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Central States (CS) Variant Overview of the Forest Vegetation Simulator

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Hoosier NF
(Bob Stone, FS-R9)

Central States (CS) Variant Overview of the Forest Vegetation Simulator

Authors and Contributors:

The FVS staff has maintained model documentation for this variant in the form of a variant overview since its release in 1993. The original author was Renate Bush. In 2006, Gary Dixon reformulated many of the model components, created a test version of the variant and wrote this new variant overview. 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. Gary Dixon cross-checked information contained in this variant overview with the FVS source code.

FVS Staff. 2008 (revised April 16, 2024). Central States (CS) 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)	905 – Mark Twain	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation (default location)	10 (1000 feet)	
Latitude (default location)	37.95	
Longitude (default location)	91.77	
Site Species	WO	
Site Index	65 feet (total age; 50 years)	
Maximum Stand Density Index	Species specific	
Maximum Basal Area	Species specific	
Volume Equations	National Volume Estimator Library	
Pulpwood Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
905 – Mark Twain	5.0 / 4.0 inches	5.0 / 4.0 inches
908 – Shawnee	6.0 / 5.0 inches	5.0 / 4.0 inches
911 – Wayne-Hoosier, 912 - Hoosier	6.0 / 4.0 inches	5.0 / 4.0 inches
Stump Height	0.5 feet	0.5 feet
Merchantable Sawlog Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
905 – Mark Twain (eastern redcedar)		6.0 / 5.0 inches
905 – Mark Twain (all other species)	9.0 / 7.6 inches	9.0 / 7.6 inches
908 – Shawnee	11.0 / 9.6 inches	9.0 / 7.6 inches
911 – Wayne-Hoosier, 912 - Hoosier	11.0 / 9.6 inches	9.0 / 7.6 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Basal Area Factor	40 BAF	
Small-Tree Fixed Area Plot	1/300th Acre	
Breakpoint DBH	5.0 inches	

1.0 Introduction

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

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

The original Central States (CS) variant was developed in 1993 using relationships from the CS-TWIGS model (Shifley 1987; Miner and others 1988), and equations from other variants for FVS relationships not present in CS-TWIGS. The model was reformulated in 2006 to improve model estimates; the only remnant of the original CS-TWIGS formulation was in the large tree diameter growth equation. In 2017, the large tree diameter growth equations from LS-TWIGS were replaced with equations from Deo and Froese (2013).

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 CS variant covers forested areas in Illinois, Indiana, Iowa, and Missouri. This includes the Shawnee National Forest in Illinois, the Hoosier National Forest in Indiana, and the Mark Twain National Forest in Missouri. The suggested geographic range of use for the CS variant is shown in figure 2.0.1.

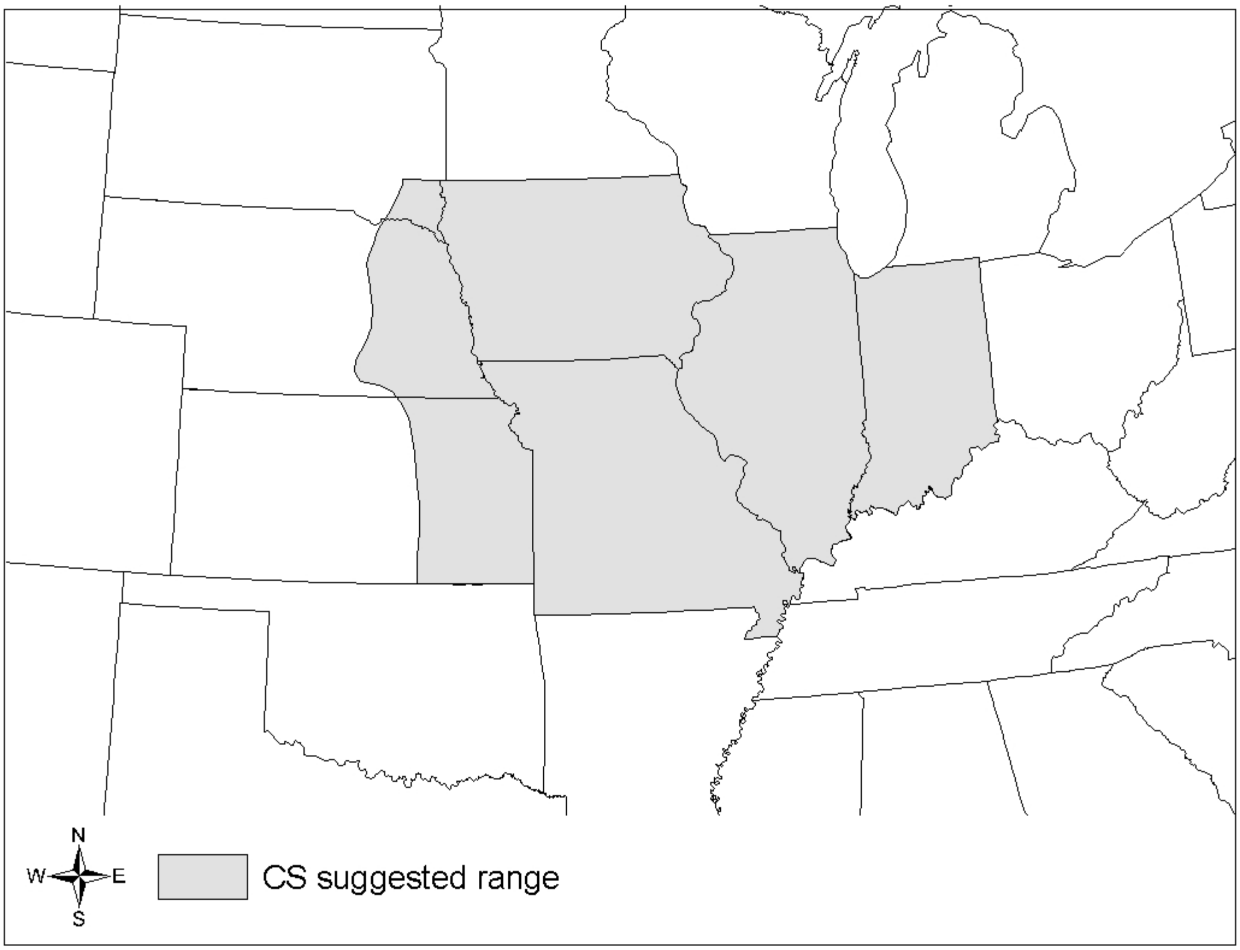

Figure 2.0.1 Suggested geographic range of use for the CS variant.

3.0 Control Variables

FVS users need to specify certain variables used by the CS 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 CS variant, a default forest code of 905 (Mark Twain National Forest) will be used. Location codes recognized in the CS variant – and their associated default latitude, longitude, and elevation values – are shown in tables 3.1.1 and 3.1.2.

Table 3.1.1 Location codes used in the CS variant.

Location Code	USFS National Forest	Latitude	Longitude	Elevation
905	Mark Twain	37.95	91.77	10 (1000 feet)
908	Shawnee	37.74	88.54	4 (400 feet)
912	Hoosier	38.86	86.49	6 (600 feet)
911	Wayne-Hoosier combined code (mapped to 912)	38.86	86.49	6 (600 feet)

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

Location Code	Location
7110	Omaha Reservation (mapped to 905)
7111	Santee Reservation (mapped to 905)
7112	Winnebago Reservation (mapped to 905)
7202	Iowa (Ks-Ne) Reservation (mapped to 905)
7203	Kickapoo (Ks) (mapped to 905)
7204	Prairie Band Of Potawatomi (mapped to 905)
7205	Sac And Fox Nation Reservation (mapped to 905)
7210	Kaw Otsa (mapped to 905)
7509	Sac And Fox/Meskwaki Settlement (mapped to 908)
7602	Quapaw Otsa (mapped to 905)
7606	Miami Otsa (mapped to 905)
7608	Modoc Otsa (mapped to 905)
7609	Osage Reservation (mapped to 905)
7611	Cherokee Otsa (mapped to 905)

3.2 Species Codes

The CS variant recognizes 91 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 eastern 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 CS variant.

Table 3.2.1 Species codes used in the CS variant.

Species Group	Species Number[1]	Species Code	FIA Code	PLANTS Symbol	Scientific Name[2]	Common Name[2]
1	1	RC	068	JUVI	*Juniperus virginiana*	eastern redcedar
1	2	JU	057	JUNIP	*Juniperus*	juniper
2	3	SP	110	PIEC2	*Pinus echinata*	shortleaf pine
3	4	VP	132	PIVI2	*Pinus viginiana*	Virginia pine
3	5	LP	131	PITA	*Pinus taeda*	loblolly pine
4	6	OS	299	2TN		other softwood[3]
4	7	WP	129	PIST	*Pinus strobus*	eastern white pine
5	8	WN	602	JUNI	*Juglans nigra*	black walnut
5	9	BN	601	JUCI	*Juglans cinerea*	butternut
6	10	TL	690	NYSSA	*Nyssa*	tupelo
6	11	TS	694	NYBI	*Nyssa biflora*	swamp tupelo
6	12	WT	691	NYAQ2	*Nyssa aquatica*	water tupelo
6	13	BG	693	NYSY	*Nyssa sylvatica*	blackgum
7	15	SH	407	CAOV2	*Carya ovata*	shagbark hickory
7	16	SL	405	CALA21	*Carya laciniosa*	shellbark hickory
7	17	MH	409	CAAL27	*Carya tomentosa*	mockernut hickory
8	18	PH	403	CAGL8	*Carya glabra*	pignut hickory
8	19	HI	400	CARYA	*Carya*	hybrid hickory
8	20	WH	401	CAAQ2	*Carya aquatica*	water hickory
8	21	BH	402	CACO15	*Carya cordiformis*	bitternut hickory
8	22	PE	404	CAIL2	*Carya illinoinensis*	pecan
8	23	BI	408	CATE9	*Carya texana*	black hickory
9	24	AB	531	FAGR	*Fagus grandifolia*	American beech
10	25	BA	543	FRNI	*Fraxinus nigra*	black ash

Species Group	Species Number[1]	Species Code	FIA Code	PLANTS Symbol	Scientific Name[2]	Common Name[2]
10	26	PA	545	FRPR	*Fraxinus profunda*	pumpkin ash
10	27	UA	546	FRQU	*Fraxinus quadrangulata*	blue ash
11	28	EC	742	PODE3	*Populus deltoides*	eastern cottonwood
12	29	RM	316	ACRU	*Acer rubrum*	red maple
12	30	BE	313	ACNE2	*Acer negundo*	boxelder
12	31	SV	317	ACSA2	*Acer saccharinum*	silver maple
13	32	BC	762	PRSE2	*Prunus serotina*	black cherry
14	33	AE	972	ULAM	*Ulmus americana*	American elm
14	34	SG	461	CELA	*Celtis laevigata*	sugarberry
14	35	HK	462	CEOC	*Celtis occidentalis*	common hackberry
14	36	WE	971	ULAL	*Ulmus alata*	winged elm
14	37	EL	970	ULMUS	*Ulmus*	elm
14	38	SI	974	ULPU	*Ulmus pumila*	Siberian elm
14	39	RL	975	ULRU	*Ulmus rubra*	slippery elm
14	40	RE	977	ULTH	*Ulmus thomasii*	rock elm
15	41	YP	621	LITU	*Liriodendron tulipifera*	tuliptree
16	42	BW	951	TIAM	*Tilia americana*	American basswood
17	43	SM	318	ACSA3	*Acer saccharum*	sugar maple
18	44	AS	540	FRAXI	*Fraxinus*	ash
18	45	WA	541	FRAM2	*Fraxinus americana*	white ash
18	46	GA	544	FRPE	*Fraxinus pennsylvanica*	green ash
19	47	WO	802	QUAL	*Quercus alba*	white oak
20	48	RO	833	QURU	*Quercus rubra*	northern red oak
20	49	SK	812	QUFA	*Quercus falcata*	southern red oak
21	50	BO	837	QUVE	*Quercus velutina*	black oak
22	51	SO	806	QUCO2	*Quercus coccinea*	scarlet oak
23	52	BJ	824	QUMA3	*Quercus marilandica*	blackjack oak
24	53	CK	826	QUMU	*Quercus muehlenbergii*	chinkapin oak
24	54	SW	804	QUBI	*Quercus bicolor*	swamp white oak
24	55	BR	823	QUMA2	*Quercus macrocarpa*	bur oak
24	56	SN	825	QUMI	*Quercus michauxii*	swamp chestnut oak
25	57	PO	835	QUST	*Quercus stellata*	post oak
25	58	DO	836	QUSI2	*Quercus similis*	bottomland post oak
26	59	CO	832	QUPR2	*Quercus prinus*	chestnut oak

Species Group	Species Number[1]	Species Code	FIA Code	PLANTS Symbol	Scientific Name[2]	Common Name[2]
27	60	PN	830	QUPA2	*Quercus palustris*	pin oak
27	61	CB	813	QUPA5	*Quercus pagoda*	cherrybark oak
27	62	QI	817	QUIM	*Quercus imbricaria*	shingle oak
27	63	OV	822	QULY	*Quercus lyrata*	overcup oak
27	64	WK	827	QUNI	*Quercus nigra*	water oak
27	65	NK	828	QUTE	*Quercus texana*	Nuttall oak
27	66	WL	831	QUPH	*Quercus phellos*	willow oak
27	67	QS	834	QUSH	*Quercus shumardii*	Shumard's oak
28	69	SS	931	SAAL5	*Sassafras albidum*	sassafras
28	70	OB	331	AEGL	*Aesculus glabra*	Ohio buckeye
28	71	CA	450	CATAL	*Catalpa*	catalpa
28	72	PS	521	DIVI5	*Diospyros virginiana*	common persimmon
28	73	HL	552	GLTR	*Gleditsia triacanthos*	honeylocust
28	74	BP	741	POBA2	*Populus balsamifera*	balsam poplar
28	75	BT	743	POGR4	*Populus grandidentata*	bigtooth aspen
28	76	QA	746	POTR5	*Populus tremuloides*	quaking aspen
28	77	BK	901	ROPS	*Robinia pseudoacacia*	black locust
29	79	SY	731	PLOC	*Platanus occidentalis*	American sycamore
29	80	BY	221	TADI2	*Taxodium distichum*	bald cypress
29	81	RB	373	BENI	*Betula nigra*	river birch
29	82	SU	611	LIST2	*Liquidamber styraciflua*	sweetgum
29	83	WI	920	SALIX	*Salix*	willow
29	84	BL	922	SANI	*Salix nigra*	black willow
30	85	OH	998	2TB		other hardwood[3]
30	86	AH	391	CACA18	*Carpinus caroliniana*	American hornbeam
30	87	RD	471	CECA4	*Cercis canadensis*	eastern redbud
30	88	DW	491	COFL2	*Cornus florida*	flowering dogwood
30	89	HT	500	CRATA	*Crataegus*	hawthorn
30	90	KC	571	GYDI	*Gymnocladus dioicus*	Kentucky coffeetree
30	91	OO	641	MAPO	*Maclura pomifera*	Osage-orange
30	92	CT	651	MAAC	*Magnolia acuminata*	cucumber tree
30	93	MV	653	MAVI2	*Magnolia virginiana*	sweetbay
30	94	MB	680	MORUS	*Morus*	mulberry
30	95	HH	701	OSVI	*Ostrya virginiana*	hophornbeam
30	96	SD	711	OXAR	*Oxydendrum arboreum*	sourwood

[1]Species numbers 14, 68, and 78 represent removed species groups.
[2]Set based on the USDA Forest Service NRM TAXA lists and the USDA Plants database.
[3]Other categories use FIA codes and NRM TAXA codes that best match the other category.

3.3 Habitat Type, Plant Association, and Ecological Unit Codes

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

3.4 Site Index

Site index is used in the growth equations for the CS variant. Users should always use the site index curves from Carmean and others (1989) to estimate site index. In assigning site index, users should use site curves based on total age at an index age of 50. If site index is available, a single site index for the whole stand can be entered, a site index for each individual species in the stand can be entered, or a combination of these can be entered. If site index is missing or incorrect, the site species is set to white oak with a default site index set to 65.

Site indices for species not assigned a site index are converted from white oak site index to a species specific site index using equation {3.4.1}. If white oak is not the site species or no site index is specified for white oak, then equation {3.4.2} is used to calculate white oak's site index from the site species site index. Coefficients for equations {3.4.1} and {3.4.2} are located in Table 3.4.1.

{3.4.1} $SI_{unknown} = a_1 + a_2 * SI_{white\ oak}$

{3.4.2} $SI_{white\ oak} = (-1*a_1/a_2) + (1/a_2*SI_{site\ species})$

where:

$SI_{unknown}$ is site index of the species with unknown site index
$SI_{site\ species}$ is site index of site species
$SI_{white\ oak}$ is site index of white oak
a_1, a_2 are species group specific coefficients shown in Table 3.4.1

Table 3.4.1. Coefficients for Equation {3.4.1} and {3.4.2}.

Species Code	a_1	a_2
RC	0	0.8
JU	0	0.8
SP	-5.1489	1.062
VP	0	1.25
LP	0	1.25
OS	0	1.25
WP	0	1.35
WN	0	1.19
BN	0	1.19

Species Code	a_1	a_2
SK	-1.3344	1.082
BO	-2.706	1.106
SO	1.097	1.063
BJ	0	0.96
CK	0	0.89
SW	0	0.89
BR	0	0.89
SN	0	0.89
PO	0	0.83

Species Code	a_1	a_2
TL	0	1.15
TS	0	1.15
WT	0	1.15
BG	0	1.15
SH	0	1.08
SL	0	1.08
MH	0	1.08
PH	0	1.08
HI	0	1.1
WH	0	1.1
BH	0	1.1
PE	0	1.1
BI	0	1.1
AB	18.19	0.7695
BA	-35.098	1.729
PA	-35.098	1.729
UA	-35.098	1.729
EC	0	1.3
RM	0	1.32
BE	0	1.32
SV	0	1.32
BC	0	1.25
AE	-26.067	1.51754
SG	-26.067	1.51754
HK	-26.067	1.51754
WE	-26.067	1.51754
EL	-26.067	1.51754
SI	-26.067	1.51754
RL	-26.067	1.51754
RE	-26.067	1.51754
YP	-7.01	1.2033
BW	18.19	0.7695
SM	0	1.22
AS	-36.805	1.6748
WA	-36.805	1.6748
GA	-36.805	1.6748
WO	0	1

Species Code	a_1	a_2
DO	0	0.83
CO	2.656	0.965
PN	0	1.2
CB	0	1.2
QI	0	1.2
OV	0	1.2
WK	0	1.2
NK	0	1.2
WL	0	1.2
QS	0	1.2
SS	0	1.35
OB	0	1.35
CA	0	1.35
PS	0	1.35
HL	0	1.35
BP	3.5434	1.2407
BT	3.5434	1.2407
QA	3.5434	1.2407
BK	0	1.2
SY	0	1.35
BY	0	1.35
RB	7.5209	1.0735
SU	7.5209	1.0735
WI	7.5209	1.0735
BL	7.5209	1.0735
OH	0	0.8
AH	0	0.8
RD	0	0.8
DW	0	0.8
HT	0	0.8
KC	0	0.9
OO	0	0.9
CT	0	0.9
MV	0	0.9
MB	0	0.9
HH	0	0.9
SD	0	0.9

Species Code	a_1	a_2
RO	-1.3344	1.082

Species Code	a_1	a_2

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:

SDIMAXi 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 CS variant.

Species Code	SDI Maximum*	Mapped to
RC	354	
JU	354	eastern redcedar
SP	490	
VP	499	
LP	480	
OS	354	eastern redcedar
WP	529	
WN	283	
BN	283	black walnut
TL	430	blackgum
TS	704	
WT	726	

Species Code	SDI Maximum*	Mapped to
SK	342	
BO	370	
SO	315	
BJ	326	
CK	336	
SW	361	white oak
BR	423	
SN	417	chestnut oak
PO	311	
DO	311	post oak
CO	417	
PN	455	

Species Code	SDI Maximum*	Mapped to
BG	430	
SH	302	
SL	302	shagbark hickory
MH	230	
PH	276	
HI	302	shagbark hickory
WH	301	bitternut hickory
BH	301	
PE	338	
BI	289	
AB	364	
BA	423	
PA	408	white ash
UA	408	white ash
EC	648	
RM	421	
BE	344	
SV	590	
BC	384	
AE	282	
SG	339	
HK	420	
WE	263	
EL	282	American elm
SI	282	American elm
RL	227	
RE	282	American elm
YP	478	
BW	526	
SM	371	
AS	414	green ash
WA	408	
GA	414	
WO	361	
RO	414	

Species Code	SDI Maximum*	Mapped to
CB	405	
QI	370	black oak
OV	384	
WK	365	
NK	342	southern red oak
WL	315	
QS	342	southern red oak
SS	492	
OB	371	sugar maple
CA	492	sassafras
PS	147	
HL	338	
BP	384	
BT	520	
QA	562	
BK	343	
SY	499	
BY	692	
RB	400	
SU	430	
WI	447	black willow
BL	447	
OH	257	flowering dogwood
AH	375	
RD	422	
DW	257	
HT	463	
KC	343	black locust
OO	404	
CT	415	
MV	492	
MB	277	red mulberry
HH	304	
SD	164	

*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 are used to estimate tree heights missing in the input data and periodic small-tree diameter growth. In the CS variant, height is estimated using either the Curtis-Arney equation (Curtis 1967, Arney 1985) or the Wykoff equation (Wykoff and others 1982). The equation used by default is indicated by a C or W, in the third column of table 4.1.1. By default, the CS variant does not calibrate the height-diameter relationship for estimating missing tree heights based on measured heights in the input data. To override this, the user must use the NOHTDREG keyword and “turn on” calibration. When calibration is turned on, FVS will use the Wykoff equation form with a calibrated B_1 value, if there are at least 3 measured heights for that species over 3 inches DBH in the stand.

The functional form of the Curtis-Arney equation for trees three inches DBH and larger is shown in equation {4.1.1}. For trees less than three inches DBH using the Curtis-Arney equation, a modified Curtis-Arney equation combined with a simple linear equation is used. The functional form of the Wykoff equation is shown in equation {4.1.2}. Equation coefficients and which equation is used for which species are shown in table 4.1.1.

{4.1.1} Curtis-Arney equation

$DBH \geq 3.0”: HT = 4.5 + P_2 * \exp(-P_3 * DBH \hat{} P_4)$
$DBH < 3.0”: HT = ((4.5 + P_2 * \exp(-P_3 * 3.0 \hat{} P_4) – 4.51) * (DBH – D_{bw}) / (3 – D_{bw})) + 4.51$

{4.1.2}Wykoff functional form

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

where:

HT	is tree height
DBH	is tree diameter at breast height
D_{bw}	is bud width diameter at 4.51 feet shown in table 4.1.1
B_1 - B_2	are species-specific coefficients shown in table 4.1.1
P_2 - P_4	are species-specific coefficients shown in table 4.1.2

Coefficients for the height-diameter relationships in the CS variant are from equations fit to data for the Southern variant of FVS. Wykoff and Curtis-Arney coefficients for all species, are shown in table 4.1.1. Species for which there was not enough data to fit these relationships use coefficients from a similar species.

Table 4.1.1 Coefficients, default equation used, and surrogate species for height-diameter relationships for the CS variant.

Species Code	W or C	SN Variant Surrogate / source	Curtis-Arney Coefficients				Wykoff Coefficients	
			P_2	P_3	P_4	D_{bw}	Default B_1	B_2
RC	W	Virginia pine	926.1803	4.4621	-0.2005	0.5	4.4718	-5.0078
JU	W	juniper species	212.7933	3.4715	-0.3259	0.3	4.0374	-4.2964
SP	W	shortleaf pine	444.0922	4.1188	-0.3062	0.5	4.6271	-6.4095
VP	W	Virginia pine	926.1803	4.4621	-0.2005	0.5	4.4718	-5.0078
LP	W	loblolly pine	243.8606	4.2846	-0.4713	0.5	4.6897	-6.8801
OS	W	juniper species	212.7933	3.4715	-0.3259	0.3	4.0374	-4.2964
WP	C	eastern white pine	2108.8442	5.6595	-0.1856	0.4	4.6090	-6.1896
WN	W	black walnut	93.7104	3.6575	-0.8825	0.4	4.5018	-5.6123
BN	W	butternut	285.8798	3.5214	-0.3194	0.3	4.5018	-5.6123
TL	W	blackgum / black tupelo	319.9788	3.6731	-0.3065	0.2	4.3802	-4.7903
TS	W	swamp tupelo	252.3567	3.2440	-0.3334	0.2	4.4334	-4.5709
WT	W	water tupelo	163.9728	2.7682	-0.4410	0.2	4.4330	-4.5383
BG	C	blackgum / black tupelo	319.9788	3.6731	-0.3065	0.2	4.3802	-4.7903
SH	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
SL	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
MH	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
PH	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
HI	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
WH	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
BH	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
PE	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
BI	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
AB	W	American beech	526.1393	3.8923	-0.2259	0.1	4.4772	-4.7206
BA	W	black ash	178.9308	4.9286	-0.6378	0.2	4.6155	-6.2945
PA	W	ash species	251.4043	3.2692	-0.3591	0.2	4.4819	-4.5314
UA	W	ash species	251.4043	3.2692	-0.3591	0.2	4.4819	-4.5314
EC	W	cottonwood	190.9797	3.6928	-0.5273	0.1	4.9396	-8.1838
RM	W	red maple	268.5564	3.1143	-0.2941	0.2	4.3379	-3.8214
BE	W	butternut	285.8798	3.5214	-0.3194	0.3	4.5018	-5.6123
SV	C	silver maple	80.5118	26.9833	-2.0220	0.2	4.5991	-6.6706
BC	W	black cherry	364.0248	3.5599	-0.2726	0.1	4.3286	-4.0922
AE	W	American elm	418.5942	3.1704	-0.1896	0.1	4.6008	-7.2732
SG	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918

Species Code	W or C	SN Variant Surrogate / source	Curtis-Arney Coefficients				Wykoff Coefficients	
			P_2	P_3	P_4	D_{bw}	Default B_1	B_2
HK	C	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
WE	W	winged elm	1001.6729	4.5731	-0.1890	0.1	4.5992	-7.7428
EL	W	elm species	1005.8067	4.6474	-0.2034	0.1	4.3744	-4.5257
SI	W	elm species	1005.8067	4.6474	-0.2034	0.1	4.3744	-4.5257
RL	W	slippery elm	1337.5472	4.4895	-0.1475	0.1	4.6238	-7.4847
RE	W	elm species	1005.8067	4.6474	-0.2034	0.1	4.3744	-4.5257
YP	C	yellow-poplar	625.7697	3.8732	-0.2335	0.2	4.6892	-4.9605
BW	W	basswood	293.5715	3.5226	-0.3512	0.1	4.5820	-5.0903
SM	W	sugar maple	209.8555	2.9528	-0.3679	0.2	4.4834	-4.5431
AS	W	ash species	251.4043	3.2692	-0.3591	0.2	4.4819	-4.5314
WA	W	white ash	91.3528	6.9961	-1.2294	0.2	4.5959	-6.4497
GA	W	green ash	404.9692	3.3902	-0.2551	0.2	4.6155	-6.2945
WO	W	white oak	170.1331	3.2782	-0.4874	0.2	4.5463	-5.2287
RO	W	northern red oak	700.0636	4.1061	-0.2139	0.2	4.5202	-4.8896
SK	W	southern red oak	150.4300	3.1327	-0.4993	0.1	4.5142	-5.2205
BO	W	black oak	224.7163	3.1165	-0.3598	0.2	4.4747	-4.8698
SO	W	scarlet oak	196.0565	3.0067	-0.3850	0.2	4.5225	-4.9401
BJ	W	blackjack oak	157.4829	3.3892	-0.3915	0.2	3.9191	-4.3503
CK	W	chinkapin oak	72.7907	3.6707	-1.0988	0.1	4.3420	-5.1193
SW	W	cherrybark oak	182.6306	3.1290	-0.4639	0.1	4.7342	-6.2674
BR	W	scarlet oak	196.0565	3.0067	-0.3850	0.2	4.5225	-4.9401
SN	W	swamp chestnut oak	281.3413	3.5170	-0.3336	0.2	4.6135	-5.7613
PO	W	post oak	765.2908	4.2238	-0.1897	0.1	4.2496	-4.8061
DO	W	post oak	765.2908	4.2238	-0.1897	0.1	4.2496	-4.8061
CO	W	chestnut oak	94.5447	3.4203	-0.8188	0.2	4.4618	-4.8786
PN	W	scarlet oak	196.0565	3.0067	-0.3850	0.2	4.5225	-4.9401
CB	W	cherrybark oak	182.6306	3.1290	-0.4639	0.1	4.7342	-6.2674
QI	W	chestnut oak	94.5447	3.4203	-0.8188	0.2	4.4618	-4.8786
OV	W	overcup oak	184.0856	3.4954	-0.4621	0.2	4.5710	-6.0922
WK	W	water oak	470.0617	3.7889	-0.2512	0.1	4.5577	-4.9595
NK	W	scarlet oak	196.0565	3.0067	-0.3850	0.2	4.5225	-4.9401
WL	W	cottonwood	190.9797	3.6928	-0.5273	0.1	4.9396	-8.1838
QS	W	Shumard oak	215.0009	3.1420	-0.3907	0.1	4.6106	-5.4380
SS	C	sassafras	755.1038	4.3950	-0.2178	0.1	4.3383	-4.5018
OB	W	basswood	293.5715	3.5226	-0.3512	0.1	4.5820	-5.0903
CA	W	catalpa	190.9797	3.6928	-0.5273	0.3	4.9396	-8.1838
PS	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435

Species Code	W or C	SN Variant Surrogate / source	Curtis-Arney Coefficients				Wykoff Coefficients	
			P_2	P_3	P_4	D_{bw}	Default B_1	B_2
HL	W	honeylocust	778.9357	4.2076	-0.1873	0.1	4.3734	-5.3135
BP	W	white ash	91.3528	6.9961	-1.2294	0.2	4.5959	-6.4497
BT	W	white ash	91.3528	6.9961	-1.2294	0.2	4.5959	-6.4497
QA	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
BK	C	black locust	880.2845	4.5964	-0.2182	0.1	4.4299	-4.9920
SY	W	sycamore	644.3568	3.9205	-0.2144	0.1	4.6355	-5.2776
BY	W	baldcypress	119.5749	4.1354	-0.7963	0.2	4.6171	-6.2684
RB	W	birch species	170.5253	2.6883	-0.4008	0.1	4.4388	-4.0872
SU	W	sweetgum	290.9055	3.6240	-0.3720	0.2	4.5920	-5.1719
WI	W	willow	408.2772	3.8181	-0.2721	0.1	4.4911	-5.7928
BL	W	willow	408.2772	3.8181	-0.2721	0.1	4.4911	-5.7928
OH	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
AH	C	eastern hophornbeam	109.7324	2.2503	-0.4130	0.2	4.0322	-3.0833
RD	W	eastern redbud	103.1768	2.2170	-0.3596	0.2	3.7512	-2.5539
DW	W	flowering dogwood	863.0501	4.3856	-0.1481	0.1	3.7301	-2.7758
HT	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
KC	W	American beech	526.1393	3.8923	-0.2259	0.1	4.4772	-4.7206
OO	W	eastern hophornbeam	109.7324	2.2503	-0.4130	0.2	4.0322	-3.0833
CT	C	cucumbertree	660.1997	3.9208	-0.2112	0.2	4.6067	-5.2030
MV	W	sweetbay	184.1932	2.8457	-0.3695	0.2	4.3609	-4.1423
MB	W	mulberry species	750.1823	4.1426	-0.1594	0.2	3.9613	-3.1993
HH	W	eastern hophornbeam	109.7324	2.2503	-0.4130	0.2	4.0322	-3.0833
SD	W	sourwood	690.4918	4.1598	-0.1861	0.2	4.1352	-3.7450

4.2 Bark Ratio Relationships

Bark ratio estimates are used to convert between diameter outside bark and diameter inside bark in various parts of the model. The equation is shown in equation {4.2.1} and the appropriate bark ratios by species group are given in table 4.2.1.

{4.2.1} *DIB = BRATIO * DOB*

where:

BRATIO is species-specific bark ratio
DIB is tree diameter inside bark at breast height
DOB is tree diameter outside bark at breast height

Table 4.2.1 Bark ratios by species groups for the CS variant.

Species Groups	Bark Ratio
4, 5, 11, 20, 21	.91
2, 3, 7, 8, 9, 14, 16, 17, 18, 19, 22, 23, 24, 25, 26, 27, 28, 29	.93
1, 6, 10, 12, 13, 15, 30	.95

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 CS variant, crown ratios missing in the input data, for both live and dead trees, are predicted using equation {4.3.1.1} by Holdaway (1986) with coefficients for this equation shown in table 4.3.1.1.

{4.3.1.1} $CR = 10 * (b_1 / (1 + b_2 * BA) + (b_3 * (1 – \exp(-b_4 * DBH))))$

where:

CR is crown ratio expressed as a percent
BA is total stand basal area
DBH is tree diameter at breast height
$b_1 – b_4$ are species-specific coefficients shown in table 4.3.1.1

Table 4.3.1.1 Coefficients of the crown ratio equation {4.3.1.1} in the CS variant.

Species Group	b_1	b_2	b_3	b_4
1	4.0862	0.0096	4.2295	-0.6554
2, 3, 4	3.8229	0.0155	3.6700	-0.0931
5	5.3258	0.0059	187.8644	-0.0003
6	3.5960	0.0241	3.3785	-0.5607
7, 8	4.0007	0.0132	3.2411	-1.0554
9	3.7332	0.0040	3.6321	-0.0412
10	4.7419	0.0748	3.3270	-0.8711
11	4.5860	0.0045	4.2754	-0.0194
12	4.7334	0.0051	1.5490	-0.1920
13	3.7332	0.0040	3.6321	-0.0412
14	4.2114	0.0006	2.4917	-0.0266
15,16	3.7332	0.0040	3.6321	-0.0412
17	4.5228	0.0049	2.3243	-0.2289
18	4.7419	0.0748	3.3270	-0.8711
19	4.6207	0.0042	2.6272	-0.1684

Species Group	b_1	b_2	b_3	b_4
20	4.6941	0.0057	2.0465	-0.2326
21	5.6002	0.0072	1.7133	-0.1663
22	4.1573	0.0105	2.6185	-0.4623
23	3.6371	0.0096	3.0584	-0.6048
24	4.1897	0.0090	3.3907	-0.1566
25	3.6936	0.0039	2.7332	-0.2339
26	5.8825	0.0082	332.9834	-0.0002
27	1.9729	0.0374	5.3150	-1.0758
28	3.7332	0.0040	3.6321	-0.0412
29	4.5860	0.0045	4.2754	-0.0194
30	4.3510	0.0015	110.6709	-0.0015

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 equation {4.3.1.1} by Holdaway (1986) and the coefficients shown in Table 4.3.1.1. Crown change is checked to make sure it doesn't exceed the change possible if all height growth produces new crown. Crown change is further bounded to 1% per year for the length of the cycle to avoid drastic changes in crown ratio.

4.3.3 Crown Ratio for Newly Established Trees

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

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

where:

CR is crown ratio expressed as a proportion (bounded to $0.2 \le CR \le 0.9$)
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 CS 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 to calculate percent canopy cover (*PCC*) and crown competition factor (*CCF*) within the model. When available, forest-grown maximum crown width equations are used to compute *PCC* and open-grown maximum crown width equations are used to compute *CCF*.

The CS variant computes tree crown width using equations {4.4.1} through {4.4.5}. Species equation assignment and coefficients are shown in tables 4.4.1 and 4.4.2 for forest- and open-grown equations, respectively. Equations are numbered via the FIA species code and equation number, i.e. the forest grown equation from Bechtold (2003) assigned to Eastern white pine has the number: 12901.

{4.4.1} Bechtold (2003); Equation 01

$DBH \geq 5.0$: $FCW = a_1 + (a_2 * DBH) + (a_3 * DBH^2) + (a_4 * CR) + (a_5 * HI)$

$DBH < 5.0$: $FCW = [a_1 + (a_2 * 5.0) + (a_3 * 5.0^2) + (a_4 * CR) + (a_5 * HI)] * (DBH / 5.0)$

{4.4.2} Bragg (2001); Equation 02

$DBH \geq 5.0$: $FCW = a_1 + (a_2 * DBH^{a_3})$

$DBH < 5.0$: $FCW = [a_1 + (a_2 * 5.0^{a_3})] * (DBH / 5.0)$

{4.4.3} Ek (1974); Equation 03

$DBH \geq 3.0$: $OCW = a_1 + (a_2 * DBH^{a_3})$

$DBH < 3.0$: $OCW = [a_1 + (a_2 * 3.0^{a_3})] * (DBH / 3.0)$

{4.4.4} Krajicek and others (1961); Equation 04

$DBH \geq 3.0$: $OCW = a_1 + (a_2 * DBH)$

$DBH < 3.0$: $OCW = [a_1 + (a_2 * 3.0)] * (DBH / 3.0)$

{4.4.5} Smith and others (1992); Equation 05

$DBH \geq 3.0$: $OCW = a_1 + (a_2 * DBH * 2.54) + (a_3 * (DBH * 2.54)^2) * 3.28084$

$DBH < 3.0$: $OCW = [a_1 + (a_2 * 3.0 * 2.54) + (a_3 * (3.0 * 2.54)^2) * 3.28084] * (DBH / 3.0)$

where:

FCW is crown width of forest grown trees (used in *PCC* calculations)
OCW is crown width of open-grown trees (used in *CCF* calculations))
DBH is tree diameter at breast height, if bounded
CR is crown ratio expressed as a percent
HI is the Hopkins Index
$HI = (ELEVATION - 887) / 100) * 1.0 + (LATITUDE - 39.54) * 4.0 + (-82.52 - LONGITUDE) * 1.25$
a_1 - a_5 are the coefficients shown in tables 4.4.1 and 4.4.2

Table 4.4.1. Crown width equation assignment and coefficients for forest-grown trees in the CS variant.

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
RC	06801	1.2359	1.2962		0.0545		FCW ≤ 33
JU	06801	1.2359	1.2962		0.0545		FCW ≤ 33
SP	11001	-2.2564	1.3004		0.1031	-0.0562	FCW ≤ 34
VP	13201	-0.1211	1.2319		0.1212		FCW ≤ 34

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
LP	13101	-0.8277	1.3946		0.0768		FCW $\leq$ 55
OS	06801	1.2359	1.2962		0.0545		FCW $\leq$ 33
WP	12901	0.3914	0.9923		0.1080		FCW $\leq$ 45
WN	60201	3.6031	1.1472		0.1224		FCW $\leq$ 37
BN	60201	3.6031	1.1472		0.1224		FCW $\leq$ 37
TL	69301	5.5037	1.0567		0.0880	0.0610	FCW $\leq$ 50
TS	69401	1.3564	1.0991		0.1243		FCW $\leq$ 41
WT	69101	5.3409	0.7499		0.1047		FCW $\leq$ 37
BG	69301	5.5037	1.0567		0.0880	0.0610	FCW $\leq$ 50
SH	40701	4.5453	1.3721		0.0430		FCW $\leq$ 54
SL	40701	4.5453	1.3721		0.0430		FCW $\leq$ 54
MH	40901	1.5838	1.6318		0.0721		FCW $\leq$ 55
PH	40301	3.9234	1.5220		0.0405		FCW $\leq$ 53
HI	40701	4.5453	1.3721		0.0430		FCW $\leq$ 54
WH	40201	8.0118	1.4212				FCW $\leq$ 41
BH	40201	8.0118	1.4212				FCW $\leq$ 41
PE	40201	8.0118	1.4212				FCW $\leq$ 41
BI	40801	-5.8749	4.1555	-0.1343			DBH $\leq$ 15
AB	53101	3.9361	1.1500		0.1237	-0.0691	FCW $\leq$ 80
BA	54301	5.2824	1.1184				FCW $\leq$ 34
PA	54101	1.7625	1.3413		0.0957		FCW $\leq$ 62
UA	54101	1.7625	1.3413		0.0957		FCW $\leq$ 62
EC	74201	3.4375	1.4092				FCW $\leq$ 80
RM	31601	2.7563	1.4212	-0.0143	0.0993	-0.0276	DBH $\leq$ 50
BE	31301	6.4741	1.0778		0.0719	-0.0637	FCW $\leq$ 57
SV	31701	3.3576	1.1312		0.1011	-0.1730	FCW $\leq$ 45
BC	76201	3.0237	1.1119		0.1112	-0.0493	FCW $\leq$ 52
AE	97201	1.7296	2.0732		0.0590	-0.0869	FCW $\leq$ 50
SG	46201	7.1043	1.3041		0.0456		FCW $\leq$ 51
HK	46201	7.1043	1.3041		0.0456		FCW $\leq$ 51
WE	97101	4.3649	1.6612		0.0643		FCW $\leq$ 40
EL	97201	1.7296	2.0732		0.0590	-0.0869	FCW $\leq$ 50
SI	97201	1.7296	2.0732		0.0590	-0.0869	FCW $\leq$ 50
RL	97501	9.0023	1.3933			-0.0785	FCW $\leq$ 49
RE	97201	1.7296	2.0732		0.0590	-0.0869	FCW $\leq$ 50
YP	62101	3.3543	1.1627		0.0857		FCW $\leq$ 61
BW	95101	1.6871	1.2110		0.1194	-0.0264	FCW $\leq$ 61
SM	31801	4.9399	1.0727		0.1096	-0.0493	FCW $\leq$ 54
AS	54401	2.9672	1.3066		0.0585		FCW $\leq$ 61
WA	54101	1.7625	1.3413		0.0957		FCW $\leq$ 62

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
GA	54401	2.9672	1.3066		0.0585		FCW ≤ 61
WO	80201	3.2375	1.5234		0.0455	-0.0324	FCW ≤ 69
RO	83301	2.8908	1.4077		0.0643		FCW ≤ 82
SK	81201	2.1517	1.6064		0.0609		FCW ≤ 56
BO	83701	2.8974	1.3697		0.0671		FCW ≤ 52
SO	80601	0.5656	1.6766		0.0739		FCW ≤ 66
BJ	82401	0.5443	1.4882		0.0565		FCW ≤ 37
CK	82601	0.5189	1.4134		0.1365	-0.0806	FCW ≤ 45
SW	80201	3.2375	1.5234		0.0455	-0.0324	FCW ≤ 69
BR	82301	1.7827	1.6549		0.0343		FCW ≤ 61
SN	83201	2.1480	1.6928	-0.0176	0.0569		DBH ≤ 50
PO	83501	1.6125	1.6669		0.0536		FCW ≤ 45
DO	83501	1.6125	1.6669		0.0536		FCW ≤ 45
CO	83201	2.1480	1.6928	-0.0176	0.0569		DBH ≤ 50
PN	83001	-5.6268	1.7808		0.1231	0.1578	FCW ≤ 63
CB	81201	2.1517	1.6064		0.0609		FCW ≤ 56
QI	81701	9.8187	1.1343				FCW ≤ 54
OV	82301	1.7827	1.6549		0.0343		FCW ≤ 61
WK	82701	1.6349	1.5443		0.0637	-0.0764	FCW ≤ 57
NK	81201	2.1517	1.6064		0.0609		FCW ≤ 56
WL	83101	1.6477	1.3672		0.0846		FCW ≤ 74
QS	81201	2.1517	1.6064		0.0609		FCW ≤ 56
SS	93101	4.6311	1.0108		0.0564		FCW ≤ 29
OB	40701	4.5453	1.3721		0.0430		FCW ≤ 54
CA	93101	4.6311	1.0108		0.0564		FCW ≤ 29
PS	52101	3.5393	1.3939		0.0625		FCW ≤ 36
HL	55201	4.1971	1.5567		0.0880		FCW ≤ 46
BP	74101	6.2498	0.8655				FCW ≤ 25
BT	74301	0.6847	1.1050		0.1420	-0.0265	FCW ≤ 43
QA	74601	0.7315	1.3180		0.0966		FCW ≤ 39
BK	90101	3.0012	0.8165		0.1395		FCW ≤ 48
SY	73101	-1.3973	1.3756		0.1835		FCW ≤ 66
BY	22101	-1.0183	0.8856		0.1162		FCW ≤ 37
RB	37301	11.6634	1.0028				FCW ≤ 68
SU	61101	1.8853	1.1625		0.0656	-0.0300	FCW ≤ 50
WI	97201	1.7296	2.0732		0.0590	-0.0869	FCW ≤ 50
BL	97201	1.7296	2.0732		0.0590	-0.0869	FCW ≤ 50
OH	49101	2.9646	1.9917		0.0707		FCW ≤ 36
AH	39101	0.9219	1.6303		0.1150	-0.1113	FCW ≤ 42
RD	49101	2.9646	1.9917		0.0707		FCW ≤ 36

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
DW	49101	2.9646	1.9917		0.0707		FCW ≤ 36
HT	49101	2.9646	1.9917		0.0707		FCW ≤ 36
KC	90101	3.0012	0.8165		0.1395		FCW ≤ 48
OO	93101	4.6311	1.0108		0.0564		FCW ≤ 29
CT	65101	4.1711	1.6275				FCW ≤ 39
MV	65301	8.2119	0.9708				FCW ≤ 41
MB	68201	13.3255	1.0735				FCW ≤ 46
HH	70101	7.8084	0.8129		0.0941	-0.0817	FCW ≤ 39
SD	71101	7.9750	0.8303		0.0423	-0.0706	FCW ≤ 36

[1] Equation number is a combination of the species FIA code (###) and source (##), see equations on previous page. Maximum crown widths and DBH have been assigned to prevent poor behavior beyond the source data.

Table 4.4.2. Crown width equation assignment and coefficients for open-grown trees for the CS variant.

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
RC	06801	1.2359	1.2962		0.0545		FCW ≤ 33
JU	06801	1.2359	1.2962		0.0545		FCW ≤ 33
SP	11005	0.5830	0.2450	0.0009			FCW ≤ 45
VP	13201	-0.1211	1.2319		0.1212		FCW ≤ 34
LP	13105	0.7380	0.2450	0.000809			FCW ≤ 66
OS	06801	1.2359	1.2962		0.0545		FCW ≤ 33
WP	12903	1.6200	3.1970	0.7981			FCW ≤ 58
WN	60201	3.6031	1.1472		0.1224		FCW ≤ 37
BN	60201	3.6031	1.1472		0.1224		FCW ≤ 37
TL	69301	5.5037	1.0567		0.0880	0.0610	FCW ≤ 50
TS	69401	1.3564	1.0991		0.1243		FCW ≤ 41
WT	69101	5.3409	0.7499		0.1047		FCW ≤ 37
BG	69301	5.5037	1.0567		0.0880	0.0610	FCW ≤ 50
SH	40703	2.3600	3.5480	0.7986			FCW ≤ 54
SL	40703	2.3600	3.5480	0.7986			FCW ≤ 54
MH	40901	1.5838	1.6318		0.0721		FCW ≤ 55
PH	40301	3.9234	1.5220		0.0405		FCW ≤ 53
HI	40703	2.3600	3.5480	0.7986			FCW ≤ 54
WH	40201	8.0118	1.4212				FCW ≤ 41
BH	40201	8.0118	1.4212				FCW ≤ 41
PE	40201	8.0118	1.4212				FCW ≤ 41
BI	40801	-5.8749	4.1555	-0.1343			DBH ≤ 15
AB	53101	3.9361	1.1500		0.1237	-0.0691	FCW ≤ 80
BA	54301	5.2824	1.1184				FCW ≤ 34

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
PA	54101	1.7625	1.3413		0.0957		FCW ≤ 62
UA	54101	1.7625	1.3413		0.0957		FCW ≤ 62
EC	74203	2.9340	2.5380	0.8617			FCW ≤ 80
RM	31603	0.00	4.7760	0.7656			FCW ≤ 55
BE	31301	6.4741	1.0778		0.0719	-0.0637	FCW ≤ 57
SV	31701	3.3576	1.1312		0.1011	-0.1730	FCW ≤ 45
BC	76203	0.6210	7.0590	0.5441			FCW ≤ 52
AE	97203	2.8290	3.4560	0.8575			FCW ≤ 72
SG	46201	7.1043	1.3041		0.0456		FCW ≤ 51
HK	46201	7.1043	1.3041		0.0456		FCW ≤ 51
WE	97101	4.3649	1.6612		0.0643		FCW ≤ 40
EL	97203	2.8290	3.4560	0.8575			FCW ≤ 72
SI	97203	2.8290	3.4560	0.8575			FCW ≤ 72
RL	97501	9.0023	1.3933			-0.0785	FCW ≤ 49
RE	97203	2.8290	3.4560	0.8575			FCW ≤ 72
YP	62101	3.3543	1.1627		0.0857		FCW ≤ 61
BW	95101	1.6871	1.2110		0.1194	-0.0264	FCW ≤ 61
SM	31803	0.8680	4.1500	0.7514			FCW ≤ 54
AS	54403	0.0000	4.7550	0.7381			FCW ≤ 61
WA	54101	1.7625	1.3413		0.0957		FCW ≤ 62
GA	54403	0.0000	4.7550	0.7381			FCW ≤ 61
WO	80204	1.8000	1.8830				FCW ≤ 69
RO	83303	2.8500	3.7820	0.7968			FCW ≤ 82
SK	81201	2.1517	1.6064		0.0609		FCW ≤ 56
BO	83704	4.5100	1.6700				FCW ≤ 52
SO	80601	0.5656	1.6766		0.0739		FCW ≤ 66
BJ	82401	0.5443	1.4882		0.0565		FCW ≤ 37
CK	82601	0.5189	1.4134		0.1365	-0.0806	FCW ≤ 45
SW	80204	1.8000	1.8830				FCW ≤ 69
BR	82303	0.9420	3.5390	0.7952			FCW ≤ 78
SN	83201	2.1480	1.6928	-0.0176	0.0569		DBH ≤ 50
PO	83501	1.6125	1.6669		0.0536		FCW ≤ 45
DO	83501	1.6125	1.6669		0.0536		FCW ≤ 45
CO	83201	2.1480	1.6928	-0.0176	0.0569		DBH ≤ 50
PN	83001	-5.6268	1.7808		0.1231	0.1578	FCW ≤ 63
CB	81201	2.1517	1.6064		0.0609		FCW ≤ 56
QI	81701	9.8187	1.1343				FCW ≤ 54
OV	82303	0.9420	3.5390	0.7952			FCW ≤ 78
WK	82701	1.6349	1.5443		0.0637	-0.0764	FCW ≤ 57
NK	81201	2.1517	1.6064		0.0609		FCW ≤ 56

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
WL	83101	1.6477	1.3672		0.0846		FCW ≤ 74
QS	81201	2.1517	1.6064		0.0609		FCW ≤ 56
SS	93101	4.6311	1.0108		0.0564		FCW ≤ 29
OB	40703	2.3600	3.5480	0.7986			FCW ≤ 54
CA	93101	4.6311	1.0108		0.0564		FCW ≤ 29
PS	52101	3.5393	1.3939		0.0625		FCW ≤ 36
HL	55201	4.1971	1.5567		0.0880		FCW ≤ 46
BP	74101	6.2498	0.8655				FCW ≤ 25
BT	74301	0.6847	1.1050		0.1420	-0.0265	FCW ≤ 43
QA	74603	4.2030	2.1290	1.0000			FCW ≤ 43
BK	90101	3.0012	0.8165		0.1395		FCW ≤ 48
SY	73101	-1.3973	1.3756		0.1835		FCW ≤ 66
BY	22101	-1.0183	0.8856		0.1162		FCW ≤ 37
RB	37301	11.6634	1.0028				FCW ≤ 68
SU	61101	1.8853	1.1625		0.0656	-0.0300	FCW ≤ 50
WI	97203	2.8290	3.4560	0.8575			FCW ≤ 72
BL	97203	2.8290	3.4560	0.8575			FCW ≤ 72
OH	49101	2.9646	1.9917		0.0707		FCW ≤ 36
AH	39101	0.9219	1.6303		0.1150	-0.1113	FCW ≤ 42
RD	49101	2.9646	1.9917		0.0707		FCW ≤ 36
DW	49101	2.9646	1.9917		0.0707		FCW ≤ 36
HT	49101	2.9646	1.9917		0.0707		FCW ≤ 36
KC	90101	3.0012	0.8165		0.1395		FCW ≤ 48
OO	93101	4.6311	1.0108		0.0564		FCW ≤ 29
CT	65101	4.1711	1.6275				FCW ≤ 39
MV	65301	8.2119	0.9708				FCW ≤ 41
MB	68201	13.3255	1.0735				FCW ≤ 46
HH	70101	7.8084	0.8129		0.0941	-0.0817	FCW ≤ 39
SD	71101	7.9750	0.8303		0.0423	-0.0706	FCW ≤ 36

[1] Equation number is a combination of the species FIA code (###) and source (##), see equations on previous page. Maximum crown widths and DBH have been assigned to prevent poor behavior beyond the source data.

4.5 Crown Competition Factor

The CS 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. In the CS variant, crown competition factor for an individual tree is calculated using equation {4.5.1}, and is based on crown width of open-grown trees.

{4.5.1} All species

DBH > 0.1": $CCF_t = 0.001803 * OCW_t$^2

$DBH \leq$ 0.1": $CCF_t = 0.001$

where:

CCF_t	is crown competition factor for an individual tree
OCW_t	is open-grown crown width for an individual tree
DBH	is tree diameter at breast height

4.6 Small Tree Growth Relationships

Trees are considered "small trees" for FVS modeling purposes when they are smaller than some threshold diameter. This threshold diameter is set to 5.0" for all species in the CS variant.

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.

FVS blends small tree growth estimates with large tree growth estimates to assure a smooth transition between the two models. In the CS variant both height growth and diameter growth estimates use this blending technique. Small and large tree estimates are weighted over the diameter range 1.5"-5.0" *DBH* for all species. The weight is calculated using equation {4.6.1} and applied as shown in equation {4.6.2}.

{4.6.1}

$DBH \leq$ 1.5": $XWT = 0$
1.5" < DBH < 5.0": $XWT = (DBH – 1.5) / (5.0 – 1.5)$
$DBH \geq$ 5.0": $XWT = 1$

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

where:

XWT	is the weight applied to the growth estimates
DBH	is tree diameter at breast height
STGE	is the growth estimate obtained using the small-tree growth model

LTGE is the growth estimate obtained using the large-tree growth model

For example, the closer a tree's *DBH* value is to the minimum diameter of 1.5", the more the growth estimate will be weighted towards the small-tree growth model estimate. The closer a tree's *DBH* value is to the maximum diameter of 5.0", the more the growth estimate will be weighted towards the large-tree growth model estimate. If a tree's *DBH* value falls outside of the range 1.5" – 5.0", then only the small-tree or large-tree growth model estimate is used.

4.6.1 Small Tree Height Growth

Small tree height growth is estimated by calculating a potential height growth and modifying the estimate based on intra-stand competition. The estimate is then adjusted by cycle length, scaling factors computed by FVS based on the input small-tree height increment data, and any growth multipliers entered by the user. Potential height growth and the modifier value are estimated using the same equations described in section 4.7.2 to calculate large tree height growth. However, the scaling factor, 0.8, shown in equation {4.7.2.3} is not applied when estimating small tree height growth. Small tree height growth estimates are weighted with large tree height growth estimates as described above.

4.6.2 Small Tree Diameter Growth

Small tree diameter increment is estimated using the height-diameter relationships discussed in section 4.1. The functions are algebraically solved to estimate diameter as a function of height. Height at the start of the projection cycle is known. Height at the end of the projection cycle is obtained by adding the height growth (section 4.6.1) to the starting height. Diameter is predicted at the start of the projection cycle based on the height at the start of the projection cycle; diameter at the end of the projection cycle is estimated from the height at the end of the projection cycle. Small tree diameter growth is calculated as the difference between the predicted diameter at the start of the projection cycle and predicted diameter at the end of the projection cycle, and adjusted for bark ratio. Small tree diameter growth estimates are weighted with large tree diameter growth estimates as described above.

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 5.0" for all species in the CS 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 CS variant uses a large-tree diameter increment model based on Deo and Froese (2013) identified in equation {4.7.1.1}.

{4.7.1.1} $\ln(DDS) = b_1 + (b_2 * (1/DBH)) + (b_3 * DBH) + (b_4 * DBH^2) (b_5 * (DBH/QMD5)) + (b_6 * DBH^2/QMD5) + (b_7 * BA5) + (b_8 * BAL5) + (b_9 * CR) + (b_{10} * CR^2) + (b_{11} * SI)$

where:

DDS	is the predicted 10-year periodic change in squared **outside**-bark diameter. *DDS* is converted to a squared **inside**-bark diameter before predicting diameter growth.
DBH	is tree diameter at breast height
QMD5	is quadratic mean diameter of trees 5 in. or greater in DBH
CR	is crown ratio expressed as a percent
SI	is site index of the species
BA5	is the basal area per acre in trees over 5 in. DBH
BAL5	is the basal area in trees larger than subject tree that are 5 in. or greater in DBH
b_1- b_{11}	are species-specific coefficients shown in tables 4.7.1.1 and 4.7.1.2

Some stand and tree values are bound based on the species:

for BO:	if QMD5>12, then QMD5=12
for SP, TL, TS, WT, BG:	if QMD5>13, then QMD5=13
for SH. SL. MH, EC, CK, SW, BR, SN:	if QMD5>25, then QMD5=25
for AB:	if QMD5>40, then QMD5=40
for SO:	if QMD5>11, then QMD5=11
for AS, WA, GA, CO:	if QMD5>20, then QMD5=20
for RO, SK:	if QMD5>30, then QMD5=30
for OO:	if QMD5>17, then QMD5=17
for WP, OS:	if CR>50, then CR=50
for WN, BN, TL:	if CR>75, then CR=75
for EC, YP:	if CR>60, then CR=60
for AS, WA, GA:	if CR>80, then CR=80
for BC, SY, BY, RB, SU, WI, BL:	if CR>85, then CR=85

Table 4.7.1.1 Coefficients (b_1 – b_6) for the 10-year diameter growth equation in the CS variant.

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
RC	3.09820	-8.58440				
JU	3.09820	-8.58440				
SP	0.64882			0.01234	2.87386	-0.20916

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
VP	2.76330	-10.45000				
LP	2.76330	-10.45000				
OS	-0.70797		0.07533		2.12877	-0.05909
WP	-0.70797		0.07533		2.12877	-0.05909
WN	2.95910	-9.51990				
BN	2.95910	-9.51990				
TL	-0.28233			0.01581	3.37463	-0.26631
TS	-0.28233			0.01581	3.37463	-0.26631
WT	-0.28233			0.01581	3.37463	-0.26631
BG	-0.28233			0.01581	3.37463	-0.26631
SH	1.08270	-5.46950	0.12337		0.40029	-0.03136
SL	1.08270	-5.46950	0.12337		0.40029	-0.03136
MH	1.08270	-5.46950	0.12337		0.40029	-0.03136
PH	-0.64747		0.26917	-0.00342	0.48856	-0.03745
HI	-0.64747		0.26917	-0.00342	0.48856	-0.03745
WH	-0.64747		0.26917	-0.00342	0.48856	-0.03745
BH	-0.64747		0.26917	-0.00342	0.48856	-0.03745
PE	-0.64747		0.26917	-0.00342	0.48856	-0.03745
BI	-0.64747		0.26917	-0.00342	0.48856	-0.03745
AB	-0.07129		0.14458		1.85880	-0.08029
BA	0.89302	-14.16700				
PA	0.89302	-14.16700				
UA	0.89302	-14.16700				
EC	1.81510		0.09153		1.02090	-0.03235
RM	2.23020	-6.99620	0.11324	-0.00186		
BE	2.23020	-6.99620	0.11324	-0.00186		
SV	2.23020	-6.99620	0.11324	-0.00186		
BC	3.23650	-10.26800				
AE	1.23520	-5.21440	0.18300	-0.00314		
SG	1.23520	-5.21440	0.18300	-0.00314		
HK	1.23520	-5.21440	0.18300	-0.00314		
WE	1.23520	-5.21440	0.18300	-0.00314		
EL	1.23520	-5.21440	0.18300	-0.00314		

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
SI	1.23520	-5.21440	0.18300	-0.00314		
RL	1.23520	-5.21440	0.18300	-0.00314		
RE	1.23520	-5.21440	0.18300	-0.00314		
YP	3.42640	-7.86590	0.05771			-0.02000
BW	3.71790	-8.96970				
SM	2.97130	-10.11500				
AS	-0.29734		0.20494		1.03840	-0.08002
WA	-0.29734		0.20494		1.03840	-0.08002
GA	-0.29734		0.20494		1.03840	-0.08002
WO	1.09010	-3.68390	0.11623		0.70038	-0.04289
RO	0.02098		0.14061		1.21010	-0.05494
SK	0.02098		0.14061		1.21010	-0.05494
BO	1.89700	-5.72030		0.00346	0.93903	-0.05092
SO	2.03520	-5.28840		0.00513	1.16850	-0.07164
BJ	3.86780	-11.27600				
CK	0.93769	-5.11930	0.09743		0.47749	-0.02443
SW	0.93769	-5.11930	0.09743		0.47749	-0.02443
BR	0.93769	-5.11930	0.09743		0.47749	-0.02443
SN	0.93769	-5.11930	0.09743		0.47749	-0.02443
PO	1.36920	-5.03520	0.12165			-0.03038
DO	1.36920	-5.03520	0.12165			-0.03038
CO	-1.73610		0.26087		1.76660	-0.11006
PN	3.98500	-13.51900				
CB	3.98500	-13.51900				
QI	3.98500	-13.51900				
OV	0.93769	-5.11930	0.09743		0.47749	-0.02443
WK	3.98500	-13.51900				
NK	3.98500	-13.51900				
WL	3.98500	-13.51900				
QS	3.98500	-13.51900				

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
SS	3.38410	-10.28200				
OB	3.02200	-13.62700				
CA	3.02200	-13.62700				
PS	3.02200	-13.62700				
HL	3.21620	-8.59700				
BP	3.02200	-13.62700				
BT	3.02200	-13.62700				
QA	3.02200	-13.62700				
BK	3.02200	-13.62700				
SY	3.86690	-8.87037				
BY	3.86690	-8.87037				
RB	3.86690	-8.87037				
SU	3.86690	-8.87037				
WI	3.86690	-8.87037				
BL	3.86690	-8.87037				
OH	3.03080	-8.10590				
AH	3.03080	-8.10590				
RD	3.03080	-8.10590				
DW	3.03080	-8.10590				
HT	3.03080	-8.10590				
KC	2.95910	-9.51990				
OO	-0.18599		0.20178		0.54649	-0.04667
CT	3.03080	-8.10590				
MV	3.03080	-8.10590				
MB	3.03080	-8.10590				
HH	3.03080	-8.10590				
SD	3.03080	-8.10590				

Table 4.7.1.2 Coefficients (b_7 – b_{11}) for the 10-year diameter growth equation in the CS variant.

Species Code	b_7	b_8	b_9	b_{10}	b_{11}
RC	-0.00386		0.01628		
JU	-0.00386		0.01628		
SP	-0.00162	-0.00318	0.02252		
VP	-0.00324		0.05754	-0.00041	
LP	-0.00324		0.05754	-0.00041	
OS			0.06590	-0.00046	
WP			0.06590	-0.00046	
WN		-0.00169	0.03012		0.00356
BN		-0.00169	0.03012		0.00356
TL			0.01650		
TS			0.01650		
WT			0.01650		
BG			0.01650		
SH	-0.00160		0.02491	-0.00017	0.00543
SL	-0.00160		0.02491	-0.00017	0.00543
MH	-0.00160		0.02491	-0.00017	0.00543
PH	-0.00230		0.02673	-0.00021	0.00744
HI	-0.00230		0.02673	-0.00021	0.00744
WH	-0.00230		0.02673	-0.00021	0.00744
BH	-0.00230		0.02673	-0.00021	0.00744
PE	-0.00230		0.02673	-0.00021	0.00744
BI	-0.00230		0.02673	-0.00021	0.00744
AB			0.01373		
BA			0.15110	-0.00141	
PA			0.15110	-0.00141	
UA			0.15110	-0.00141	
EC		-0.00428		0.00031	
RM		-0.00171	0.03114	-0.00014	
BE		-0.00171	0.03114	-0.00014	
SV		-0.00171	0.03114	-0.00014	
BC		-0.00150	0.02457		0.00235
AE	-0.00439	0.00331	0.02814	-0.00011	0.00447
SG	-0.00439	0.00331	0.02814	-0.00011	0.00447
HK	-0.00439	0.00331	0.02814	-0.00011	0.00447
WE	-0.00439	0.00331	0.02814	-0.00011	0.00447
EL	-0.00439	0.00331	0.02814	-0.00011	0.00447

Species Code	b_7	b_8	b_9	b_{10}	b_{11}
SI	-0.00439	0.00331	0.02814	-0.00011	0.00447
RL	-0.00439	0.00331	0.02814	-0.00011	0.00447
RE	-0.00439	0.00331	0.02814	-0.00011	0.00447
YP		-0.00521	0.04625	-0.00023	-0.00431
BW		-0.00278	0.01517		
SM		-0.00303	0.02898	-0.00013	0.00383
AS		-0.00195	0.02569		0.00424
WA		-0.00195	0.02569		0.00424
GA		-0.00195	0.02569		0.00424
WO		-0.00302	0.02757	-0.00021	0.00351
RO			0.01366		0.00955
SK			0.01366		0.00955
BO	-0.00176		0.03088	-0.00016	0.00540
SO		-0.00139	0.03739	-0.00031	
BJ	-0.00537		0.00904		
CK		-0.00092	0.01140		0.01240
SW		-0.00092	0.01140		0.01240
BR		-0.00092	0.01140		0.01240
SN		-0.00092	0.01140		0.01240
PO		-0.00351	0.01313		0.00915
DO		-0.00351	0.01313		0.00915
CO			0.01933		0.00774
PN		-0.00233	0.03135	-0.00019	
CB		-0.00233	0.03135	-0.00019	
QI		-0.00233	0.03135	-0.00019	
OV		-0.00092	0.01140		0.01240
WK		-0.00233	0.03135	-0.00019	
NK		-0.00233	0.03135	-0.00019	
WL		-0.00233	0.03135	-0.00019	
QS		-0.00233	0.03135	-0.00019	
SS		-0.00170	0.03201	-0.00026	
OB	-0.00288		0.04569	-0.00037	0.00766
CA	-0.00288		0.04569	-0.00037	0.00766
PS	-0.00288		0.04569	-0.00037	0.00766
HL		-0.00261	0.01869		0.00599
BP	-0.00288		0.04569	-0.00037	0.00766
BT	-0.00288		0.04569	-0.00037	0.00766
QA	-0.00288		0.04569	-0.00037	0.00766
BK	-0.00288		0.04569	-0.00037	0.00766

Species Code	b_7	b_8	b_9	b_{10}	b_{11}
SY		-0.00535	0.02034		
BY		-0.00535	0.02034		
RB		-0.00535	0.02034		
SU		-0.00535	0.02034		
WI		-0.00535	0.02034		
BL		-0.00535	0.02034		
OH	-0.00179		0.00489		
AH	-0.00179		0.00489		
RD	-0.00179		0.00489		
DW	-0.00179		0.00489		
HT	-0.00179		0.00489		
KC		-0.00169	0.03012		0.00356
OO	-0.00704	0.00554	0.04276	-0.00024	
CT	-0.00179		0.00489		
MV	-0.00179		0.00489		
MB	-0.00179		0.00489		
HH	-0.00179		0.00489		
SD	-0.00179		0.00489		

4.7.2 Large Tree Height Growth

The large-tree height growth model also uses the modeling technique of estimating a potential height growth and modifying this potential growth based on tree competition. Potential height growth is estimated using site index curves from Carmean et al (1989). Surrogate curves, based on general growth form for the species, were chosen for species for which curves were not given in Carmean et al. The general form of the equation to estimate height given tree age and site index is shown in equation {4.7.2.1}. Algebraic manipulation to estimate tree age from height and site index yields the equation shown in {4.7.2.2}. Coefficients by species and which of the Carmean et al equations are used for which species are shown in table 4.7.2.1.

{4.7.2.1} $HT = b_6 + b_1 * SI\text{^}b_2 * (1 – \exp(b_3 * A))\text{ ^ }(b_4 * SI\text{^}b_5)$

{4.7.2.2} $A = 1./b_3*(\ln(1-((HT-b_6)/b_1/SI\text{^}b_2)\text{^}(1./b_4/SI\text{^}b_5)))$

where:

HT is tree height
SI is species site index
A is tree age
$b_1 – b_6$ are coefficients shown in table 4.7.2.1
b_6 = 0 for total age curves; b_6 = 4.5 for breast-height age curves

First, tree age is estimated using site index and the height of the tree at the beginning of the cycle. Next, age is incremented by 10 years and a new height is estimated using the updated age and site index. The difference between the new estimated height and the tree height at the beginning of the cycle is potential height growth. A small random component is applied to insure some distribution in estimated heights.

Potential height growth gets modified by a combination of two factors. One factor is the same modifier, CM, calculated using equation {4.7.1.2} and applied to large-tree diameter growth. The other is a function of individual tree height relative to the average height of the 40-largest diameter trees in the stand. The potential height growth modifier is shown in equation {4.7.2.3}, and the resulting height growth estimate is shown in equation {4.7.2.4}. Estimated height growth is then adjusted for cycle length and user-supplied growth multipliers.

{4.7.2.3} $PHMOD = [1 – ((1 – CM) * (1 – RELHT))] * 0.8$

{4.7.2.4} $HTG_i = PHTG * PHMOD$

where:

HTG_i	is estimated height growth of an individual tree
PHTG	is potential height growth estimated as described above
PHMOD	is potential height growth modifier
CM	is growth modifier as described in section 4.7.1
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand

Table 4.7.2.1. Coefficients for site index curves used in the CS variant.

Species Code	Carmean et al Figure	Site Index Curve Coefficients					
		b_1	b_2	b_3	b_4	b_5	b_6
RC	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
JU	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
SP	78	1.4232	0.9989	-0.0285	1.2156	0.0088	0.0
VP	125	0.7716	1.1087	-0.0348	0.1099	0.5274	0.0
LP	110	1.1421	1.0042	-0.0374	0.7632	0.0358	0.0
OS	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
WP	104	3.2425	0.7980	-0.0435	52.0549	-0.7064	0.0
WN	16	1.2898	0.9982	-0.0289	0.8546	0.0171	0.0
BN	16	1.2898	0.9982	-0.0289	0.8546	0.0171	0.0
TL	27	1.3213	0.9995	-0.0254	0.8549	-0.0016	0.0
TS	27	1.3213	0.9995	-0.0254	0.8549	-0.0016	0.0
WT	26	1.2721	0.9995	-0.0256	0.7447	-0.0019	0.0
BG	27	1.3213	0.9995	-0.0254	0.8549	-0.0016	0.0
SH	10	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.0
SL	10	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.0
MH	10	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.0
PH	10	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.0

Species Code	Carmean et al Figure	Site Index Curve Coefficients					
		b_1	b_2	b_3	b_4	b_5	b_6
HI	10	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.0
WH	10	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.0
BH	10	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.0
PE	19	1.5932	1.0124	-0.0122	0.6245	0.0130	0.0
BI	10	1.8326	1.0015	-0.0207	1.4080	-0.0005	0.0
AB	11	29.7300	0.3631	-0.0127	16.7616	-0.6804	0.0
BA	14	4.2286	0.7857	-0.0178	4.6219	-0.3591	0.0
PA	15	1.6505	0.9096	-0.0644	125.7045	-0.8908	0.0
UA	12	1.5768	0.9978	-0.0156	0.6705	0.0182	0.0
EC	28	1.3615	0.9813	-0.0675	1.5494	-0.0767	0.0
RM	1	2.9435	0.9132	-0.0141	1.6580	-0.1095	0.0
BE	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
SV	4	1.0645	0.9918	-0.0812	1.5754	-0.0272	0.0
BC	35	7.1846	0.6781	-0.0222	13.9186	-0.5268	0.0
AE	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.0
SG	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.0
HK	19	1.5932	1.0124	-0.0122	0.6245	0.0130	0.0
WE	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.0
EL	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.0
SI	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.0
RL	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.0
RE	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.0
YP	25	1.2941	0.9892	-0.0315	1.0481	-0.0368	0.0
BW	51	4.7633	0.7576	-0.0194	6.5110	-0.4156	0.0
SM	2	3.3721	0.8407	-0.0150	2.6208	-0.2661	0.0
AS	12	1.5768	0.9978	-0.0156	0.6705	0.0182	0.0
WA	12	1.5768	0.9978	-0.0156	0.6705	0.0182	0.0
GA	15	1.6505	0.9096	-0.0644	125.7045	-0.8908	0.0
WO	41	4.5598	0.8136	-0.0132	2.2410	-0.1880	0.0
RO	38	0.4737	1.2905	-0.0236	0.0979	0.6121	0.0
SK	37	1.2866	0.9962	-0.0355	1.4485	-0.0316	0.0
BO	49	2.9989	0.8435	-0.0200	3.4635	-0.3020	0.0
SO	42	1.6763	0.9837	-0.0220	0.9949	0.0240	0.0
BJ	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
CK	36	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.0
SW	44	1.3466	0.9590	-0.0574	8.9538	-0.3454	0.0
BR	36	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.0
SN	44	1.3466	0.9590	-0.0574	8.9538	-0.3454	0.0
PO	36	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.0
DO	36	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.0

Species Code	Carmean et al Figure	Site Index Curve Coefficients					
		b_1	b_2	b_3	b_4	b_5	b_6
CO	46	1.9044	0.9752	-0.0162	0.9262	0.0	0.0
PN	36	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.0
CB	43	1.0945	0.9938	-0.0755	2.5601	0.0114	0.0
QI	36	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.0
OV	45	1.3295	0.9565	-0.0668	16.0085	-0.4157	0.0
WK	44	1.3466	0.9590	-0.0574	8.9538	-0.3454	0.0
NK	36	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.0
WL	36	2.1037	0.9140	-0.0275	3.7962	-0.2530	0.0
QS	43	1.0945	0.9938	-0.0755	2.5601	0.0114	0.0
SS	50	0.9680	1.0301	-0.0468	0.1639	0.4127	0.0
OB	1	2.9435	0.9132	-0.0141	1.6580	-0.1095	0.0
CA	14	4.2286	0.7857	-0.0178	4.6219	-0.3591	0.0
PS	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
HL	50	0.9680	1.0301	-0.0468	0.1639	0.4127	0.0
BP	25	1.2941	0.9892	-0.0315	1.0481	-0.0368	0.0
BT	32	5.2188	0.6855	-0.0301	50.0071	-0.8695	0.0
QA	32	5.2188	0.6855	-0.0301	50.0071	-0.8695	0.0
BK	50	0.9680	1.0301	-0.0468	0.1639	0.4127	0.0
SY	25	1.2941	0.9892	-0.0315	1.0481	-0.0368	0.0
BY	21	1.0902	1.0298	-0.0354	0.7011	0.1178	0.0
RB	5	2.2835	0.9794	-0.0054	0.5819	-0.0281	0.0
SU	19	1.5932	1.0124	-0.0122	0.6245	0.0130	0.0
WI	50	0.9680	1.0301	-0.0468	0.1639	0.4127	0.0
BL	50	0.9680	1.0301	-0.0468	0.1639	0.4127	0.0
OH	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
AH	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
RD	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
DW	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
HT	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
KC	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0.0
OO	50	0.9680	1.0301	-0.0468	0.1639	0.4127	0.0
CT	25	1.2941	0.9892	-0.0315	1.0481	-0.0368	0.0
MV	27	1.3213	0.9995	-0.0254	0.8549	-0.0016	0.0
MB	16	1.2898	0.9982	-0.0289	0.8546	0.0171	0.0
HH	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0
SD	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0.0

5.0 Mortality Model

The CS 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 CS variant.

Species Code	p_0	p_1
RC	5.5876999	-0.0053480
JU	9.6942997	-0.0127328
SP	5.5876999	-0.0053480
VP	5.5876999	-0.0053480
LP	5.5876999	-0.0053480
OS	9.6942997	-0.0127328
WP	5.5876999	-0.0053480
WN	5.9617000	-0.0340128
BN	5.9617000	-0.0340128
TL	5.1676998	-0.0077681
TS	5.9617000	-0.0340128
WT	5.9617000	-0.0340128
BG	5.1676998	-0.0077681

Species Code	p_0	p_1
SH	5.9617000	-0.0340128
SL	5.9617000	-0.0340128
MH	5.9617000	-0.0340128
PH	5.9617000	-0.0340128
HI	5.9617000	-0.0340128
WH	5.9617000	-0.0340128
BH	5.9617000	-0.0340128
PE	5.9617000	-0.0340128
BI	5.9617000	-0.0340128
AB	5.1676998	-0.0077681
BA	5.9617000	-0.0340128
PA	5.1676998	-0.0077681
UA	5.1676998	-0.0077681
EC	5.9617000	-0.0340128
RM	5.1676998	-0.0077681
BE	5.9617000	-0.0340128
SV	5.1676998	-0.0077681
BC	5.9617000	-0.0340128
AE	5.1676998	-0.0077681
SG	5.9617000	-0.0340128
HK	5.9617000	-0.0340128
WE	5.1676998	-0.0077681
EL	5.1676998	-0.0077681
SI	5.1676998	-0.0077681
RL	5.1676998	-0.0077681
RE	5.1676998	-0.0077681
YP	5.9617000	-0.0340128
BW	5.1676998	-0.0077681
SM	5.1676998	-0.0077681
AS	5.1676998	-0.0077681
WA	5.9617000	-0.0340128
GA	5.1676998	-0.0077681
WO	5.9617000	-0.0340128
RO	5.9617000	-0.0340128
SK	5.9617000	-0.0340128
BO	5.9617000	-0.0340128
SO	5.9617000	-0.0340128
BJ	5.9617000	-0.0340128

Species Code	p_0	p_1
CK	5.9617000	-0.0340128
SW	5.9617000	-0.0340128
BR	5.9617000	-0.0340128
SN	5.9617000	-0.0340128
PO	5.9617000	-0.0340128
DO	5.9617000	-0.0340128
CO	5.9617000	-0.0340128
PN	5.9617000	-0.0340128
CB	5.9617000	-0.0340128
QI	5.9617000	-0.0340128
OV	5.9617000	-0.0340128
WK	5.9617000	-0.0340128
NK	5.9617000	-0.0340128
WL	5.9617000	-0.0340128
QS	5.9617000	-0.0340128
SS	5.1676998	-0.0077681
OB	5.1676998	-0.0077681
CA	5.9617000	-0.0340128
PS	5.9617000	-0.0340128
HL	5.9617000	-0.0340128
BP	5.9617000	-0.0340128
BT	5.9617000	-0.0340128
QA	5.9617000	-0.0340128
BK	5.1676998	-0.0077681
SY	5.9617000	-0.0340128
BY	5.5876999	-0.0053480
RB	5.9617000	-0.0340128
SU	5.9617000	-0.0340128
WI	5.1676998	-0.0077681
BL	5.1676998	-0.0077681
OH	5.9617000	-0.0340128
AH	5.1676998	-0.0077681
RD	5.1676998	-0.0077681
DW	5.1676998	-0.0077681
HT	5.9617000	-0.0340128
KC	5.1676998	-0.0077681
OO	5.1676998	-0.0077681
CT	5.9617000	-0.0340128

Species Code	p_0	p_1
MV	5.9617000	-0.0340128
MB	5.1676998	-0.0077681
HH	5.1676998	-0.0077681
SD	5.1676998	-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 height relative to the average stand height (*RELHT*) using equation {5.0.3}. This value is then adjusted by a species-specific mortality modifier representing the species shade tolerance shown in equation {5.0.4}.

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} $MR = 0.84525 - (0.01074 * RELHT) + (0.0000002 * RELHT^3)$

{5.0.4} $MORT = MR * (1 - MWT) * 0.1$

where:

MR	is the proportion of the tree record attributed to mortality (bounded: $0.01 \leq MR \leq 1$)
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand
MORT	is the final mortality rate of the tree record
MWT	is a mortality weight value shown in Table 5.0.2

Table 5.0.2 *MWT* values for the mortality equation {5.0.4} in the CS variant.

Species Code	*MWT*
RC	0.20
JU	0.70
SP	0.30
VP	0.30
LP	0.30
OS	0.30
WP	0.50
WN	0.30

Species Code	*MWT*
SK	0.50
BO	0.50
SO	0.10
BJ	0.70
CK	0.30
SW	0.50
BR	0.50
SN	0.30

Species Code	*MWT*
BN	0.30
TL	0.30
TS	0.70
WT	0.30
BG	0.30
SH	0.50
SL	0.90
MH	0.30
PH	0.50
HI	0.50
WH	0.50
BH	0.50
PE	0.50
BI	0.50
AB	0.70
BA	0.30
PA	0.50
UA	0.30
EC	0.10
RM	0.85
BE	0.70
SV	0.70
BC	0.40
AE	0.50
SG	0.50
HK	0.50
WE	0.30
EL	0.50
SI	0.50
RL	0.70
RE	0.50
YP	0.30
BW	0.70
SM	0.90
AS	0.30
WA	0.30
GA	0.70
WO	0.50
RO	0.50

Species Code	*MWT*
PO	0.30
DO	0.70
CO	0.50
PN	0.30
CB	0.30
QI	0.30
OV	0.50
WK	0.30
NK	0.90
WL	0.30
QS	0.70
SS	0.30
OB	0.30
CA	0.70
PS	0.90
HL	0.70
BP	0.10
BT	0.10
QA	0.10
BK	0.10
SY	0.50
BY	0.50
RB	0.30
SU	0.30
WI	0.90
BL	0.10
OH	0.30
AH	0.90
RD	0.30
DW	0.90
HT	0.30
KC	0.10
OO	0.30
CT	0.50
MV	0.50
MB	0.30
HH	0.70
SD	0.70

6.0 Regeneration

The CS 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 CS variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
RC	No	0.5	0.33	16.0
JU	No	0.3	2.10	27.0
SP	Yes	0.5	0.25	14.0
VP	No	0.5	0.42	14.0
LP	No	0.5	0.25	14.0
OS	No	0.3	0.25	16.0
WP	No	0.4	0.33	20.0
WN	Yes	0.4	0.33	20.0
BN	Yes	0.3	0.33	18.0
TL	Yes	0.2	0.33	16.0
TS	Yes	0.2	3.59	20.0
WT	Yes	0.2	0.33	20.0
BG	Yes	0.2	0.33	16.0
SH	Yes	0.3	0.33	14.0
SL	Yes	0.3	0.33	14.0
MH	Yes	0.3	0.33	18.0
PH	Yes	0.3	0.33	14.0
HI	Yes	0.3	0.33	14.0
WH	Yes	0.3	0.33	14.0
BH	Yes	0.3	0.33	14.0
PE	Yes	0.3	0.33	14.0
BI	Yes	0.3	0.33	14.0
AB	Yes	0.1	0.25	14.0
BA	Yes	0.2	0.33	18.0
PA	Yes	0.2	0.42	28.0
UA	Yes	0.2	0.50	20.0
EC	Yes	0.1	0.42	24.0
RM	Yes	0.2	1.00	20.0
BE	Yes	0.3	0.33	16.0

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
SV	Yes	0.2	0.42	18.0
BC	Yes	0.1	0.42	26.0
AE	Yes	0.1	0.33	16.0
SG	Yes	0.3	0.33	14.0
HK	Yes	0.1	0.25	12.0
WE	Yes	0.1	0.50	20.0
EL	Yes	0.1	0.33	16.0
SI	Yes	0.1	0.50	20.0
RL	Yes	0.1	0.33	12.0
RE	Yes	0.1	0.50	20.0
YP	Yes	0.2	0.42	24.0
BW	Yes	0.1	0.33	16.0
SM	Yes	0.2	0.25	16.0
AS	Yes	0.2	0.42	24.0
WA	Yes	0.2	0.42	24.0
GA	Yes	0.2	0.42	24.0
WO	Yes	0.2	0.33	16.0
RO	Yes	0.2	0.42	20.0
SK	Yes	0.1	0.33	16.0
BO	Yes	0.2	0.33	16.0
SO	Yes	0.2	0.33	16.0
BJ	Yes	0.2	2.80	20.0
CK	Yes	0.1	0.33	12.0
SW	Yes	0.1	0.33	16.0
BR	Yes	0.2	0.25	14.0
SN	Yes	0.2	0.33	12.0
PO	Yes	0.1	0.25	12.0
DO	Yes	0.1	2.80	20.0
CO	Yes	0.2	0.33	16.0
PN	Yes	0.2	1.40	20.0
CB	Yes	0.1	0.33	14.0
QI	Yes	0.2	0.25	14.0
OV	Yes	0.2	0.50	20.0
WK	Yes	0.1	0.33	16.0
NK	Yes	0.2	1.40	20.0
WL	Yes	0.1	0.25	14.0
QS	Yes	0.1	0.50	20.0
SS	Yes	0.1	0.50	18.0
OB	Yes	0.1	0.55	20.0
CA	Yes	0.3	0.63	20.0

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
PS	Yes	0.1	0.25	12.0
HL	Yes	0.1	5.00	20.0
BP	Yes	0.2	0.42	24.0
BT	Yes	0.2	0.42	20.0
QA	Yes	0.3	0.42	20.0
BK	Yes	0.1	0.58	24.0
SY	Yes	0.1	0.58	24.0
BY	Yes	0.2	1.40	20.0
RB	Yes	0.1	0.33	18.0
SU	Yes	0.2	0.33	18.0
WI	Yes	0.1	4.70	20.0
BL	Yes	0.1	1.00	32.0
OH	No	0.1	0.33	10.0
AH	Yes	0.2	0.42	20.0
RD	Yes	0.2	2.10	20.0
DW	Yes	0.1	0.25	18.0
HT	Yes	0.1	0.25	16.0
KC	Yes	0.1	0.50	20.0
OO	Yes	0.2	0.25	12.0
CT	Yes	0.2	0.33	20.0
MV	Yes	0.2	0.42	20.0
MB	Yes	0.2	2.10	20.0
HH	Yes	0.2	0.42	20.0
SD	Yes	0.2	0.33	16.0

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} $PS = (1.6134 - 0.0184 * (((DSTMP_i / 0.7788 - 0.21525) * 2.54)))/(1 + \exp(1.6134 - 0.0184 * (((DSTMP_i / 0.7788) - 0.21525) * 2.54)))$

{6.0.5} $PS = (6.0065 - 0.0777*((DSTMP_i / 0.7801) * 2.54)) / (1 + \exp(6.0065 - 0.0777 * ((DSTMP_i / 0.7801) * 2.54)))$

{6.0.6} $PS = (6.4205 - 0.1097 * (((DSTMP_i / 0.8188 - 0.23065) * 2.54))) / (1 + \exp(6.4205 - 0.1097 * (((DSTMP_i / 0.8188) - 0.23065) * 2.54)))$

{6.0.7} $PS = ((57.3 - 0.0032 * (DSTMP_i)\text{^}3) / 100)$

{6.0.8} $PS = (1 / (1 + \exp(-(2.3656 - 0.2781 * (DSTMP_i / 0.7801)))))$

{6.0.9} $PS = (1 / (1 + \exp(-(-2.8058 + 22.6839 * (1 / ((DSTMP_i / 0.7788) - 0.4403))))))$

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

{6.0.11} $PS = ((89.191 - 2.611 * DSTMP_i) / 100)$

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 CS variant.

Species Code	Sprouting Probability	Number of Sprout Records	Source*
SP	0.42 for DBH < 7”, 0 for DBH > 7”	1, 0	Wayne Clatterbuck (personal communication) Ag. Handbook 654
WN	0.8 for DBH < 8", 0.5 for DBH > 8"	1	Schlesinger 1977 Schlesinger 1989 Coladonato 1991
BN	0.3 for DBH < 8", 0 for DBH > 8"	1, 0	Ag. Handbook 654

Species Code	Sprouting Probability	Number of Sprout Records	Source*
TL	0.9	1	Ag. Handbook 654
TS	0.9	1	Hook and DeBell 1970 Ag. Handbook 654
WT	0.9	1	Hook and DeBell 1970 Ag. Handbook 654
BG	0.9	1	Hook and DeBell 1970 Ag. Handbook 654
SH	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Nelson 1965
SL	0.75 for DBH < 24", 0.5 for DBH > 24"	1	Ag. Handbook 654
MH	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Nelson 1965
PH	0.75 for DBH < 24", 0.5 for DBH > 24"	1	Ag. Handbook 654
HI	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Ag. Handbook 654
WH	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Ag. Handbook 654
BH	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Nelson 1965 Fayle 1966
PE	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Wolstenholme 1976 Ag. Handbook 654
BI	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Nelson 1965 Ag. Handbook 654
AB	0.5 for DBH < 4", 0 for DBH > 4"	1, 0	Ag. Handbook 654
BA	0.8 for DBH < 12", 0.5 for DBH > 12"	{6.0.1}	Curtis 1959 Lees and West 1988
PA	0.8 for DBH < 12", 0.5 for DBH > 12"	{6.0.1}	Ag. Handbook 654
UA	0.8 for DBH < 12", 0.5 for DBH > 12"	{6.0.1}	Ag. Handbook 654
EC	0.4 for DBH < 25", 0 for DBH > 25"	1, 0	Ag. Handbook 654
RM	0.8 for DBH < 12", 0.5 for DBH > 12"	{6.0.1}	Solomon and Barton 1967 Prager and Goldsmith 1977
BE	0.6 for DBH < 15", 0.3 for DBH > 15"	1	Maeglin and Ohman 1973 Eyre 1980
SV	0.8 for DBH < 12",	{6.0.1}	Ag. Handbook 654

Species Code	Sprouting Probability	Number of Sprout Records	Source*
	0.5 for DBH > 12"		
BC	0.8 for DBH < 12", 0.5 for DBH > 12"	1	Hough 1965 Powell and Tryon 1979
AE	0.7	1	Ag. Handbook 654
SG	0.8	1	Ag. Handbook 654
HK	0.4 for DBH < 8", 0.2 for DBH > 8"	1	Ag. Handbook 654
WE	0.7	1	Ag. Handbook 654
EL	0.7	1	Ag. Handbook 654
SI	0.7	1	Ag. Handbook 654
RL	0.7	1	Ag. Handbook 654
RE	0.7	1	Ag. Handbook 654
YP	0.8 for DBH < 25", 0.5 for DBH > 25"	{6.0.2}	Ag. Handbook 654
BW	0.8	{6.0.2}	Ag. Handbook 654
SM	{6.0.11}	{6.0.1}	MacDonald and Powell 1983 Ag. Handbook 654
AS	0.8 for DBH < 12", 0.5 for DBH > 12"	1	Ag. Handbook 654
WA	0.8 for DBH < 12", 0.5 for DBH > 12"	1	Ag. Handbook 654
GA	0.8 for DBH < 12", 0.5 for DBH > 12"	1	Ag. Handbook 654
WO	Eq. {6.0.4}	1	Sands and Abrams 2009 Westfall 2010 Ag. Handbook 654
RO	Eq. {6.0.7}	{6.0.1}	Johnson 1975 Ag. Handbook 654
SK	0.8 for DBH < 10", 0.5 for DBH > 10"	1	Ag. Handbook 654
BO	Eq. {6.0.5}	1	Sands and Abrams 2009 Westfall 2010 Ag. Handbook 654
SO	Eq. {6.0.7}	1	Johnson 1975 Ag. Handbook 654
BJ	Eq. {6.0.8}	1	Johnson 1977 Ag. Handbook 654
CK	0.7	1	Ag. Handbook 654
SW	90% of Eq. {6.0.4} predictions	1	Ag. Handbook 654

Species Code	Sprouting Probability	Number of Sprout Records	Source*
BR	0.8	1	Ag. Handbook 654
SN	Eq. {6.0.6}	1	Sands and Abrams 2009 Westfall 2010 Ag. Handbook 654
PO	Eq. {6.0.9}	1	Johnson 1977 Ag. Handbook 654
DO	Eq. {6.0.9}	1	Johnson 1977 Ag. Handbook 654
CO	Eq. {6.0.6}	1	Sands and Abrams 2009 Westfall 2010 Ag. Handbook 654
PN	0.8	1	Ag. Handbook 654
CB	Eq. {6.0.7}	{6.0.1}	Johnson 1975 Ag. Handbook 654
QI	Eq. {6.0.7}	{6.0.1}	Johnson 1975 Ag. Handbook 654
OV	0.4 for DBH < 8", 0 for DBH > 8"	1, 0	Ag. Handbook 654
WK	0.7	1	Carey 1992-1
NK	0.8 for DBH < 10", 0.5 for DBH > 10"	1	Ag. Handbook 654
WL	0.8 for DBH < 10", 0.5 for DBH > 10"	1	Ag. Handbook 654
QS	0.6 for DBH < 10", 0.3 for DBH > 10"	1	Ag. Handbook 654
SS	0.8	{6.0.2}	Ag. Handbook 654
OB	0.4 for DBH < 8", 0 for DBH > 8"	1, 0	Ag. Handbook 654
CA	No info available— default to 0.7	1	n/a
PS	0.7	1	Ag. Handbook 654
HL	0.7	1	Ag. Handbook 654
BP	0.8 for DBH < 25", 0.5 for DBH > 25"	{6.0.2}	Ag. Handbook 654
BT	0.8	{6.0.2}	Ag. Handbook 654
QA	Eq. {6.0.10}	2	Keyser 2001
BK	0.9	{6.0.1}	Ag. Handbook 654
SY	0.7	1	Steinbeck et al. 1972 Sullivan 1994
BY	0.8 for DBH < 12",	1	Ag. Handbook 654

Species Code	Sprouting Probability	Number of Sprout Records	Source*
	0.5 for DBH > 12"		
RB	0.7	1	Sullivan 1993
SU	0.7	1	Coladonato 1992-1 Ag. Handbook 654
WI	0.9	1	Ag. Handbook 654
BL	0.9	1	Ag. Handbook 654
AH	No info available—default to 0.7	1	n/a
RD	0.8	1	Armstrong 1980
DW	0.7 for DBH < 8", 0.9 for DBH > 8"	{6.0.1}	Ag. Handbook 654
HT	No info available—default to 0.7	1	n/a
KC	No info available—default to 0.7	1	n/a
OO	0.8	1	Carey 1994-1
CT	0.7	1	Ag. Handbook 654
MV	0.8	{6.0.2}	Jones et al. 2000
MB	0.8	1	Ag. Handbook 654
HH	0.8	1	Ag. Handbook 654
SD	0.9	{6.0.1}	Ag. Handbook 654

*Many of the sources stemmed from those referenced in Agricultural Handbook 654, Silvics of North America. For the sake of being concise, only "Ag. Handbook 654" was listed when multiple publications were referenced from that handbook. When necessary, species-specific probabilities were based upon similarities with other species, either due to documented similarities or an assumed similarity. In the latter cases, assumptions were necessary due to a lack of previous research findings for these species.

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

Volume is calculated for three merchantability standards: merchantable stem cubic feet, sawlog stem cubic feet, and sawlog stem board feet (International ¼-inch). 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 for the CS variant are shown in table 7.0.1.

Table 7.0.1 Volume merchantability standards for the CS variant.

Pulpwood Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
905 – Mark Twain	5.0 / 4.0 inches	5.0 / 4.0 inches
908 – Shawnee	6.0 / 5.0 inches	5.0 / 4.0 inches
911 – Wayne-Hoosier, 912 - Hoosier	6.0 / 4.0 inches	5.0 / 4.0 inches
Stump Height	0.5 feet	0.5 feet
Sawtimber Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
905 – Mark Twain (eastern redcedar)		6.0 / 5.0 inches
905 – Mark Twain (all other species)	9.0 / 7.6 inches	9.0 / 7.6 inches
908 – Shawnee	11.0 / 9.6 inches	9.0 / 7.6 inches
911 – Wayne-Hoosier, 912 - Hoosier	11.0 / 9.6 inches	9.0 / 7.6 inches
Stump Height	1.0 foot	1.0 foot

For both cubic and board foot prediction, Clark's profile models (Clark et al. 1991) are used for all species and all location codes in the CS variant. Equation number is 900CLKE***, where *** signifies the three-digit FIA species code.

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 CS 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 Disease models have been developed through the participation and contribution of various organizations led by Forest Health Protection. The models are maintained by the Forest Management Service Center and regional Forest Health Protection specialists. There are no insect and disease models currently available for the CS variant. However, FVS addfiles that simulate the effects of known agents within the CS variant may be found in chapter 8 of the Essential FVS Users Guide (Dixon 2002).

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11.0 Appendices

There are no appendices for the CS variant.

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