Forest Service Handbook
National Headquarters (WO)
Washington, DC

Forest Service Handbook 2409.12a – Timber Volume Estimator Handbook
Chapter 50 - Application

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Approved by: Jack Ward Thomas, Chief

Date approved:

Responsible Staff:

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Superseded Document(s):

Digest: Following is an explanation of the changes throughout the directive by section.

2409.12a: Establishes new Timber Volume Estimator Handbook that provides Service-wide standards and instructions for preparation of equations or tables used to estimate the timber content of trees.

Table of Contents

50.2 - Objective

Use volume estimates to:

1. Predict current standing timber inventory volumes, future potential yields, and long term sustained yield.

2. Develop timber sale volumes based on timber cruise data.

3. Analyze efficiency and effectiveness of timber management practices.

51 - Standardization

51.1 - Approved Regional Volume Estimators

Regional Foresters should supplement this section with the approved regional and local volume estimators for all tree species and tree conditions found within the region (sec. 04.21). Include tree quality or value predictors. Display volume functions by species and geographic limitations. Describe any other limitations on volume estimator use. If the volume estimator has been calibrated, include the calibration functions.

51.2 - Total Cubic Content

The volume of the tree is its total cubic content. Do not confuse the total cubic content with the cubic product content of the tree as determined by a scaling process and formula application.

51.21 - Smalian's Formula

Use Smalian's formula, which is the form of a frustum of a paraboloid to estimate the cubic volume in a log. A discussion of this formula is contained in Bruce and Schumacher (sec. 08). It is the basis for the cubic log scaling rule (FSH 2409.11a).

Smalian's formula Ls based on equation:

$$V = K (D_0^2 + D_1^2) L$$

where,

V = volume in cubic feet

D_0 = diameter at the small end in inches

D_1 = diameter at the large end in inches

L = length in feet

K = .002727

51.22 - Approximating Total Volume

When possible, mathematically integrate stem profile functions to obtain a volume function. There are some stem profile equations which do not have an integral form. In such cases, approximate a true integral by segmenting the tree into short pieces, calculating the volume for each piece, and adding up the pieces. Since the utility of most stem profile equations is best if they are imbedded into a computer program, consider the approximation procedure to be practical.

Use the following procedure to find the total fiber content of the tree:

1. Ground to 1 foot. Treat this segment as a cylinder with both large and small end diameter equal to the inside bark diameter calculated at a height of 1 foot.

2. One foot to the tip. Determine a diameter for each 4-foot piece up the tree starting at 1 foot, resulting in diameters at 1 foot, 5 feet, 9 feet, and so forth. Calculate the volume for each 4-foot piece using Smalian's formula. Expect the top piece to be some length other than 4 feet and sum the pieces and the 1-foot stump to equal the height of the tree. Section 51.31, Exhibit 01 illustrates this process.

51.3 - Merchantable Volume

51.31 - Segmentinq the Tree

Recognize that segment lengths affect both the calculation of cubic volume and board foot product estimation. See FSH 2409.12, Timber Cruising Handbook; FSH 2409.11, National Forest Log Scaling Handbook; and FSH 2409.11a, Cubic Scaling Handbook for additional direction. Use the following segmentation rules to determine the volume of a tree:

1. The 20-foot rule (FSH 2409.11, The National Forest Log Scaling Handbook).

2. The 16-foot rule (FSH 2409.11, The National Forest Log Scaling Handbook).

3. The 40-foot West Coast Bureau rule (FSH 2409.11, The National Forest Log Scaling Handbook).

4. The 20-foot cubic rule (FSH 2409.11a, The National Forest: Cubic Scaling Handbook).

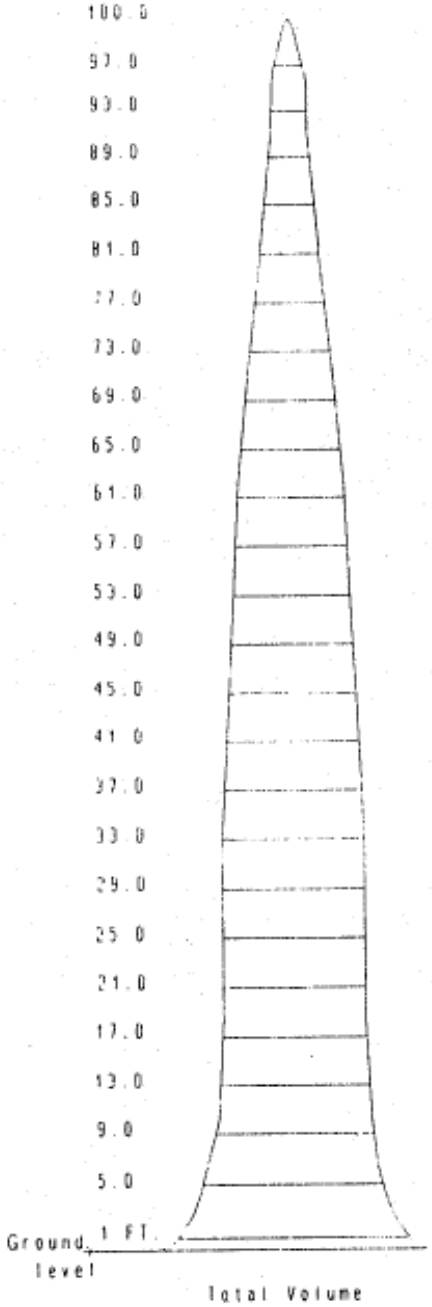
5. The nominal log length rule.

The first four rules are scaling rules and define how a log should be segmented if it were presented for scaling. For tree volumes in this handbook, it is assumed that the logs are uncut and presented for scaling in tree lengths.

If the nominal log length rule is used in cruising timber, it is customary to go up the tree in 16 foot increments until the stem diameter is less than specified for merchantability. The top piece may be less than the nominal 16 feet, and if so, round down to the nearest length that is a multiple of 2 feet. Consider visualized segments that are graded and have defect estimates made for them.

51.31 - Exhibit 01

Main Stem Total Fiber Content in Cubic Feet



Height Above Ground (ft.)	Diameter inside Bark (in.)	Cubic Foot Volume
100.0	0.0	
97.0	2.66	.06
93.0	4.23	.27
89.0	5.5	.52
85.0	6.65	.81
81.0	7.73	1.13
77.0	8.78	1.49
73.0	9.78	1.88
69.0	10.77	2.30
65.0	11.74	2.77
61.0	12.67	3.25
57.0	13.55	3.75
53.0	14.38	4.26
49.0	15.17	4.77
45.0	15.93	5.28
41.0	16.66	5.80
37.0	17.37	6.32
33.0	18.05	6.85
29.0	18.72	7.38
25.0	19.36	7.91
21.0	19.99	8.45
17.0	20.61	8.99
13.0	21.21	9.54
9.0	21.8	10.09
5.0	22.38	10.65
Ground, 1 FT. level	29.23	14.78 4.66
Total Volume		133.96

51.32 - Trim

In the rules discussed in section 51.31 there is an assumed trim. This is specified in advance and is usually .5 feet per log or 4 inches per log. When merchantable volume is calculated, do not include trim. When selling sawlogs or veneer logs, do not charge for the trim piece.

51.33 - Rounding Diameters

When determining the merchantable volume, do not use log diameters in fractional form. For example, round a 12.3 inch diameter inside bark (dib) to 12 inches, a 12.6 inch dib to 13 inches.

51.34 - Top Log

Under the log scaling rules identified in section 51.31, segment the top log of a tree according to a published table, such as those found in the National Log Scaling Handbook, FSH 2409.11 (sec. l7), or calculate it according to the rule being used. Also, determine the merchantability (utilization) specification for top diameter.

As an example, a tree may be 54 feet in length from the stump to the minimum merchantable top diameter. Under the 20-foot rule no segment may be longer than 20 feet and should be in 2-foot multiples. Thus the 54-foot piece, may have three logs for which there would be 1.5 (0.5 x 3) feet of trim. Round the trim to 2 feet, and determine the "scaled" length to be 52 feet (54 minus 2). Divide the 52-foot piece into segments of approximately equal length with the smallest log on top resulting in two logs of 18 feet and a top log of 16 feet.

51.35 - Merchantable Cubic Volume

After the tree is segmented, calculate cubic volume. Calculate the inside bark diameters using diameter breast height of the tree along with the height up the bole. Calculate height up the bole by adding the segments plus the trim allowance. For the butt log, the big end diameter is the inside bark diameter 4 feet above the large end. Thus, each log has a small end diameter, a large end diameter, and a nominal length. Use Smalian's formula to calculate the gross cubic volume. See FSH 2409.11a, Cubic Scaling Handbook for detailed direction on calculating merchantable cubic volume of each segment.

Recognize that Smalian's formula overestimates cubic volume for long segments and accordingly, avoid very long segments. Watch for cases where the merchantable cubic volume exceeds the total cubic volume calculated using the pseudo-integration method. Note also that in the scaling rules, diameters and lengths are rounded.

51.36 - Board Foot Scale

Use board foot log rules to estimate the products in board feet for logs of specific diameters and lengths. For rules such as Scribner Decimal C based on log diagrams, look up the Scribner Decimal C volume in tables in the National Forest Log Scaling Handbook, FSH 2409.11 or other

factor tables. Recognize that factor tables may be slightly different from the actual Scribner table, especially for small diameter logs. Apply the board foot rule to the same segments which were calculated for the merchantable cubic volume.

For formula rules such as the International 1/4 inch rule use the equation:

$$\text{International 1/4 inch rule (Bd. ft.)} = 0.049762\ LD^2 + 0.006220\ L^2D - 0.185476\ LD + 0.000259\ L^3 - 0.011592\ L^2 + 0.042222\ L$$

where:

D = diameter inside bark at the small end of the log in inches
L = log length in feet

Recognize that conversion between board foot rules and from board foot to cubic varies with log size and if conversion is necessary, convert on a log-by-log basis. Also board foot rules estimate lumber cut from logs, but actual output may be different. Calculate overrun to express the variation between the estimate (log scale) and the actual lumber (mill tally) sawn from the log:

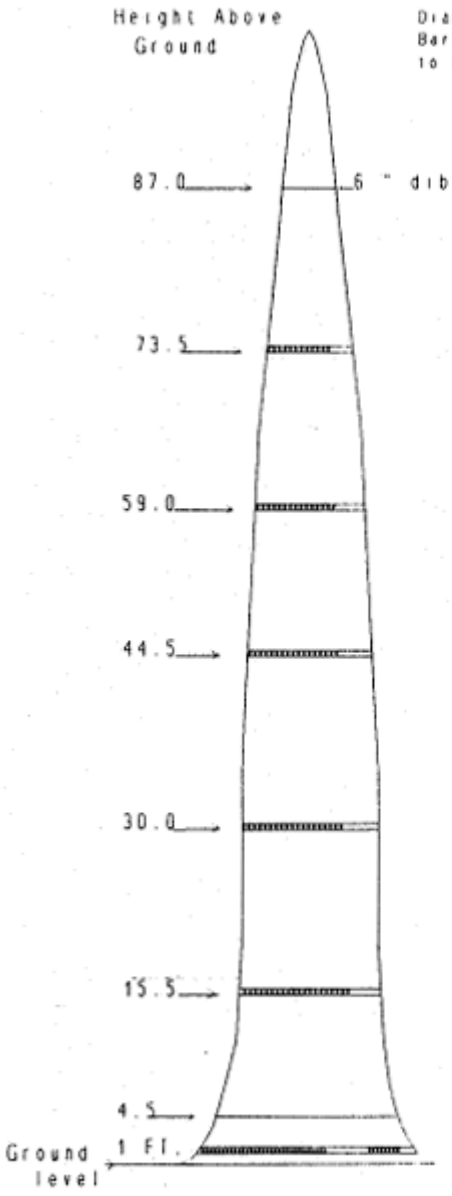
$$\text{percent overrun} = [(\text{mill tally} / \text{log scale})]100$$

51.37 - Examples of Seqmentation and Volume Calculation

See exhibits 01 through 06 which illustrate the segmentation rules described in 51.31 to 51.34 needed to calculate volume and product estimates. Exhibit 07 summarizes the volumes presented in the figures. Note that each method gives a slightly different answer. For the example tree, the differences are small. For other tree sizes, this difference could be large. Recognize that as the trees get shorter, the relative effect of the segmentation rule become more important.

51.37 - Exhibit 01

Segmentation According to the 16 Foot Rule (FSH 2409.11)



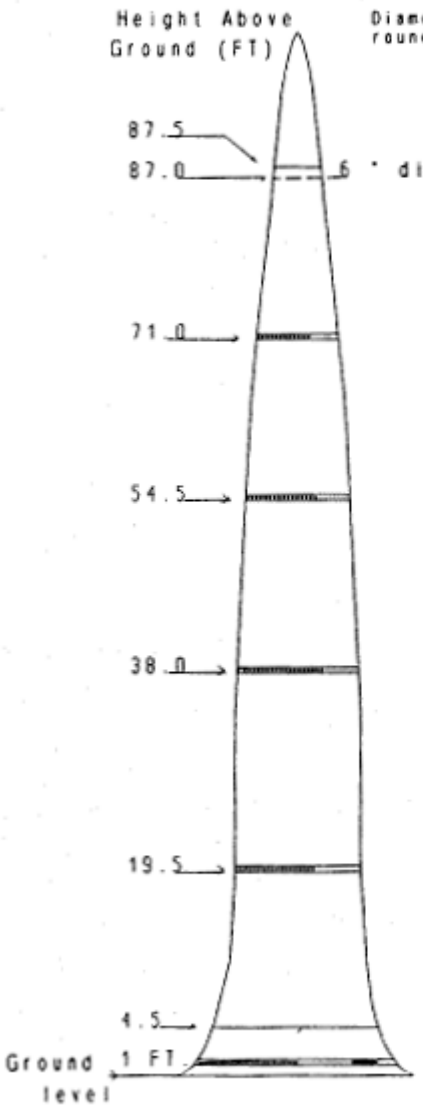
Height Above Ground	Diameter inside Bark rounded to nearest inch	Cubic Foot Volume	Board Foot Volume Scribner Int'l 1/4
87.0	6 " dib 6.0		
		4.8	1.0 1.5
73.5	10.0		
		10.3	4.0 5.5
59.0	13.0		
		16.2	8.0 10.0
44.5	16.0		
		22.1	14.0 15.5
30.0	18.0		
		29.2	19.0 20.0
15.5	21.0		
		37.0	27.0 28.0
4.5	23.0		
Ground level 1 Ft.		---	--- ---
	Total Volume	119.6	73.0 80.5

[Trim length of 5 ft]

51.37 - Exhibit 02

51.37 - Exhibit 02

Segmentation According to the 20 Foot Rule (FSH 2409.11)

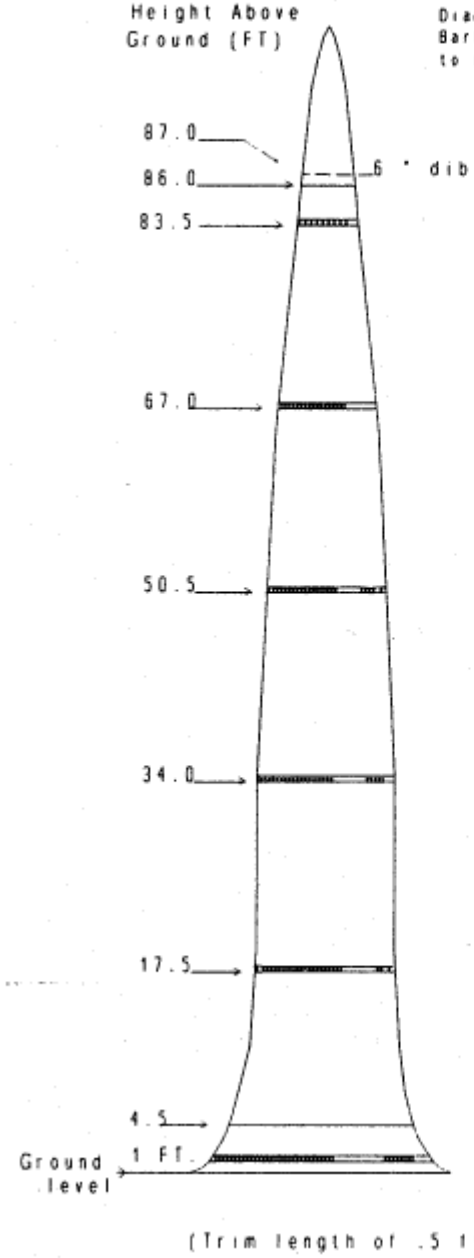


Height Above Ground (FT)	Diameter Inside Bark rounded to nearest inch	Cubic Foot Volume	Board Foot Volume Scribner	Board Foot Volume Int'nl 1/4
87.5				
87.0	6.0			
		5.9	2.0	2.0
71.0	10.0			
		12.9	6.0	6.5
54.5	14.0			
		21.2	11.0	13.5
38.0	17.0			
		33.8	21.0	23.5
19.5	20.0			
		45.6	31.0	33.0
4.5	23.0			
Ground level 1 FT.	Total Volume	119.4	71.0	78.5

(Trim Length is .5 ft)
Note: Scaling length is 86 ft, this will leave an unused .5ft which will round up to the next foot.

51.37 - Exhibit 03

Nominal Log Length of 16 Feet. Top Segment Scaled as it is.

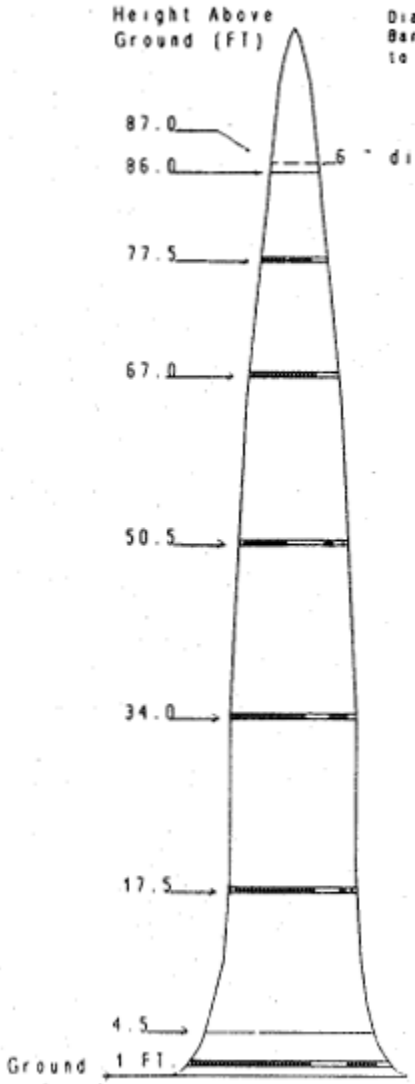


Height Above Ground (FT)	Diameter Inside Bark rounded to nearest inch	Cubic Foot Volume	Board Foot Volume Scribner	Board Foot Volume Int'nl 1/4
87.0				
86.0	6.0	.5	0	0
83.5	7.0	7.4	3.0	3.0
67.0	11.0	15.1	7.0	8.0
50.5	15.0	24.0	14.0	16.0
34.0	18.0	31.6	21.0	23.0
17.5	20.0	40.5	28.0	29.0
4.5	23.0			
Ground level 1 FT.				
		Total Volume 119.1	73.0	79.0

(Trim length of .5 ft)

51.37 - Exhibit 04

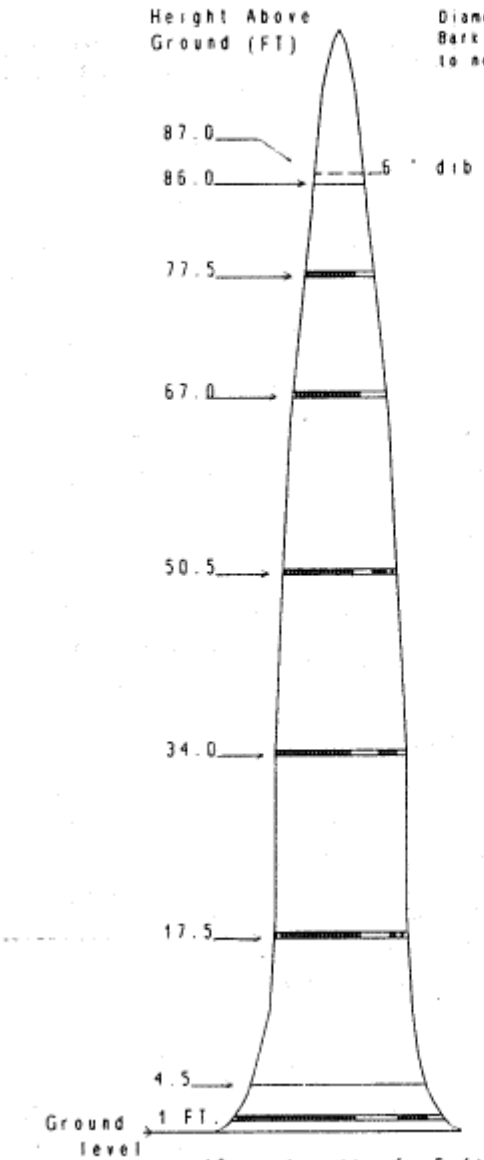
Nominal Log Length of 16 Feet. 16 Foot Maximum Length Rule.



Height Above Ground (FT)	Diameter Inside Bark rounded to nearest inch	Cubic Foot Volume	Board Foot Volume Scribner	Board Foot Volume Int'nl 1/4
87.0 – 86.0	6.0			
		2.6	.5	1.0
77.5	9.0			
		5.5	3.0	3.0
67.0	11.0			
		15.1	7.0	8.0
50.5	15.0			
		24.0	14.0	16.0
34.0	18.0			
		31.6	21.0	23.0
17.5	20.0			
		40.5	28.0	29.0
4.5	23.0			
Ground level 1 FT.				
(Trim length of .5 ft)				
	Total Volume	119.3	73.5	80.0

51.37 - Exhibit 05

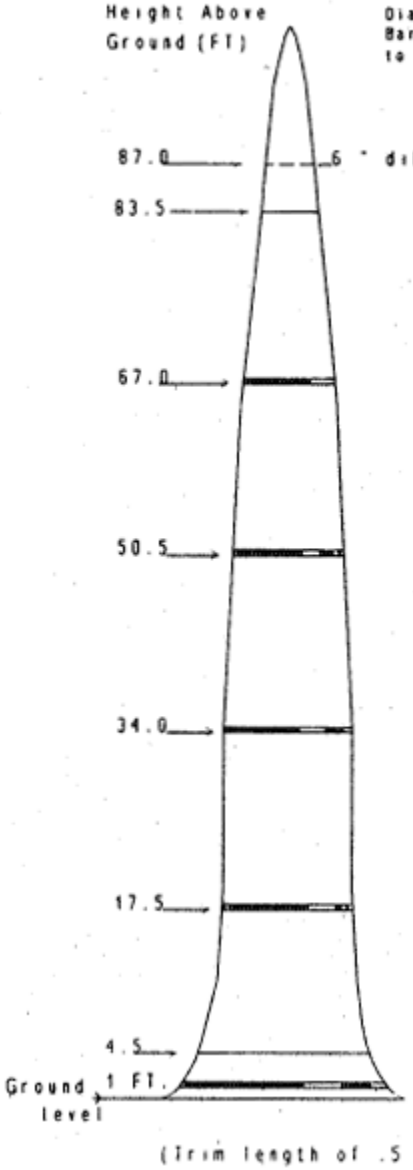
Nominal Log Length of 16 Feet. If Top is Less than Half Log, use 16 Foot Maximum Length if More, Scale as it is.



Height Above Ground (FT)	Diameter Inside Bark rounded to nearest inch	Cubic Foot Volume	Board Foot Volume Scribner	Board Foot Volume Int'nl 1/4
86.0	6.0			
		2.6	.5	1.0
77.5	9.0			
		5.5	3.0	3.0
67.0	11.0			
		15.1	7.0	8.0
50.5	15.0			
		24.0	14.0	16.0
34.0	18.0			
		31.6	21.0	23.0
17.5	20.0			
		40.5	28.0	29.0
4.5	23.0			
Total Volume		119.3	73.5	80.0

51.37 - Exhibit 06

Nominal Log Length of 16 Feet. Top Segment Rounded to Nearest Half Log.



Height Above Ground (FT)	Diameter Inside Bark rounded to nearest inch	Cubic Foot Volume	Board Foot Volume Scribner	Board Foot Volume Int'l 1/4
87.0	6 " dib			
83.5	7.0			
		7.4	3.0	3.0
67.0	11.0			
		15.1	7.0	8.0
50.5	15.0			
		24.0	14.0	16.0
34.0	18.0			
		31.6	21.0	23.0
17.5	20.0			
		40.5	28.0	29.0
4.5	23.0			
1 FT.				
Ground level	Total Volume	118.6	73.0	79.0

51.37 - Exhibit 07

Summarization of Volume by Segmentation Rule

	Total Fiber	From Ex 01	From Ex 02	From Ex 03	From Ex 04	From Ex 05	From Ex06
Gross Sawlog	119.6	119.4	119.1	119.3	119.3	118.6	
Trim	5.9	5.0	5.3	5.4	5.4	5.2	
Top	1.3	1.2	1.4	1.4	1.4	2.2	
Stump	4.6	4.6	4.6	4.6	4.6	4.6	
Total	134.0	131.4	130.2	130.4	130.7	130.7	130.6

51.4 - Automated Procedures

To minimize computational errors, use a computer program to calculate the segments, cubic, and board foot volumes. Ensure that the program is specific for each Region and Forest, and has embedded in it the standards approved by the Regional Forester (sec. 04.2).

51.5 - Metric

Metric units have the same characteristics as cubic feet. Use cubic meters for volume. Use formulas that have the same characteristics as the cubic foot formulas, except apply the constant K:

$$K = .00007854$$

52 - Volume Estimator Uses and Capabilities

52.1 - Types of Volume Estimators

52.11 - Profile Equations

Use profile equations that describe the stem form whenever possible. Profile equations are superior to other tree volume estimators because they calculate diameter all along the stem. Use profile equations not only in determining tree volume, but also if). determining log volume, grade, and value. Use them to determine changes due to bucking practices and different top diameter specifications. For a technical description of profile equations see chapter 30.

52.12 - Direct Volume Estimators

These may include volume tables, D^2H equations, alignment charts, logarithmic equations, local volume equations, or tarif tables. For a technical description of direct volume estimators see chapter 30. Avoid new development of this type of estimator.

52.13 - Aerial Estimators

Apply aerial photo volume estimation through a double sampling technique. Volume estimators for use with photo measurements often have parameters of total tree height, crown diameter, and crown area. Conduct field sampling of ground plots and compare with the photo plots of the same area. Consider bias involved in photo volume estimators to be resolved by double sampling.

52.14 - Biomass Estimators

Biomass estimators may be used to find the amount of wood, bark, and foliage in standing material, regardless of quality or size. Biomass is measured in weight; however, use the

traditional predictors, diameter and height, and regression analysis to predict weight. Use the diameter at the base of the live crown as the best indicator of crown weight.

52.2 - Flexibility

The flexibility of a volume estimator depends upon the type of estimator, its complexity, available computer capacity, and its intended use. Flexibility refers to range and ease of application. See chapter 30 for discussion of flexibility of specific volume estimators.

52.3 - Limitations of Estimators

Identify the estimator's limitation which may be geographical, technical, data related, or practical. Take reasonable care so that resulting volume estimates are not erroneous. See section 33.32 Exhibit 01 for a ranking of various volume estimator models.

53 - Applying the Estimators

53.1 - Typical Trees

A typical tree is normally formed and is described by its height and diameter breast height. Most stem profile equations are developed for normally formed trees. Apply them directly to normal trees.

53.2 - Nontypical Stands or Trees

To apply a volume estimator to a nontypical (abnormal) tree or stand, determine which stand or tree conditions were excluded from the development of the normal volume estimators. For example, forked or deformed trees or defective stands or local stand variations may have been excluded from volume estimator development. Use felled tree data, a dendrometer or laser device to develop a location or stand correction ratio as necessary to adjust stand volumes for abnormal trees or stands. Use localized procedures such as "fall, buck, and scale" or "correction factor scaling."

53.21 - Defective Stands

Identify highly defective stands which may vary in form from normal stands. For example, defect may cause excessive butt swell. Develop appropriate adjustments to the volume estimates locally such as developing a local regression equation based on normally formed trees in the stand

53.22 - Locality Based Form Variations

Identify local conditions such as elevation, site quality, age class, or disease that have major influence on tree form. If consistent, important variation occurs use calibration procedures (sec. 43). Develop a new estimator (sec. 32) if justified by an extensive condition and a large amount

of cruising or inventory to be done. If differences are minor or on an individual stand or tree basis, use procedures in sections 53.2-53.22.

53.3 - Tree Height

For general purposes, use total height in feet as the basis for applying volume estimators.

53.31 - Missing and Abnormal Tops

Determine heights for use of stem profile equations when trees are forked, or have missing or deformed tops. Estimate what the normal tree height of the tree would have been without the abnormality, and apply the estimator directly. Do this by developing a local regression equation based on normally formed trees in the stand, or by the cruiser making an estimate of total height. Estimate the missing or reduced volume as defect (sec. 53.5).

53.32 - Height to a Merchantable Top

In the case of hardwoods, height may have been measured to a merchantable top. If a tree species typically has no well defined bole above this point, do not measure total height. Do not measure total height when it is impossible or highly inaccurate. Use stem profile equations constructed from the ground to a merchantable height. Apply the equations by knowing the merchantable diameter and estimating height to the given diameter, or by measuring the diameter at the merchantable top using a dendrometer or laser device when merchantable diameter typically occurs where the bole ends at the base of the crown.

53.33 - Tree Height Measured in Logs

Avoid estimating heights in units of length such as 16-foot logs. Use shorter units such as feet or meters. Recognize, however, that some estimates of tree height are in logs.

Stem profile equations utilize total height in feet, and if log height is collected, transform it to total height in feet for use in a stem profile equation. Develop a local regression of log height verses total height and base this regression on trees which were actually measured for total height.

53.4 - Utilization Specifications

Adjust volume estimates and estimators when changes in utilization specifications occur. These may affect merchantable log lengths, average tree volume, number of logs per unit of measure, and volume per acre. Even though volume tables based on a single fixed top diameter or set log lengths cannot be adjusted easily or accurately for changes in utilization specifications, the estimators must be adapted to the specifications in use. See field unit supplements to the Timber Sale Preparation Handbook, FSH 2409.18, section 54.5 or other local direction for applicable utilization specifications.

53.5 - Defect and Net Volume

Almost all volume estimators are constructed to determine gross volume. Therefore, determine defect and the net volume, as needed for timber sales or inventory purposes according to the directions in the Cubic Scaling Handbook, FSH 2409.11a, the National Forest Log Scaling Handbook, FSH 2409.11, and the Timber Cruising Handbook, FSH 2409.12.

53.6 - Appraisal Data Needs

Recognize that different geographic areas may require variations of a volume estimator based on appraisal practices. Use estimators to predict overrun, tree quality or grade, and lumber tally volumes, as needed in timber appraisals. Adapt the volume estimators accordingly. Table 01 lists some of the common appraisal data elements that may be computed or measured in volume estimation processes. See FSH 2409.18, sections 45-49.4 for appraisal direction.

53.6 - Table 01

Common Appraisal Items That Can Be Computed in Volume Estimation Processes.

1. Average DBH.
2. Average tree height.
3. Average merchantable tree height.
4. Volume per tree.
5. Woods and scaling defect.
6. Logs per thousand Board Feet (MBF) (16 or 32 foot).
7. Total number of logs (16 or 32 foot).
8. Overrun
9. Tree quality.
10. Largest log.
11. Largest tree.
12. Log grade.
13. Height to live limb.
14. Average volume per acre.
15. Total number of trees.