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YOUNG-GROWTH SIERRA REDWOOD VOLUME EQUATIONS FOR MOUNTAIN HOME DEMONSTRATION STATE FOREST

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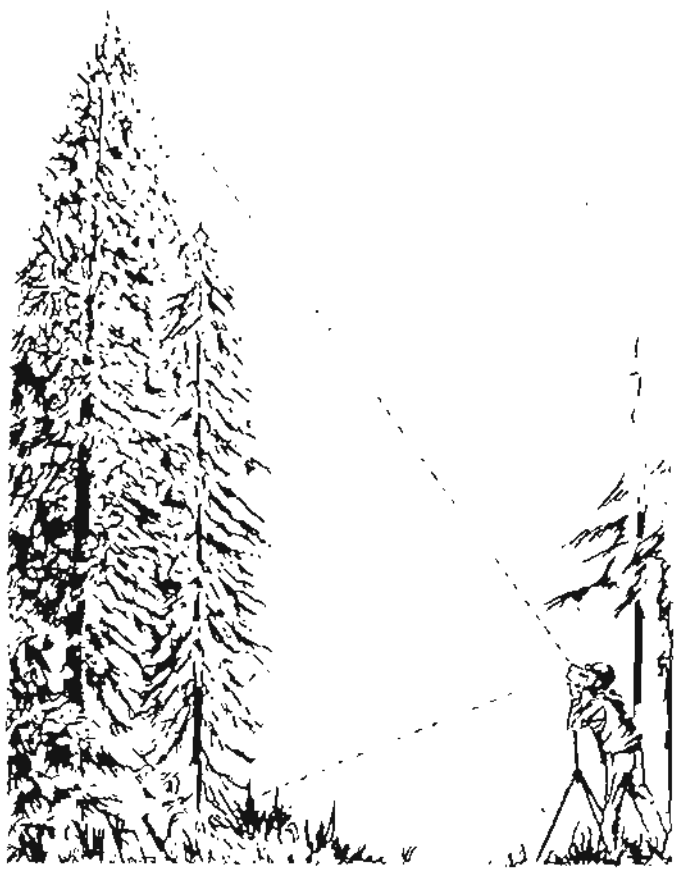

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ABSTRACT

Volume estimation equations for young-growth Sierra redwood [*Sequoiadendron giganteum* (Lindl.) Decne] have been developed for determining cubic foot or Scribner board foot volume. Three different equation types were developed: local, standard and Girard's form class. Sample tree measurements were made using a Tele-relaskop. The new equations provide a more accurate estimate of volume than previously existing Sierra redwood volume equations.

KEYWORDS: Sierra redwood, volume estimation

INTRODUCTION

Young-growth Sierra redwood [*Sequoiadendron giganteum* (Lindl.) Decne] is an important timber resource in the central and southern Sierras occurring on an estimated 35,600 acres. Over the past several years the amount of young-growth Sierra redwood harvested has gradually increased and this trend is expected to continue (Benson, personal communication, 1985).

Young-growth Sierra redwood are characterized as having pointed tops, shallow-furrowed bark and persistent limbs, including those that are dead, on the entire bole.

The purpose of this study was to develop volume equations based on diameter, height, and a stem form descriptor that would apply to young-growth trees in stands of different densities where tree forms may vary.

BACKGROUND

Accurate volume estimation equations are important for developing reliable estimates of harvest volume, timber inventory, and for thinning, stocking and growth and yield studies.

Volume estimation equations for Sierra redwood were developed by Wensel and Schoenheide (1971), for Mountain Home Demonstration State Forest. However, while these equations have been shown to be applicable to trees that have developed in open stand conditions, they have historically underestimated the volume of trees growing in dense stands on Mountain Home Demonstration State Forest.

The specific objective of this project was to develop local, standard, and form class volume equations and tables for young-growth Sierra redwood that will:

1) Represent a wider range of diameters (10 to 80 inches) and corresponding heights,

2) Accurately estimate volume for all values of taper, and

3) Will be applicable to the various stand conditions at Mountain Home Demonstration State Forest.

METHODS

Field sampling took place during the summer of 1986. One-hundred-sixty-seven sample trees were measured while standing using a Tele-relaskop. Descriptive statistics for the sample trees are provided in Table 1.

In addition to the standing tree measurements, a sub-sample of 29 trees were felled and measured. The relationship of standing tree volume to cut tree volume for the cut trees was used to adjust volume of the standing trees.

Volume Equation Development

Three types of volume estimation equations were developed in

Table 1. Summary of descriptive statistics for the sample trees.

Variable	N	Minimum	Maximum	Mean	Standard Deviation
DBH (inches)	160	11.4	112.4	35.1	15.9
Total Height (feet)	160	46	243	132	39
Girard Form Class (percent)	160	35.7	93.1	67.2	7.3
Total Volume (cubic feet)	160	12.8	4,000.0	327.3	425.9
Total Volume (board feet)	160	48	29,498	2,133	3,095

Table 2. Volume estimation equation coefficients and regression statistics.

Units	b_0	b_1	b_2	b_3	R^2	SEE	N
Local							
Cubic Feet	0.04469696	2.390837			0.962	1.23	158
Board Feet	0.08723565	2.699116			0.947	1.33	158
Standard							
Cubic Feet	0.002438339	1.694874	1.098957		0.986	1.14	160
Board Feet	0.001682608	1.755956	1.490641		0.981	1.19	160
Form Quotient							
Cubic Feet	0.000043153	1.723417	0.999809	1.049283	0.994	1.09	158
Board Feet	0.0000081253	1.795709	1.354768	1.390969	0.991	1.12	158

both cubic feet and Scribner board feet units: 1) local volume equation (equation 1), standard volume equation (equation 2) and form class volume equation (equation 3). The form for each equation is given below. A log base 10 transformation of the equation variables was used to linearize the data and to equalize the variation.

Local $V = b_0\ DBH^{b_1}$ [1]

Standard $V = b_0\ DBH^{b_1}\ H^{b_2}$ [2]

Form Class $V = b_0\ DBH^{b_1}\ H^{b_2}\ F^{b_3}$ [3]

where: V = Volume inside bark in cubic or board feet,
DBH = Diameter outside bark at breast-height in inches,
H = Total Height in feet,
F = Girard Form Class in percent, and
b_i = regression coefficients.

Table 2 lists the equation coefficients and summarizes the results of the equation development. Volume tables are provided in the Appendix.

TEST OF EQUATION RELIABILITY

A test of the accuracy of the volume equations was performed using an independent sample tree data set provided by the Mountain Home Demonstration State Forest staff. The sample data measurements included DBH, total height and the scaled volume (Scribner board feet) for 311 trees. Descriptive statistics for these trees are given in Table 3. The estimated volume using the study equations was compared to the scaled volume of the independent sample trees. In addition to this comparison a comparison was also made between

Table 3. Descriptive statistics for the independent test trees.

Variable	N	Minimum	Maximum	Mean	Standard Deviation
DBH (inches)	311	11.3	58.4	20.1	8.0
Total Height (feet)	311	45	208	95	30
Total Volume (board feet)	311	30	4,000	390	553

Table 4. Summary of root mean squared error and aggregate difference for board foot volumes for the study equations and old equations against 311 trees of scaled volume.

	Aggregate Difference (percent)		Root Mean Squared Error (percent)	
Equation	Study equations	Old equations	Study equations	Old equations
Local	4.4	-43.0	2.9	8.2
Standard	12.4	-32.4	4.2	4.8
Form Class	7.0	N/A	2.4	N/A

the scaled volume of the independent sample trees and the volume estimated using the equations developed by Wensel and Schoenheide (1971).

Two tests were used for the comparison of the volume estimated by the various equations: the aggregate difference test and the root mean square error test.

Aggregate Difference Method

Aggregate difference is the difference between the sum of the estimated tree volumes and the sum of the scaled tree volumes for the sample trees. The results of the aggregate difference are summarized in Table 4.

Results based on the aggregate difference test indicate that the new equations overestimated the scaled volume by 12.4 percent for the standard volume equation while the form class and the local equations provided better estimates. The old equations significantly underestimated the scaled volume.

Form class was not measured for the independent test sample trees, however by using the average form class of 67.2 percent obtained from the original sample trees, an aggregate difference of 7.0 percent was obtained.

Based on this analysis the new equations appear to provide a better estimate of Scribner board foot volume.

Root Mean Squared Error Method

Another measure of the reliability of an equation is the extent to which the individual observations of sample tree volume deviate from the regression surface (MacLean and Berger, 1976).

A measure of the residual variation is the root mean squared error (Equation [9]); that is, the root of the mean squared difference between the predicted and actual volumes. The results of this comparison, expressed as a percent of the average tree volume, are summarized in Table 4.

$$\text{RMS (\%)} = \frac{\sqrt{\frac{\sum(\text{Est.Vol.} - \text{Act.Vol})^2}{N}}}{\frac{\sum \text{Act.Vol}}{N}} \times 100 \quad [9]$$

where: RMS = Percent root mean squared error,
Est. Vol. = Estimated tree volume based on volume estimation equations,
Act. Vol. = Actual tree volume, and
N = number of trees.

The root mean squared error of 4.2 and 2.9 percent for the new standard and local volume equations, respectively, indicate that they more closely estimate the actual scaled volume when compared to the old equations with RMS errors of 4.8 and 8.2 percent.

LITERATURE CITED

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MacLean, C.and J. Berger. Softwood tree volume equations for major California species. Res. Note PNW-266. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1976. 33 p.

Wensel, Lee C. and Richard L. Schoenheide. Tree Volume Equations and Tables from Dendrometer Measurements. University of California Division of Agricultural Sciences. Hilgardia, Volume 41, Number 4. September, 1971.

Table 5. Standard volume table* for Sierra redwood in Scribner board feet (6 inch log).

Diameter breast-height outside bark (inches)	Total height (feet)																		
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220
10	23	31	43	54	66	79	92	106	121	136	152								
12	32	45	59	74	91	108	127	146	166	187	209								
14	42	59	77	97	119	142	166	191	218	245	274								
16	54	75	98	123	150	179	210	242	275	310	346								
18	66	92	120	152	185	220	258	297	338	381	426	472							
20	79	110	145	182	223	265	310	358	407	459	512	568							
22	94	131	171	216	263	314	367	423	481	542	606	671							
24	109	152	200	251	306	365	427	493	561	632	706	782	861	943	1027				
26	126	175	230	289	353	420	492	567	646	727	812	900	991	1085	1181				
28	143	199	262	329	402	479	560	646	735	828	925	1025	1129	1236	1346				
30	161	225	295	372	453	541	632	729	830	935	1044	1157	1274	1395	1519	1646	1777		
32	181	252	331	416	508	605	708	816	930	1047	1170	1296	1427	1562	1701	1844	1991		
34				463	565	673	788	908	1034	1165	1301	1442	1588	1738	1892	2051	2214		
36				512	625	744	871	1004	1143	1288	1438	1594	1755	1921	2092	2268	2448		
38				563	687	819	958	1104	1257	1416	1582	1753	1930	2113	2300	2494	2692		
40				616	752	896	1048	1208	1375	1550	1731	1918	2112	2312	2517	2729	2945		
42				671	819	976	1142	1316	1498	1688	1886	2090	2301	2518	2742	2973	3209		
44				728	888	1059	1239	1428	1626	1832	2046	2268	2497	2733	2976	3226	3482		
46							1340	1544	1758	1981	2212	2452	2699	2955	3217	3488	3765	4049	4339
48							1444	1664	1894	2135	2384	2642	2909	3184	3467	3758	4057	4363	4676
50							1551	1788	2035	2293	2561	2838	3125	3421	3725	4037	4358	4687	5024
52							1661	1915	2180	2457	2744	3041	3348	3664	3990	4325	4669	5021	5382
54							1775	2046	2330	2625	2932	3249	3577	3916	4264	4622	4989	5365	5750
56							1892	2181	2483	2798	3125	3463	3813	4174	4545	4926	5318	5719	6130
58										2976	3323	3683	4055	4439	4834	5239	5656	6082	6519
60										3158	3527	3909	4304	4711	5130	5561	6003	6456	6919
62										3346	3736	4141	4559	4990	5434	5890	6358	6838	7329
64										3537	3951	4379	4821	5277	5746	6228	6723	7230	7749
66										3734	4170	4622	5088	5570	6065	6574	7096	7632	8180
68										3935	4394	4870	5362	5869	6391	6928	7478	8042	8620
70										4140	4624	5125	5642	6176	6725	7289	7869	8462	9070
72													5928	6489	7066	7659	8268	8891	9530
74													6220	6809	7414	8037	8675	9330	10000
76													6519	7135	7770	8422	9091	9777	10479
78													6823	7468	8132	8815	9515	10233	10968
80													7133	7808	8502	9216	9948	10698	11467

* Volume (board feet) = 0.00168260*DBH^1.755956*Total Height^1.490641

Table 6. Standard volume table* for Sierra redwood in cubic feet.

Diameter breast-height outside bark (inches)	Total height (feet)																		
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220
10	7	9	11	13	15	17	19	21	23	25	28								
12	9	12	15	18	20	23	26	29	32	35	38								
14	12	16	19	23	26	30	34	37	41	45	49								
16	15	20	24	29	33	38	42	47	52	56	61								
18	19	24	29	35	40	46	52	57	63	69	75	81							
20	23	29	35	42	48	55	62	68	75	82	89	96							
22	26	34	41	49	57	65	72	80	89	97	105	113							
24	31	39	48	57	66	75	84	93	103	112	122	131	141	151	160				
26	35	45	55	65	75	86	96	107	118	128	139	150	161	172	184				
28	40	51	62	74	85	97	109	121	133	146	158	170	183	195	208				
30	45	57	70	83	96	109	123	136	150	164	177	191	206	220	234	248	263		
32	50	64	78	92	107	122	137	152	167	183	198	214	229	245	261	277	293		
34				102	119	135	152	168	185	202	219	237	254	272	289	307	325		
36				113	131	149	167	185	204	223	242	261	280	299	319	338	358		
38				124	143	163	183	203	224	244	265	286	307	328	349	371	392		
40				135	156	178	200	222	244	266	289	312	335	358	381	404	428		
42				147	170	193	217	241	265	289	314	339	364	389	414	439	465		
44				159	184	209	235	261	287	313	340	366	393	420	448	475	503		
46							253	281	309	338	366	395	424	453	483	512	542	572	602
48							272	302	332	363	394	425	456	487	519	551	583	615	647
50							291	324	356	389	422	455	489	522	556	590	624	659	693
52							311	346	381	416	451	486	522	558	594	631	667	704	741
54							332	369	406	443	481	518	557	595	633	672	711	750	790
56							353	392	432	471	511	551	592	633	674	715	756	798	840
58										500	542	585	628	672	715	759	803	847	891
60										530	575	620	665	711	757	804	850	897	944
62										560	607	655	703	752	801	850	899	948	998
64										591	641	691	742	793	845	897	949	1001	1053
66										622	675	728	782	836	890	945	999	1054	1110
68										655	710	766	823	879	936	994	1051	1109	1167
70										688	746	805	864	924	983	1044	1104	1165	1226
72													906	969	1032	1095	1158	1222	1286
74													949	1015	1081	1147	1213	1280	1347
76													993	1062	1131	1200	1269	1339	1409
78													1038	1109	1181	1254	1326	1400	1473
80													1083	1158	1233	1309	1385	1461	1537

* Volume (board feet) 0.001682608*DBH^1.755956*Total Height^1.490641

Table 7. Local volume table* for Sierra redwood in Scribner board feet.

Diameter breast-height outside bark (inches)	One tenth inch									
	0	1	2	3	4	5	6	7	8	9
10	44	56	71	89	108	130	155	183	213	247
12	71	89	108	130	155	183	213	247	283	323
14	108	130	155	183	213	247	283	323	366	413
16	155	183	213	247	283	323	366	413	463	517
18	213	247	283	323	366	413	463	517	575	637
20	283	323	366	413	463	517	575	637	703	772
22	366	413	463	517	575	637	703	772	846	925
24	463	517	575	637	703	772	846	925	1008	1095
26	575	637	703	772	846	925	1008	1095	1187	1283
28	703	772	846	925	1008	1095	1187	1283	1385	1491
30	846	925	1008	1095	1187	1283	1385	1491	1602	1719
32	1008	1095	1187	1283	1385	1491	1602	1719	1840	1967
34	1187	1283	1385	1491	1602	1719	1840	1967	2099	2237
36	1385	1491	1602	1719	1840	1967	2099	2237	2380	2529
38	1602	1719	1840	1967	2099	2237	2380	2529	2683	2844
40	1840	1967	2099	2237	2380	2529	2683	2844	3010	3182
42	2099	2237	2380	2529	2683	2844	3010	3182	3361	3545
44	2380	2529	2683	2844	3010	3182	3361	3545	3736	3933
46	2683	2844	3010	3182	3361	3545	3736	3933	4136	4346
48	3010	3182	3361	3545	3736	3933	4136	4346	4563	4786
50	3361	3545	3736	3933	4136	4346	4563	4786	5016	5253
52	3736	3933	4136	4346	4563	4786	5016	5253	5497	5748
54	4136	4346	4563	4786	5016	5253	5497	5748	6006	6271
56	4563	4786	5016	5253	5497	5748	6006	6271	6543	6823
58	5016	5253	5497	5748	6006	6271	6543	6823	7110	7404
60	5497	5748	6006	6271	6543	6823	7110	7404	7706	8016
62	6006	6271	6543	6823	7110	7404	7706	8016	8334	8659
64	6543	6823	7110	7404	7706	8016	8334	8659	8992	9333
66	7110	7404	7706	8016	8334	8659	8992	9333	9682	10039
68	7706	8016	8334	8659	8992	9333	9682	10039	10405	10778
70	8334	8659	8992	9333	9682	10039	10405	10778	11160	11551

* Volume (board feet) = 0.08723565*DBH^2.69911

Table 8. Local volume table* for Sierra redwood in cubic feet.

Diameter breast-height outside bark (inches)	One tenth inch									
	0	1	2	3	4	5	6	7	8	9
10	11	14	17	21	25	29	34	39	45	51
12	17	21	25	29	34	39	45	51	58	65
14	25	29	34	39	45	51	58	65	72	81
16	34	39	45	51	58	65	72	81	89	98
18	45	51	58	65	72	81	89	98	108	118
20	58	65	72	81	89	98	108	118	129	140
22	72	81	89	98	108	118	129	140	152	164
24	89	98	108	118	129	140	152	164	177	191
26	108	118	129	140	152	164	177	191	205	220
28	129	140	152	164	177	191	205	220	235	251
30	152	164	177	191	205	220	235	251	267	285
32	177	191	205	220	235	251	267	285	302	321
34	205	220	235	251	267	285	302	321	340	359
36	235	251	267	285	302	321	340	359	380	401
38	267	285	302	321	340	359	380	401	422	445
40	302	321	340	359	380	401	422	445	468	491
42	340	359	380	401	422	445	468	491	516	541
44	380	401	422	445	468	491	516	541	566	593
46	422	445	468	491	516	541	566	593	620	647
48	468	491	516	541	566	593	620	647	676	705
50	516	541	566	593	620	647	676	705	735	766
52	566	593	620	647	676	705	735	766	797	829
54	620	647	676	705	735	766	797	829	862	896
56	676	705	735	766	797	829	862	896	930	965
58	735	766	797	829	862	896	930	965	1001	1038
60	797	829	862	896	930	965	1001	1038	1075	1113
62	862	896	930	965	1001	1038	1075	1113	1152	1192
64	930	965	1001	1038	1075	1113	1152	1192	1233	1274
66	1001	1038	1075	1113	1152	1192	1233	1274	1316	1359
68	1075	1113	1152	1192	1233	1274	1316	1359	1403	1447
70	1152	1192	1233	1274	1316	1359	1403	1447	1493	1539

* Volume (cubic feet) = 0.04469696 * DBH^2.390837

Table 9. Form class volume table* for Sierra redwood in Scribner board feet (6 inch top, Girard Form Class = 65%).

Diameter breast-height outside bark (inches)	Total height (feet)																		
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220
10	25	34	43	53	64	75	86	98	111	123	136								
12	35	47	60	74	89	104	120	136	154	171	189								
14	46	62	79	98	117	137	158	180	203	226	250								
16	58	79	101	124	149	174	201	229	257	287	317								
18	72	97	124	153	184	215	248	283	318	354	392	430							
20	87	117	150	185	222	260	300	342	384	428	474	520							
22	103	139	178	220	263	309	356	405	456	508	562	617							
24	120	163	208	257	308	361	416	474	533	594	657	721	787	855	923				
26	139	188	241	297	355	417	481	547	616	686	758	833	909	987	1066				
28	159	215	275	339	406	476	549	625	703	784	866	951	1038	1127	1218				
30	180	243	311	383	459	539	622	707	796	887	981	1077	1175	1276	1378	1483	1590		
32	202	273	349	431	516	605	698	794	894	996	1101	1209	1320	1433	1548	1665	1785		
34				480	575	675	778	886	996	1111	1228	1348	1471	1597	1726	1857	1991		
36				532	637	748	862	981	1104	1231	1361	1494	1630	1770	1912	2058	2206		
38				586	702	824	950	1081	1217	1356	1499	1646	1797	1950	2107	2268	2431		
40				643	770	903	1042	1186	1334	1487	1644	1805	1970	2139	2311	2486	2665		
42				702	841	986	1138	1294	1456	1623	1794	1970	2150	2334	2522	2714	2909		
44				763	914	1072	1237	1407	1583	1764	1951	2142	2338	2538	2742	2950	3163		
46							1339	1524	1715	1911	2113	2320	2532	2749	2970	3196	3426		
48							1446	1645	1851	2063	2281	2504	2733	2967	3206	3449	3698	3950	4207
50							1556	1770	1992	2220	2454	2695	2941	3193	3450	3712	3979	4251	4527
52							1669	1899	2137	2382	2633	2891	3155	3426	3701	3983	4269	4561	4858
54							1786	2033	2287	2549	2818	3094	3377	3666	3961	4262	4569	4881	5198
56							1907	2170	2441	2721	3008	3303	3605	3913	4228	4550	4877	5210	5549
58										2898	3204	3518	3839	4168	4503	4845	5194	5549	5910
60										3080	3405	3738	4080	4429	4786	5150	5520	5897	6281
62										3266	3611	3965	4327	4698	5076	5462	5855	6255	6662
64										3458	3823	4198	4581	4973	5374	5782	6198	6622	7053
66										3654	4040	4436	4842	5256	5679	6111	6551	6998	7453
68										3856	4263	4681	5108	5545	5992	6447	6911	7384	7864
70										4062	4491	4931	5381	5842	6312	6792	7281	7778	8284
72													5660	6145	6640	7144	7658	8182	8714
74													5946	6455	6974	7505	8045	8594	9153
76													6238	6771	7317	7873	8439	9016	9602
78													6535	7095	7666	8249	8842	9446	10061
80													6839	7425	8023	8632	9253	9886	10529

* Volume (board feet) = 0.0000081253 * DBH^1.795709 * Total Height^1.354768 * 65^1.390969

Table 10. Form class volume table* for Sierra redwood in cubic feet (Girard Form Class = 65%).

Diameter breast-height outside bark (inches)	Total height (feet)																		
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220
10	7	9	11	13	15	16	18	20	22	24	25	27	29	31	33	35	36	38	40
12	10	12	15	17	20	22	25	27	30	32	35	37	40	42	45	47	50	52	55
14	13	16	20	23	26	29	33	36	39	42	46	49	52	55	59	62	65	68	72
16	16	20	25	29	33	37	41	45	49	53	57	61	65	70	74	78	82	86	90
18	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110
20	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132
22	28	35	43	50	57	64	71	78	85	92	99	106	113	120	128	135	142	149	156
24	33	41	49	58	66	74	82	91	99	107	115	123	132	140	148	156	165	173	181
26	38	47	57	66	76	85	95	104	113	123	132	142	151	161	170	180	189	198	208
28	43	54	64	75	86	97	107	118	129	140	150	161	172	183	193	204	215	225	236
30	48	60	73	85	97	109	121	133	145	157	169	181	193	206	218	230	242	254	266
32	54	68	81	95	108	122	135	149	162	176	189	203	216	230	243	257	270	284	297
34				105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330
36				116	132	149	166	182	199	215	232	248	265	281	298	315	331	348	364
38				127	145	164	182	200	218	236	254	273	291	309	327	345	363	382	400
40				139	159	179	199	218	238	258	278	298	318	338	357	377	397	417	437
42				151	173	194	216	238	259	281	302	324	346	367	389	410	432	454	475
44				164	187	211	234	257	281	304	328	351	374	398	421	445	468	491	515
46							253	278	303	328	354	379	404	429	455	480	505	530	556
48							272	299	326	353	381	408	435	462	489	516	544	571	598
50							292	321	350	379	408	438	467	496	525	554	583	612	642
52							312	343	374	406	437	468	499	530	562	593	624	655	686
54							333	366	400	433	466	500	533	566	599	633	666	699	733
56							355	390	426	461	496	532	567	603	638	674	709	745	780
58										490	527	565	603	640	678	716	753	791	829
60										519	559	599	639	679	719	759	799	839	878
62										549	592	634	676	718	761	803	845	887	930
64										580	625	669	714	759	803	848	893	937	982
66										612	659	706	753	800	847	894	941	988	1035
68										644	694	743	793	842	892	941	991	1040	1090
70										677	729	781	833	885	938	990	1042	1094	1146
72													875	930	984	1039	1094	1148	1203
74													917	974	1032	1089	1146	1204	1261
76													960	1020	1080	1140	1200	1260	1320
78													1004	1067	1130	1192	1255	1318	1381
80													1049	1115	1180	1246	1311	1377	1442

* Volume (cubic feet) = 0.000043153 * DBH^1.723417 * Total Height^0.999809 * 65^1.049283