0.742
SS	4.5.1	Sitka spruce, Smith 1966	6.5	1.8
LP	4.5.1	white and grand fir, Paine and Hann 1982	6.1880	1.0069
RC	4.5.1	western redcedar, Smith 1966	4.0	1.6
WH	4.5.1	western hemlock, Paine and Hann 1982	4.5652	1.4147
MH	4.5.1	western hemlock, Paine and Hann 1982	4.5652	1.4147
OS	4.5.2	white spruce, Russell and Weiskittel 2011	1.50	0.496
AD	4.5.1	alder, Smith 1966	8.0	1.53
RA	4.5.1	alder, Smith 1966	8.0	1.53
PB	4.5.2	paper birch, Russell and Weiskittel 2011	1.48	0.623
AB	4.5.2	paper birch, Russell and Weiskittel 2011	1.48	0.623
BA	4.5.2	ash/cottonwood, Smith 1966	0.5	1.62
AS	4.5.2	quaking aspen, Russell and Weiskittel 2011	1.31	0.586
CW	4.5.1	ash/cottonwood, Smith 1966	0.5	1.62
WI	4.5.1	ash/cottonwood, Smith 1966	0.5	1.62
SU	4.5.1	ash/cottonwood, Smith 1966	0.5	1.62
OH	4.5.1	ash/cottonwood, Smith 1966	0.5	1.62

4.6 Small Tree Growth Relationships

Trees are considered “small trees” for FVS modeling purposes when they are smaller than some threshold diameter. The threshold diameter is set to 1.0” for all species in the AK variant; however, both height and diameter growth are averaged with large tree predictions across species-specific diameter ranges.

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

4.6.1 Small Tree Height Growth

The small-tree height growth model predicts periodic potential height growth (POTHTG) from height growth curves identified in section 3.4. Height growth is computed by subtracting the current predicted height from the predicted height 10 years in the future, as depicted in equations {4.6.1.1} and {4.6.1.2}. Coefficients for each equation are in table 4.6.1.1.

{4.6.1.1} Hegyi (et.al 1981)

$HT = C_1 * XSITE * (1 - EXP(C_2 * AGET))^{\wedge} C_3$

{4.6.1.2} Payandeh (1974)

$HT = B_1 * XSITE^{\wedge} B_2 * (1 - EXP(B_3 * AGET))^{\wedge} (B_4 * XSITE^{\wedge} B_5)$

where:

HT	is predicted tree height, used for current and future height growth.
XSITE	is species site index

AGET	is tree age where equations are presented above are solved for age. Future age adds ten years to the *AGET* estimate.
HT	tree height in feet
$C_1 - C_3$	are species-specific coefficients
$B_1 - B_5$	are species-specific coefficients

Table 4.6.1.1 Coefficients for the small tree height growth equations {4.6.1.1} and {4.6.1.2} in the AK variant.

Species Code	Equation	B_1 or C_1	B_2 or C_2	B_3 or C_3	B_4	B_5	X_{MIN}	X_{MAX}	DG_{Max}
SF	{4.6.1.1}	1.1945	-0.0236	1.7918			1.0	5.0	5.0
AF	{4.6.1.1}	1.3832	-0.0155	1.3597			1.0	5.0	5.0
YC	{4.6.1.1}	1.1243	-0.0263	1.5662			1.0	8.0	5.0
TA	{4.6.1.1}	1.1637	-0.0215	1.2243			1.0	3.0	3.0
WS	{4.6.1.1}	1.2883	-0.0181	1.4177			1.0	3.0	3.0
LS	{4.6.1.1}	1.2883	-0.0181	1.4177			1.0	3.0	3.0
BE	{4.6.1.1}	1.1637	-0.0215	1.2243			1.0	3.0	3.0
SS	{4.6.1.2}	1.5469	1.0018	-0.0114	1.0883	0.0072	1.0	5.0	5.0
LP	{4.6.1.1}	1.0236	-0.0465	2.4269			1.0	8.0	5.0
RC	{4.6.1.1}	1.1243	-0.0263	1.5662			1.0	8.0	5.0
WH	{4.6.1.2}	1.5469	1.0018	-0.0114	1.0883	0.0072	1.0	7.0	5.0
MH	{4.6.1.2}	1.5469	1.0018	-0.0114	1.0883	0.0072	1.0	8.0	5.0
OS	{4.6.1.1}	1.2883	-0.0181	1.4177			1.0	3.0	3.0
AD	{4.6.1.1}	1.1318	-0.0226	1.1233			1.0	3.0	3.0
RA	{4.6.1.1}	1.0142	-0.0421	0.9422			1.0	3.0	3.0
PB	{4.6.1.1}	1.1580	-0.0175	0.7687			1.0	3.0	3.0
AB	{4.6.1.1}	1.1580	-0.0175	0.7687			1.0	3.0	3.0
BA	{4.6.1.1}	1.1318	-0.0226	1.1233			1.0	3.0	3.0
AS	{4.6.1.1}	1.2025	-0.0158	0.7994			1.0	3.0	3.0
CW	{4.6.1.1}	1.1318	-0.0226	1.1233			1.0	3.0	3.0
WI	{4.6.1.1}	1.1318	-0.0226	1.1233			1.0	3.0	3.0
SU	{4.6.1.1}	1.1318	-0.0226	1.1233			1.0	3.0	3.0
OH	{4.6.1.1}	1.1318	-0.0226	1.1233			1.0	3.0	3.0

For all species, a small random error is then added to the height growth estimate. The estimated height growth is then adjusted to account for cycle length, user-defined, small-tree height growth adjustments, and adjustments due to small tree height increment calibration from input data. Then, the small-tree estimate is averaged with an estimate from the large-tree height growth model, explained in section 4.7.2, to obtain an average small tree height growth estimate from the initial potential estimate.

Finally, height growth estimates are weighted with the height growth estimates from the large tree model over a range of diameters (X_{min} and X_{max}), 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. The weight applied to the growth estimate is calculated using equation {4.6.1.3}, and applied as shown in equation {4.6.1.4}. The range of diameters for each species is shown in table 4.6.1.1.

{4.6.1.3}

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

{4.6.1.4} Estimated growth = $[(1 - XWT) * ((STGE+LTGE)/2)] + [XWT * LTGE]$

where:

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

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 is calculated as the difference of predicted diameter at the start of the projection period and the predicted diameter at the end of the projection period, adjusted for bark ratio. These two predicted diameters are estimated using the species-specific height-diameter relationships discussed in section 4.1. By definition, diameter growth is zero for trees less than 4.5 feet tall.

Diameter growth estimates are weighted with the diameter growth estimates from the large-tree model over a range of diameters (X_{min} and DG_{max}), similar to the weighting explained in section 4.6.1.

4.7 Large Tree Growth Relationships

Trees are considered "large trees" for FVS modeling purposes when they are equal to, or larger than, some threshold diameter. This threshold diameter is set to 1.0" for all species in the AK variant.

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

4.7.1 Large Tree Diameter Growth

The large tree diameter growth model used in most FVS variants is described in section 7.2.1 in Dixon (2002). For most variants, instead of predicting diameter increment directly, the natural log of the periodic change in squared inside-bark diameter (ln(*DDS*)) is predicted (Dixon 2002; Wykoff 1990;

Stage 1973; and Cole and Stage 1972). For variants predicting diameter increment directly, diameter increment is converted to the *DDS* scale to keep the FVS system consistent across all variants.

The AK variant uses the following equation set {4.7.1.1 – 4.7.1.3} to calculate annual diameter increment (outside bark) for all species. Equation {4.7.1.1}, with coefficients specified in table 4.7.1.1, is used to estimate a base diameter increment, while equations {4.7.1.2} and {4.7.1.3} are used to adjust the base rate due to permafrost presence/absence (*PFMod*) and to adjust species whose growth form is shrub/tree (*SPAdj*), respectively. Coefficients for species utilizing equation {4.7.1.2} are in table 4.7.1.2. *PFMod* is set to 1.0 for all other species. For species that are of shrub/tree form, diameter increment is adjusted lower based on a general species adjustment. The final growth rate is adjusted for base cycle length and bark thickness to attain a final estimate of the change in inside-bark diameter. There are additional adjustments to scale the estimate to cycle length and apply any user-supplied modifiers.

{4.7.1.1} Used for all species

$$BaseDG = \exp(b_1 + b_2 * DBH^2 + b_3 * \ln(DBH) + b_4 * PBAL + b_5 * PRD + b_6 * \ln(CR) + b_7 * EL + b_8 * SL + b_9 * SL * \cos(ASP) + b_{10} * \ln(SI))$$

{4.7.1.2} Used for species in Table 4.7.1.2

$$PFMod = \exp(b_1 + b_2 * PERM + b_3 * DBH^2 + b_4 * \ln(DBH) + b_5 * PBAL + b_6 * PRD + b_7 * \ln(CR) + b_8 * EL + b_9 * SL + b_{10} * SL * \cos(ASP)) / BASEDG$$

{4.7.1.3} $DI = BASEDG * PFMOD * SPAdj * YR$

where:

BaseDG	is annual diameter increment (in / year)
DBH	is tree diameter at breast height
PBAL	is plot basal area in trees larger than the subject tree
PRD	is plot level relative density (plot Zeide SDI / plot SDI max)
CR	is crown ratio expressed as a percentage
EL	is stand elevation (ft)
SL	is stand slope expressed as a percent
ASP	is stand aspect in radians
SI	is species site index
PFMod	is a permafrost presence modifier
PERM	is the effect of permafrost presence in a stand (value of 1 if present, 0 if absent)
DI	is diameter increment for the default cycle length
SPAdj	is a species adjustment where AD, WI and OH = 0.45, SU = 0.65, and all others = 1.00
YR	is the default cycle length (10 years)
$b_1 – b_{10}$	are species-specific coefficients

Table 4.7.1.1 Coefficients ($b_1 - b_{10}$) for the diameter growth equation {4.7.1.1} in the AK variant.

Species Code	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
SF	-8.58075	-0.00044	0.033655	-0.00228	0	0.819909	0	0.001604	0.00002	0.712498
AF	-8.58075	-0.00044	0.033655	-0.00228	0	0.819909	0	0.001604	0.00002	0.712498
YC	-9.48511	-0.00044	0.081005	-0.0006	0	0.819909	0	0.001604	0.00002	0.712498
TA	-6.58523	-0.00228	0.152853	-0.00151	-0.3532	0.727631	-0.00018	0.001225	-0.00242	0
WS	-6.31577	-0.00228	0.480982	-5.70E-05	-0.4555	0.727631	-0.00018	0.001225	-0.00242	0
LS	-6.31577	-0.00228	0.480982	-5.70E-05	-0.4555	0.727631	-0.00018	0.001225	-0.00242	0
BE	-6.58523	-0.00228	0.152853	-0.00151	-0.3532	0.727631	-0.00018	0.001225	-0.00242	0
SS	-8.58075	-0.00044	0.033655	-0.00228	0	0.819909	0	0.001604	0.00002	0.712498
LP	-9.29779	-0.00044	-0.00086	-0.0006	0	0.819909	0	0.001604	0.00002	0.712498
RC	-9.35712	-0.00044	0.243224	-0.0006	0	0.819909	0	0.001604	0.00002	0.712498
WH	-9.45806	-0.00044	0.175997	-0.0006	0	0.819909	0	0.001604	0.00002	0.712498
MH	-9.15538	-0.00044	0.044554	-0.00058	0	0.819909	0	0.001604	0.00002	0.712498
OS	-6.31577	-0.00228	0.480982	-5.70E-05	-0.4555	0.727631	-0.00018	0.001225	-0.00242	0
AD	-5.64634	-0.00228	0.212906	-0.00072	-0.76363	0.727631	-0.00018	0.001225	-0.00242	0
RA	-5.19589	-0.00228	0.425682	-0.00117	-0.62382	0.727631	-0.00018	0.001225	-0.00242	0
PB	-6.0157	-0.00228	0.35335	-0.00717	-0.3532	0.727631	-0.00018	0.001225	-0.00242	0
AB	-6.0157	-0.00228	0.35335	-0.00717	-0.3532	0.727631	-0.00018	0.001225	-0.00242	0
BA	-5.64634	-0.00228	0.212906	-0.00072	-0.76363	0.727631	-0.00018	0.001225	-0.00242	0
AS	-6.70493	-0.00228	0.669461	-0.00056	-0.48014	0.727631	-0.00018	0.001225	-0.00242	0
CW	-5.64634	-0.00228	0.212906	-0.00072	-0.76363	0.727631	-0.00018	0.001225	-0.00242	0
WI	-5.64634	-0.00228	0.212906	-0.00072	-0.76363	0.727631	-0.00018	0.001225	-0.00242	0
SU	-5.64634	-0.00228	0.212906	-0.00072	-0.76363	0.727631	-0.00018	0.001225	-0.00242	0
OH	-5.64634	-0.00228	0.212906	-0.00072	-0.76363	0.727631	-0.00018	0.001225	-0.00242	0

Table 4.7.1.2 Coefficients ($b_1 - b_{10}$) for the permafrost modifier equation {4.7.1.2} in the AK variant.

Species Code	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
TA	-6.52972	-0.34922	-0.00271	0.161256	-0.00187	-0.02879	0.736013	-0.00014	0.001702	-0.00182
WS	-6.27434	-0.34922	-0.00271	0.476859	-0.00053	-0.48209	0.736013	-0.00014	0.001702	-0.00182
LS	-6.27434	-0.34922	-0.00271	0.476859	-0.00053	-0.48209	0.736013	-0.00014	0.001702	-0.00182
BE	-6.52972	-0.34922	-0.00271	0.161256	-0.00187	-0.02879	0.736013	-0.00014	0.001702	-0.00182
OS	-6.27434	-0.34922	-0.00271	0.476859	-0.00053	-0.48209	0.736013	-0.00014	0.001702	-0.00182
PB	-6.09354	-0.34922	-0.00271	0.373362	-0.00735	-0.33031	0.736013	-0.00014	0.001702	-0.00182
AB	-6.09354	-0.34922	-0.00271	0.373362	-0.00735	-0.33031	0.736013	-0.00014	0.001702	-0.00182
BA	-5.52778	-0.34922	-0.00271	0.082885	-0.00132	-0.81985	0.736013	-0.00014	0.001702	-0.00182

Species Code	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
AS	-6.86117	-0.34922	-0.00271	0.712862	-0.00053	-0.46258	0.736013	-0.00014	0.001702	-0.00182
CW	-5.52778	-0.34922	-0.00271	0.082885	-0.00132	-0.81985	0.736013	-0.00014	0.001702	-0.00182
WI	-5.52778	-0.34922	-0.00271	0.082885	-0.00132	-0.81985	0.736013	-0.00014	0.001702	-0.00182
SU	-5.52778	-0.34922	-0.00271	0.082885	-0.00132	-0.81985	0.736013	-0.00014	0.001702	-0.00182
OH	-5.52778	-0.34922	-0.00271	0.082885	-0.00132	-0.81985	0.736013	-0.00014	0.001702	-0.00182

4.7.2 Large Tree Height Growth

The AK variant uses the following equation set {4.7.2.1 – 4.7.2.3} to calculate annual height increment for all species. Equation {4.7.2.1}, with coefficients specified in table 4.7.2.1, is used to estimate a base height increment, while equations {4.7.2.2} and {4.7.2.3} are used to adjust the base rate due to permafrost presence/absence (*PFHMod*) and species whose growth form is shrub/tree (*SPAdj*), respectively. Coefficients for species utilizing equation {4.7.2.2} are in table 4.7.2.2. *PFHMod* is set to 1.0 for all other species. For species that are of shrub/tree form, height increment is adjusted lower based on a general species adjustment. The final growth rate is adjusted for base cycle length. There are additional adjustments to scale the estimate to cycle length and apply any user-supplied modifiers.

{4.7.2.1} Used for all species

$$BaseHG = \exp(b_1 + b_2 * DBH^2 + b_3 * \ln(DBH) + B_4 * EL + B_5 * \ln(SI) + b_6 * \ln(DG10))$$

{4.7.2.2} Used for species in Table 4.7.2.2

$$PFHMod = \exp(b_1 + b_2 * PERM + b_3 * DBH^2 + b_4 * \ln(DBH) + B_5 * EL + b_6 * \ln(DG10)) / BASEHG$$

{4.7.2.3} $HI = BASEHG * PFHMOD * SPAdj * YR$

where:

BaseHG	is annual height increment (in / year)
DBH	is tree diameter at breast height
EL	is stand elevation (ft)
SI	is species site index
DG10	is 10-year, outside-bark diameter growth
PFHMod	is a permafrost presence modifier
PERM	is the effect of permafrost presence in a stand (value of 1 if present, 0 if absent)
HI	is height increment for the default cycle length
SPAdj	is a species adjustment where AD, WI and OH = 0.45, SU = 0.65, and all others = 1.00
YR	is the default cycle length (10 years)
$b_1 – b_6$	are species-specific coefficients

Table 4.7.2.1 Coefficients ($b_1 - b_6$) for height-growth equation {4.7.2.1} in the AK variant.

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
SF	-2.18236	-0.000447	-0.00488	0	0.429243	0.489281
AF	-2.18236	-0.000447	-0.00488	0	0.429243	0.489281
YC	-2.955092	-0.000447	0.125393	0	0.429243	0.376732
TA	-0.663746	-0.003814	0.176358	-0.000075	0	0.560124
WS	-0.501134	-0.003814	0.209621	-0.000075	0	0.517799
LS	-0.501134	-0.003814	0.209621	-0.000075	0	0.517799
BE	-0.663746	-0.003814	0.176358	-0.000075	0	0.560124
SS	-2.18236	-0.000447	-0.00488	0	0.429243	0.489281
LP	-3.19512	-0.000447	0.166453	0	0.429243	0.342411
RC	-2.979661	-0.000447	0.130947	0	0.429243	0.374658
WH	-2.404892	-0.000447	0.044809	0	0.429243	0.469563
MH	-2.770793	-0.000447	0.099358	0	0.429243	0.408836
OS	-0.501134	-0.003814	0.209621	-0.000075	0	0.517799
AD	-0.174905	-0.003814	-0.051622	-0.000075	0	0.539313
RA	-0.710501	-0.003814	0.396143	-0.000075	0	0.195472
PB	-0.306839	-0.003814	0.062956	-0.000075	0	0.392915
AB	-0.306839	-0.003814	0.062956	-0.000075	0	0.392915
BA	-0.174905	-0.003814	-0.051622	-0.000075	0	0.539313
AS	-0.630114	-0.003814	0.068496	-0.000075	0	0.367413
CW	-0.174905	-0.003814	-0.051622	-0.000075	0	0.539313
WI	-0.174905	-0.003814	-0.051622	-0.000075	0	0.539313
SU	-0.174905	-0.003814	-0.051622	-0.000075	0	0.539313
OH	-0.174905	-0.003814	-0.051622	-0.000075	0	0.539313

Table 4.7.2.2 Coefficients ($b_1 - b_6$) for height-growth equation {4.7.2.2} in the AK variant.

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
TA	-0.661722	-0.130016	-0.003807	0.17915	-0.000067	0.53748
WS	-0.509243	-0.130016	-0.003807	0.221303	-0.000067	0.50946
LS	-0.509243	-0.130016	-0.003807	0.221303	-0.000067	0.50946
BE	-0.661722	-0.130016	-0.003807	0.17915	-0.000067	0.53748
OS	-0.509243	-0.130016	-0.003807	0.221303	-0.000067	0.50946
PB	-0.299268	-0.130016	-0.003807	0.057156	-0.000067	0.3977
AB	-0.299268	-0.130016	-0.003807	0.057156	-0.000067	0.3977
BA	-0.148618	-0.130016	-0.003807	-0.075692	-0.000067	0.55662
AS	-0.617425	-0.130016	-0.003807	0.060586	-0.000067	0.37556
CW	-0.148618	-0.130016	-0.003807	-0.075692	-0.000067	0.55662

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
WI	-0.148618	-0.130016	-0.003807	-0.075692	-0.000067	0.55662
SU	-0.148618	-0.130016	-0.003807	-0.075692	-0.000067	0.55662

A height growth bounding function is used to ensure tree heights do not exceed, to a large extent, the species height maximums. The bounding function is applied using the following concepts. For a tree with height less than the lower height-bounding limit, the height growth modifier is set to 1.0. For a tree with a height greater than or equal to the lower height-bounding limit and less than the upper height-bounding limit, a height growth modifier is computed using equation {4.7.2.4}. For a tree with a height greater than the upper height-bounding limit, the height growth modifier is set to 0.1. The species lower limits were determined from the height growth fitting data and the maximum limits were determined from HT-DBH relationships and a few judgement calls based on a literature. The bounding limits for the height growth bounding function are in table 4.7.2.3. The final height increment estimate is multiplied by the bounding function, equation {4.7.2.5}.

{4.7.2.4} $HGBND = 1.0 - ((HT - HTLO) / (HTHI - HTLO))$

{4.7.2.5} $HI = HI * HGBND$

where:

HGBND	is height growth bounding modifier, limited to $0.1 \leq HGBND \leq 1.0$
HT	is the total tree height (ft)
HT_{LO}	is the lower height-bounding limit
HT_{HI}	is the upper height-bounding limit

Table 4.7.2.3 Bounds for the height growth bounding equation {4.7.2.4} in the AK variant.

Species Code	*HTLO*	*HTHI*
SF	131	211
AF	83	150
YC	92	139
TA	47	77
WS	78	123
LS	78	123
BE	47	77
SS	131	211

Species Code	*HTLO*	*HTHI*
LP	70	98
RC	102	151
WH	130	214
MH	83	150
OS	78	123
AD	38	59
RA	86	120
PB	77	102

Species Code	*HTLO*	*HTHI*
AB	77	102
BA	84	130
AS	76	102
CW	84	130
WI	38	59
SU	55	85
OH	38	59

5.0 Mortality Model

All species in the AK variant use annualized individual tree survival equations for estimating mortality. The annual probability of survival is based on a tree's size and competitive status. Equation 5.0.1 is used to calculate the annual survival rate for all species.

{5.0.1} $RIP = (EXP(X)/(1 + EXP(X)))$

$$X = b_1 + b_2*DBH + b_3*DBH^2 + b_4*PTBAL + b_5*BAL/DBH$$

where:

RIP is annual individual tree survival rate
DBH is tree diameter at breast height, set to *DSURV* when *DBH* is less than *DSURV*
PTBAL plot level basal area in trees larger than subject tree
$b_1 - b_5$ are species-specific coefficients shown in table 5.01

Table 5.0.1 Coefficients used in the survival equation {5.0.1} in the AK variant.

Species Code	b_1	b_2	b_3	b_4	b_5	*DSURV*
SF	5.106086	0.036136	-0.000634	0.0	-0.010747	0.50
AF	5.106086	0.036136	-0.000634	0.0	-0.010747	0.50
YC	5.334283	0.036136	-0.001034	0.0	-0.004540	0.50
TA	5.129246	0.402707	-0.051774	-0.004365	0.0	0.10
WS	4.585373	0.402707	-0.020537	-0.004414	0.0	0.10
LS	4.585373	0.402707	-0.020537	-0.004414	0.0	0.10
BE	5.129246	0.402707	-0.051774	-0.004365	0.0	0.10
SS	5.106086	0.036136	-0.000634	0.0	-0.010747	0.50
LP	4.935148	0.036136	-0.000850	0.0	-0.008488	0.50
RC	6.090056	0.036136	-0.000745	0.0	-0.005608	0.50
WH	5.120483	0.036136	-0.00105	0.0	-0.005131	0.50
MH	5.440943	0.036136	-0.000942	0.0	-0.005375	0.50
OS	4.585373	0.402707	-0.020537	-0.004414	0.0	0.10
AD	2.651991	0.402707	-0.011288	-0.002557	0.0	0.10
RA	2.987803	0.402707	-0.014038	-0.005462	0.0	0.10
PB	3.255821	0.402707	-0.018658	-0.007307	0.0	0.10
AB	3.255821	0.402707	-0.018658	-0.007307	0.0	0.10
BA	2.651991	0.402707	-0.011288	-0.002557	0.0	0.10
AS	2.833541	0.402707	-0.015719	-0.010755	0.0	0.10
CW	2.651991	0.402707	-0.011288	-0.002557	0.0	0.10
WI	2.651991	0.402207	-0.011288	-0.002557	0.0	0.10
SU	2.651991	0.402207	-0.011288	-0.002557	0.0	0.10
OH	2.651991	0.402207	-0.011288	-0.002557	0.0	0.10

The estimated annual survival rates are adjusted for the length of a projection cycle using a compound interest formula (Hamilton 1976). The adjusted survival rates are then converted to mortality rates as defined in equation {5.0.2} and then applied to the trees per acre represented by the tree record in a stand. If the stand density is above the maximum stand density index (or basal area maximum) after the rates are applied, the predicted mortality rates are reapplied to each tree record until the stand is below the maximum density.

{5.0.2} $WKI = P * (1 - RIP^Y) * X$

where:

WKI	is individual tree mortality rate adjusted to the length of the cycle
P	is trees per acre represented by the tree record
RIP	is annual individual tree survival rate
Y	is length of the current projection cycle in years
X	is any user-supplied mortality multipliers

6.0 Regeneration

The AK variant contains a full establishment model which is explained in section 5.4.2 of the Essential FVS Users Guide (Dixon 2002). In short, the full establishment model automatically adds regeneration from advanced, subsequent, and excess regeneration pools following significant stand disturbances and adds ingrowth absent of disturbance every 20 years. Automatic regeneration and ingrowth occurrence are based on the user-defined or calculated forest type for the stand. If a valid forest type is not found, no species are added. Species occurrence by valid forest type is found in table 6.0.1.

Table 6.0.1 Species occurrence by valid forest types resulting in automatic regeneration and ingrowth in the AK variant.

FIA Forest Type[1]	Description	Species included in automatic tallies and ingrowth
122	white spruce	TA, WS, BE, MH, PB, BA, AS
125	black spruce	TA, WS, BE, PB, BA, AS
270, 268	mountain hemlock	YC, WS, SS, LP, WH, MH
271	Alaska cedar	YC, SS, LP, RC, WH, MH, RA
281	lodgepole pine	YC, SS, LP, RC, WH, MH, RA
301, 264	western hemlock	YC, SS, LP, RC, WH, MH, RA
304	western redcedar	YC, SS, LP, RC, WH, MH, RA
305	Sitka spruce	YC, SS, RC, WH, MH, RA
703, 704, 709	cottonwood	WS, BE, SS, WH, PB, CW
901	aspen	TA, WS, BE, PB, BA, AS
902	paper birch	TA, WS, BE, SS, MH, PB, BA, AS
904	balsam poplar	TA, WS, BE, MH, PB, BA, AS
911	red alder	SS, WH, RA

[1]First forest type listed was used to fit data and additional forest types listed are mapped to first.

There are thirteen steps to predicting and adding automatic regeneration and ingrowth to a simulation, see table 6.0.2. This process is based on probability equations that take into consideration stand and plot location (latitude); abiotic factors such as slope, aspect, and elevation; density; plot composition; and forest type random effects. Further description is beyond the scope of explanation offered in this overview.

Table 6.0.2 Key processes for predicting automatic regeneration and ingrowth in the AK variant.

Step	Description
1	initialize and replicate plots
2	perform calibration tasks
3	compute years since disturbance
4	calculate stocking and species probabilities
5	estimate the number of regenerating trees per plot
6	estimate the number of regenerating species per plot
7	pick species to occupy plots

Step	Description
8	estimate heights of best trees
9	add planted trees
10	identify best trees
11	accumulate plot statistics
12	pass regeneration to treelist
13	print regeneration summary

In addition to automatic regeneration and ingrowth, sprouts are added to the simulation following harvest or burning resulting in main stem loss of known sprouting species, see table 6.0.3 for sprouting species. Users may also input regeneration and ingrowth into simulations manually through establishment model keywords as explained in section 5.4.3 of the Essential FVS Users Guide (Dixon 2002). The following description applies to how sprouting occurs and entering regeneration and ingrowth through keywords.

Table 6.0.3 Regeneration parameters by species in the AK variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
SF	No	0.3	1.0	20.0
AF	No	0.3	0.5	20.0
YC	No	0.3	0.5	12.0
TA	No	0.2	0.5	13.0
WS	No	0.4	0.5	13.0
LS	No	0.4	0.5	13.0
BE	No	0.2	0.5	13.0
SS	No	0.4	0.5	20.0
LP	No	0.4	1.0	9.0
RC	No	0.3	0.5	15.0
WH	No	0.3	0.5	19.0
MH	No	0.3	0.5	10.0
OS	No	0.4	0.5	13.0
AD	Yes	0.2	1.0	7.6
RA	Yes	0.2	1.0	30.0
PB	Yes	0.1	1.0	20.0
AB	Yes	0.1	1.0	20.0
BA	Yes	0.2	1.0	16.9
AS	Yes	0.3	1.0	18.0
CW	Yes	0.2	1.0	16.9
WI	Yes	0.1	1.0	7.6
SU	Yes	0.1	1.0	11.0
OH	No	0.2	1.0	7.6

Logic rule {6.0.1} is used to determine the number of sprout records for balsam poplar and black cottonwood, two sprout records are created for quaking aspen, and one sprout record is created for all other species. The trees-per-acre represented by each sprout record is determined using general sprouting probability equation {6.0.2} and probability of sprouting equations in {6.0.3} through {6.0.7}. See table 6.0.4 for species-specific sprouting probabilities 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 6.0.3 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} Number of sprout records

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

{6.0.2} $TPA_s = TPA_i * PS$

{6.0.3} Probability of sprouting
$DSTMP_i < 25.9$: $PS = ((99.9999 - 3.8462 * DSTMP_i) / 100)$,
$DSTMP_i >= 25.9$: $PS = 0$.
{6.0.4} Probability of sprouting
$DSTMP_i < 6.0$: $PS = 0.92$
$6.0 <= DSTMP_i < 9.0$: $PS = -0.1333 * DSTMP_i + 1.70$
$DSTMP_i >= 9.0$: $PS = 0.50$
{6.0.5} Probability of sprouting
$DSTMP_i < 6.25$: $PS = 0.39$
$6.25 <= DSTMP_i < 8.75$, $PS = 0.32$
$DSTMP_i >= 9.0$: $PS = 0.25$
{6.0.6} Probability of sprouting
$PS = (TPA_i / (ASTPAR * 2)) * ((ASBAR / 198) * (40100.45 - 3574.02 * RSHAG ^ 2 + 554.02 * RSHAG ^ 3 - 3.5208 * RSHAG ^ 5 + 0.011797 * RSHAG ^ 7))$
{6.0.7} Probability of sprouting
$PS = 0.90$

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 AK variant.

Species Code	Sprouting Probability	Source
AD, RA	{6.0.3}	Harrington (1984) Uchytil (1989)
PB, AB	{6.0.4}	Hutnik and Cunningham (1965) Bjorkbom (1972)
BA, CW	{6.0.5}	Zasada (1981)
AS	{6.0.6}	Keyser (2001)
WI, SU	{6.0.7}	Burns and Honkala (1990)

Regeneration of seedlings may be specified by using PLANT or NATURAL keywords. Height of the seedlings is estimated in two steps. First, the height is estimated when a tree is 5 years old (or the end of the cycle – whichever comes first) by using the small-tree height growth equations found in section 4.6.1. Users may override this value by entering a height in field 6 of the PLANT or NATURAL 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 6.0.3. 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 AK 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 merchantability standards and equation numbers for the AK variant are shown in tables 7.0.1 – 7.0.3.

Table 7.0.1 Volume merchantability standards by location code for the AK variant. Stump Height is set to 1.0 foot.

Location Code	**Merchantable Cubic Foot** (Minimum DBH / Top Diameter)	**Merchantable Board Foot** (Minimum DBH / Top Diameter)
713	6.0 / 4.0 inches	9.0 / 6.0 inches
703, 1002, 1003, 1005, 8134, 8135, 8112	9.0 / 7.0 inches	9.0 / 7.0 inches
1004	9.0 / 6.0 inches	9.0 / 6.0 inches
720, 7400, 7401, 7402,7403, 7404, 7405, 7406, 7407, 7408	5.0 / 4.0 inches	9.0 / 6.0 inches

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

Species Code	Volume Category[1]	Equation Number[2]	Model Name
SF	1	A00F32W260	Flewelling Profile-32ft Log Rule
SF	2	A01DEMW000	Demars Profile Model
AF	1	A00F32W260	Flewelling Profile-32ft Log Rule
AF	2	A01DEMW000	Demars Profile Model
YC	1	A00F32W042	Flewelling Profile-32ft Log Rule
YC	2	A00DVEW094	Larson Volume Equation
TA	1,2	A00DVEW095	Larson Volume Equation
WS	1,2	A00DVEW094	Larson Volume Equation
LS	1,2	A00DVEW094	Larson Volume Equation
BE	1,2	A00DVEW095	Larson Volume Equation
SS	1,2	A00F32W098	Flewelling Profile-32ft Log Rule
LP	1	A00F32W260	Flewelling Profile-32ft Log Rule
LP	2	A01DEMW000	Demars Profile Model
RC	1	A00F32W242	Flewelling Profile-32ft Log Rule
RC	2	A01DEMW000	Demars Profile Model
WH	1,2	A00F32W260	Flewelling Profile-32ft Log Rule
MH	1	A00F32W260	Flewelling Profile-32ft Log Rule
MH	2	A01DEMW000	Demars Profile Model
OS	1,2	A00DVEW094	Larson Volume Equation

Species Code	Volume Category[1]	Equation Number[2]	Model Name
AD	1,2	A32CURW351	Curtis Profile Model-32ft Log Rule
RD	1,2	A32CURW351	Curtis Profile Model-32ft Log Rule
PB	1,2	A00DVEW375	Larson Volume Equation
AB	1,2	A00DVEW375	Larson Volume Equation
BA	1,2	A00DVEW747	Larson Volume Equation
QA	1,2	A00DVEW375	Larson Volume Equation
CW	1	A00F32W260	Flewelling Profile-32ft Log Rule
CW	2	A00DVEW747	Larson Volume Equation
WI	1,2	A00DVEW375	Larson Volume Equation
SU	1,2	A00DVEW375	Larson Volume Equation
OH	1	A00F32W260	Flewelling Profile-32ft Log Rule
OH	2	A16DEMW098	Demars Profile Model

[1] Volume category 1 location codes: 703, 1002, 1003, 1005, 8112, 8134, 8135. Volume category 2 location codes: 713, 720, 1004, 7400, 7401, 7402, 7403, 7404, 7405, 7406, 7407, 7408.
[2]Additional equation numbers are available using the VOLEQNUM keyword.

Table 7.0.3 Citations by Volume Model.

Model Name	Citation
Curtis Profile Model-32ft Log Rule	Curtis, Robert O, David Bruce, and Caryanne VanCoevering. 1968. Volume and Taper Tables for Red Alder. Pacific Northwest Forest and Range Exp. Sta. Research Paper PNW-56.
Demars Profile Model	Bruce, D., 1984. Volume estimators for Sitka spruce and western hemlock in coastal Alaska. In Inventorying forest and other vegetation of the high latitude and high altitude regions. SAF pub 84-11. Bethesada, MD. pp. 96-102.
Flewelling Profile-32ft Log Rule	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.
Larson Volume Equation	Larson, Frederic R. and Kenneth C Winterberger. 1988. Tables and Equations for Estimating Volumes of trees in the Susitna River Basin, Alaska. Pacific Northwest Research Station Research Note PNW-478.

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 AK variant, refer to the updated FFE-FVS model documentation (Rebain, comp. 2010) available on the FVS website.

9.0 Insect and Disease Extensions

The FVS Insect and Pathogen model for dwarf mistletoe has been developed for the AK variant through the participation and contribution of various organizations led by Forest Health Protection. This model is currently maintained by the Forest Management Service Center and regional Forest Health Protection specialists. Additional details regarding this model may be found in chapter 8 of the Essential FVS Users Guide (Dixon 2002).

10.0 Literature Cited

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

Bruce, D., 1984. Volume estimators for Sitka spruce and western hemlock in coastal Alaska. In Inventorying forest and other vegetation of the high latitude and high altitude regions. SAF pub 84-11. Bethesada, MD. pp. 96-102.

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

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

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

Curtis, Robert O, David Bruce, and Caryanne VanCoevering. 1968. Volume and Taper Tables for Red Alder. Pacifc Northwest Forest and Range Exp. Sta. Research Paper PNW-56.

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

Donnelly, Dennis. 1996. Internal Document On File. Fort Collins, CO: Data provided from region 6.

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.

Harrington, Constance A. 1984. Factors influencing initial sprouting of red alder. Canadian Journal of Forest Research. 14: 357-361.

Hegyi, F.; Jelink, J.J.; Viszlai, J.; Carpenter, D.B. 1979. Site Index Equations and Curves for the Major Tree Species in British Columbia. Forest Inv. Rep. No. 1. Ministry of Forests Victoria, BC. November 1979, revised September 1981.

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

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

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

Larson, Frederic R. and Kenneth C Winterberger. 1988. Tables and Equations for Estimating Volumes of trees in the Susitna River Basin, Alaska. Pacific Northwest Research Station Research Note PNW-478.

Malone, T., Liang, J. and Packee Sr, E.C., 2013. Total and merchantable volume of white spruce in Alaska. *Western Journal of Applied Forestry*, *28*, pp.71-77.

Paine, D.P., and D.W. Hann. 1982. Maximum crown width equations for southwestern Oregon tree species. For. Res. Lab., Oregon State Univ., Corvallis, OR. Res. Pap. 46. 20 p.

Payandeh, B. 1974. Nonlinear site index equations for several major Canadian timber species. The Forestry Chronicle. 194- 196.

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

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

Rijal, Baburam; Weiskittel, Aaron, and Kershaw, John. (2012). Development of regional height to diameter equations for 15 tree species in the North American Acadian Region. Forestry. 85. 379-390.

Russell, M.B. and Weiskittel, A.R., 2011. Maximum and largest crown width equations for 15 tree species in Maine. Northern Journal of Applied Forestry, 28(2), pp.84-91.

Smith, J.H.G., 1966, June. Studies of crown development are improving Canadian forest management. In Proceedings of the sixth world forestry congress (pp. 6-18).

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

Uchytil, Ronald J. 1989. Alnus rubra. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.

-----. 2009(revised frequently). Volume Estimator Library Equations. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center.

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

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

Zasada, J. C., Viereck, L. A., Foote, M. J., Parkenson, R. H., Wolff, J. O., and Landford, L. A. 1981. Natural regeneration of balsam poplar following harvesting in the Sustitna Valley, Alaska. The Forestry Chronicle, 4: 57-65.

11.0 Appendices

There are no appendices to the AK variant.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, sex, religion, age, disability, political beliefs, sexual orientation, or marital or family status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).

To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 1400 Independence Avenue, SW, Washington, DC 20250-9410 or call (202) 720-5964 (voice or TDD). USDA is an equal opportunity provider and employer.