Forest Service Handbook
Service Wide (WO)
Washington, DC

Forest Service Handbook 2409.12 – Timber Cruising Handbook

Chapter 10 – Principles of Measuring Trees

Amendment Number: 2409.12-2024-1

Effective date: October 16, 2024

Duration: This amendment is effective until superseded or removed

Superseded Directive: 2409.12 chapter 10, Principles of Measuring Trees, 2409.13-1993.1

Approved by: Christopher French, Deputy Chief National Forest System.

Date approved: May 28, 2024

Responsible Staff: Forest Management, Rangelands Management, and Vegetation Ecology (FMRMVE)

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

Section 13.1: DBH Measuring Instruments section removed.

Section 13.2: Height Measuring Instruments section removed.

Section 14.11: Reading Diameter Tape section changed to Measuring Diameter Class

Section 14.31: Diameter at Root Collar section Added.

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Timber cruising is the determination of the gross and net product volume and value (timber quality) for a tract of timber or other forest product to be removed. It involves measuring tree diameters and heights, estimating defects, and making other determinations, such as grade and form class, that may be specified by the cruise plan. This chapter deals with the technical aspects of making tree measurements.

11 - Species Identification

Each timber cruiser must properly identify tree species. Stumpage rates, merchantability specifications, and many product volume references are species related. Species may be identified by bark characteristics, form, fruit type, cones, needles, leaves, and other features.

12 – Tree Merchantability Specifications

The tree merchantability standards are region-specific and closely tied to regional appraisal, pricing, and contract practices. Use the regional standards and obtain Regional Forester approval when different standards are needed. The minimum tree and piece merchantability specifications need to be included in the cruise design phase and documented in the cruise plan. These specifications will be included in the Timber Sale Contract to identify material to be removed. Knowledge of the minimum piece and tree specifications for each end product category is required. The cruiser must recognize and record the end product potential for cruised materials. End products are subdivided into three categories:

1. Material suitable for the manufacture into lumber or veneer.
2. Material suitable for conversion into chips.
3. Material suitable for conversion into other products such as poles, pilings, rails, ties, and house logs.

The minimum piece specifications are described by:

1. Length.
2. Diameter inside bark at the small end.
3. Net product volume as a percent of gross product volume.
4. Other timber sale specifications.

The minimum tree specifications are described by:

1. Minimum number of pieces a tree must contain to be merchantable.

2. Minimum diameter breast height.

3. Piece net volume.

13 - Tree Measuring Instruments

There are many tools available to measure tree diameters and heights. For tree diameters, instruments measure the diameter, or cross section, of the tree at a height of 4.5 feet from the ground, known as diameter at breast height (DBH). The most common tools are the diameter tape and the tree caliper. Additional measurements of diameter up the stem can be taken with more specialized equipment including optical dendrometers or relaskops. For tree heights, the most common tools are clinometers, hypsometers, relaskops, and laser measurement devices. For additional information on tree measuring instruments, refer to the Timber Cruising Guidebook (?).

14 - Measuring the Tree

Measuring individual tree variables in a consistent and prescribed manner is essential. All volume estimation procedures require some or all of the following measurements:

1. Diameter breast height (DBH).

2. Reference height (measured to a specific diameter inside bark (DIB) or diameter outside bark (DOB)).

3. Total height.

4. Stump height.

5. Tree form class.

14.1 - Measuring Tree Diameter

Tree diameters should be measured to the nearest 10^{th} of an inch.

14.11 – Measuring Diameter Class

Tree diameters are normally recorded to the nearest 10^{th} of an inch; however, there are situations where diameter measurements are made and recorded to the nearest 1- or 2-inch diameter class. This may occur when the precision of the measuring instrument is only 1 or 2 inches or specified product volume estimation procedures are based on 1- or 2-inch DBH classes. Standard 1- and 2-inch classes are:

Examples of 1-inch diameter class:

5-inch class = 4.6 - 5.5 inches.

9-inch class = 8.6 - 9.5 inches.

Examples of 2-inch diameter class:

12-inch class = 11.0 - 12.9 inches.

14-inch class = 13.0 - 14.9 inches.

There are situations where diameter measurements are not rounded. This situation occurs when absolute measurements are specified. Timber sale contract minimum tree DBH and minimum piece specifications are absolute.

Example 1:

Minimum tree DBH specification = 7.0 inches.

This means 6.9 would not be rounded to 7.0 inches.

Example 2:

Minimum piece specification = 7.6 inches DIB.

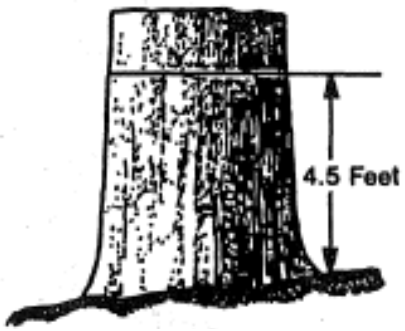
This means 7.5 would not be rounded up to 7.6 inches.

14.12 - Measuring Tree Diameter at Breast Height (DBH)

Measure DBH from the high ground side of the tree at 4.5 feet above the forest floor (ex. 01). If tree diameter cannot be measured at 4.5 feet because of abnormalities, measure as described in section 14.12d.

14.12 - Exhibit 01

Measuring DBH – Normal case

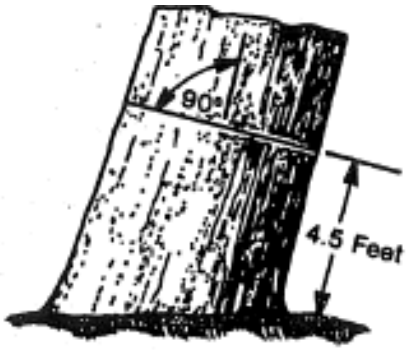


14.12a - Leaning Trees

Measure DBH on leaning trees at a right angle to the center line of the tree as shown in exhibit 01.

14.12a - Exhibit 01

Measuring DBH – Leaning trees



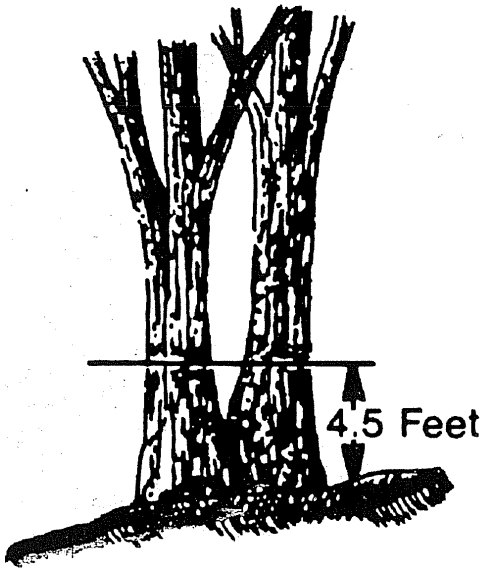
14.12b - Forked Trees

A forked tree is a tree with two or more sterns originating from one stump. Consider forking to start at the point where daylight is seen.

When a tree forks below 4.5 feet, consider as two trees and measure DBH on each stem at 4.5 feet above the ground on the high side (ex. 01). If either stem at this point is abnormal, measure as described in section 14.12d.

14.12b - Exhibit 01

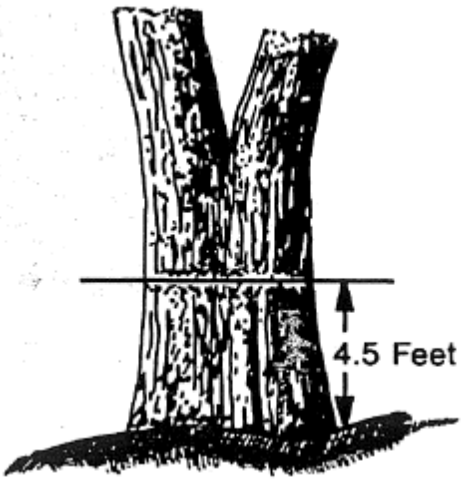
Fork occurs below 4.5 feet



When a tree forks at or above 4.5 feet, consider as one tree and record the smallest diameter at 4.5 feet or below (ex. 02).

14.12b - Exhibit 02

Fork occurs above 4.5 feet



14.12c - Trees Growing Together

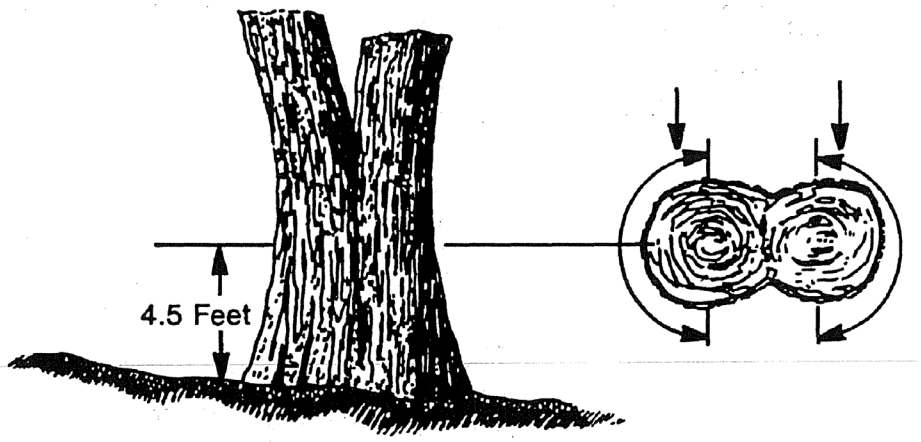
Two methods may be used to determine DBH on trees growing together.

1. If calipers are available, measure each tree at normal DBH point, 4.5 feet above high ground side.

2. If calipers are not available, use the one-half diameter method. Make two marks opposite each other on the stem at 4.5 feet. Measure the distance between the marks with a diameter tape; double the measurement to determine DBH.

14.12c - Exhibit 01

Measuring DBH on trees growing together

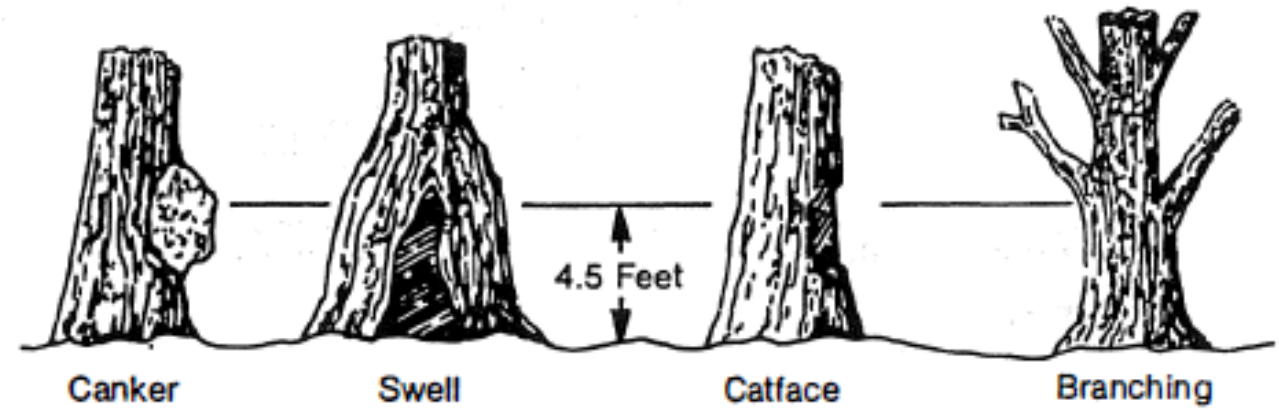


14.12d - Trees with Abnormalities at 4.5 Feet

Exhibit 01 illustrates examples of trees with abnormalities such as canker, swell, catface, or excessive branching.

14.12d - Exhibit 01

Abnormalities at 4.5 feet



Use one of the following procedures when DBH measurement cannot be taken at 4.5 feet:

1. If the tree can be measured at normally formed points above and below the abnormality, take measurements for "A" and "C" where tree exhibits normal taper and is free from influences of abnormality (exhibit 02).

   a. Measure diameter above DBH, point A.

   b. Measure diameter above DBH, point C.

   If these measurements are at **equal** distances from 4.5 feet, average A and C to arrive at DBH measurement.

   Example:

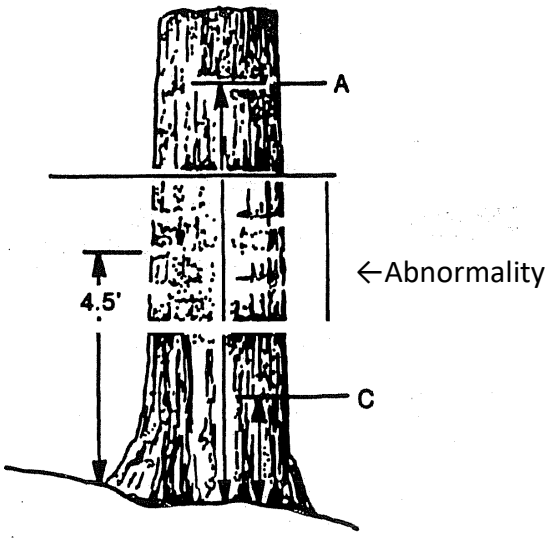
   Diameter at A = 16 inches.

   Diameter at C = 18 inches.

   DBH = $\frac{16 + 18}{2}$ = 17 inches.

14.12d - Exhibit 02

Techniques for determining DBH with abnormalities at 4.5 feet



If point A and point C are at unequal distances from 4.5 feet, interpolate the distances to arrive at DBH measurement.

Example:

Diameter at A= 16 inches

Diameter at C = 22 inches

Height of A above ground= 12 feet

Height of C above ground= 2 feet

Normal taper = $\frac{22" - 16"}{12' - 2'}$ = 0.6 inches/foot

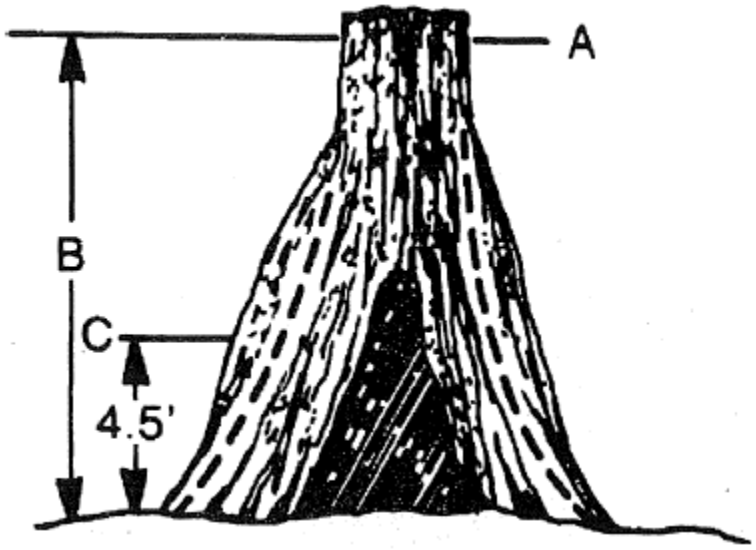
DBH = 22" - [(4.5' - 2') x 0.6"/ft.] = 20.5 inches or

DBH = 16" + [(12' - 4.5') x 0.6"/ft.] = 20.5 inches

2. If the tree cannot be measured at normal points above and below the abnormality, measure above the abnormality and apply taper from comparable trees of the same species (exhibit 03).

14.12d - Exhibit 03

Abnormal butt swell



3. Interpolate DBH measurement C based on diameter measurement A, the estimated average taper, and length B.

   a. Measure diameter above DBH where shape is normal, point A.

   b. Measure height to point A, length B.

   c. Determine average taper from comparable trees of the same species in immediate area.

   Example:

   Diameter at A = 18.0 inches

   Length of B = 12 feet

   Estimated taper = 2 inches in 8 feet or 0.25 inches per foot

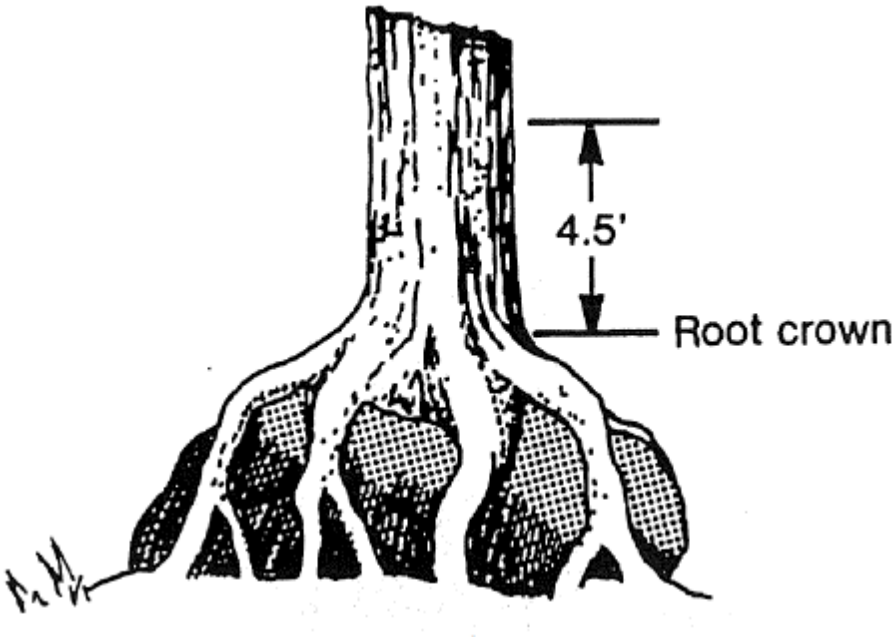
   DBH = 18” + ((12’ - 4.5’) x 0.25”) = 19.88 inches or 19.9 inches

14.12e - Trees Growing on Objects

When trees are growing on objects, such as rocks or logs, measure at 4.5 feet above the root crown rather than above the forest floor.

14.12e - Exhibit 01

Measuring DBH on trees growing on objects (rocks, logs)



14.12f - Coppice Growth

To measure DBH on coppice growth or on trees growing in clumps, follow the procedures described in section 14.12b - 14.12c.

14.12g - Broken Trees

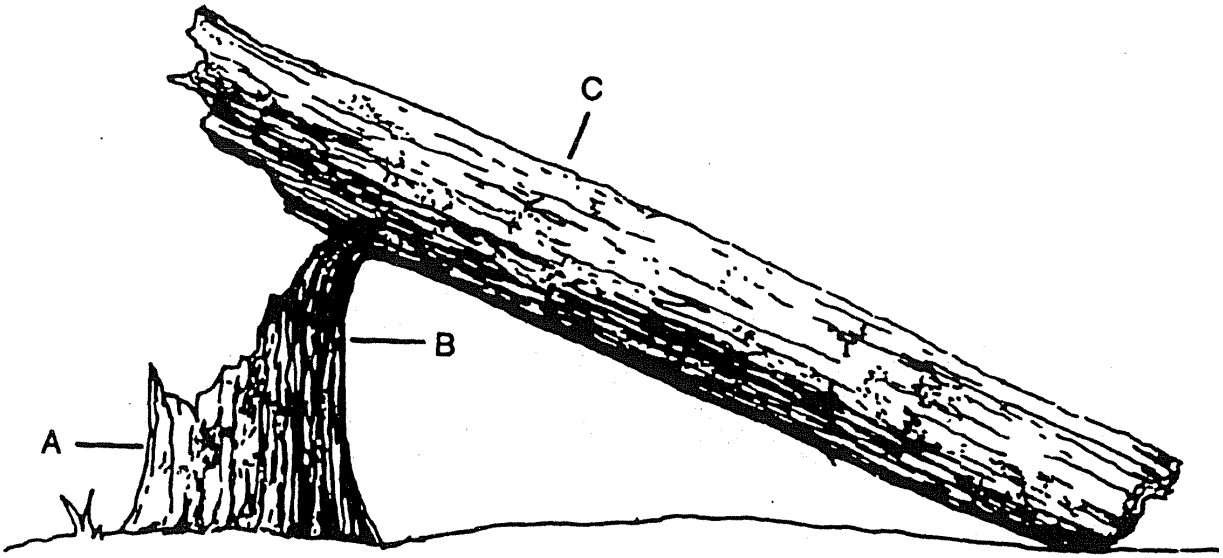
Use one of the following procedures to determine DBH on broken trees:

1. If DBH occurs either below the break A or above the break C, measure normally using calipers or diameter tape (ex. 01).

2. If DBH occurs at the break B as shown in Exhibit 01, use procedures outlined in section 14.12d.

14.12g - Exhibit 01

Measuring DBH on broken tree



14.12h- Broken Off Trees

Use one of the following procedures for determining DBH on broken off trees. Exhibit 01 illustrates these procedures.

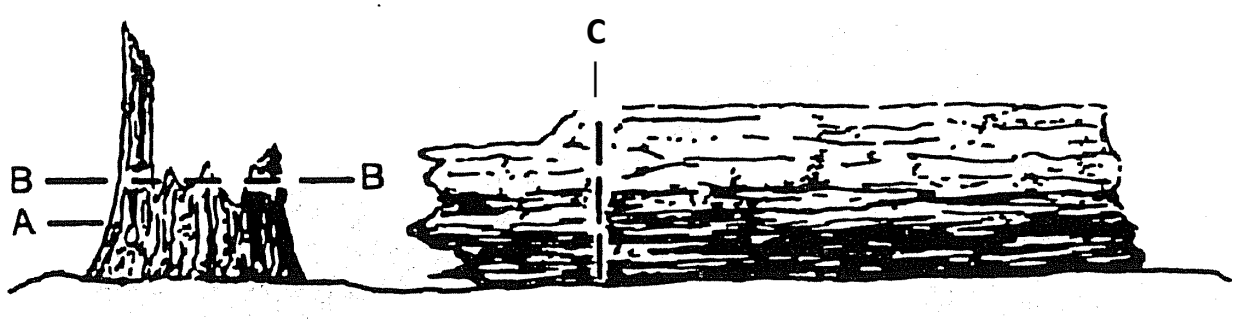
1. If DBH occurs below the break A, measure normally using calipers or diameter tape.

2. If DBH occurs at the break B, and if bole is not shattered, make the DBH measurement at the break point. If bole is shattered; use procedures in section 14.12d.

3. If DBH occurs above the break C, measure normally using calipers or diameter tape. If necessary, dig under bole, to pass the tape through.

14.12h – Exhibit 01

Measuring DBH on broken off tree

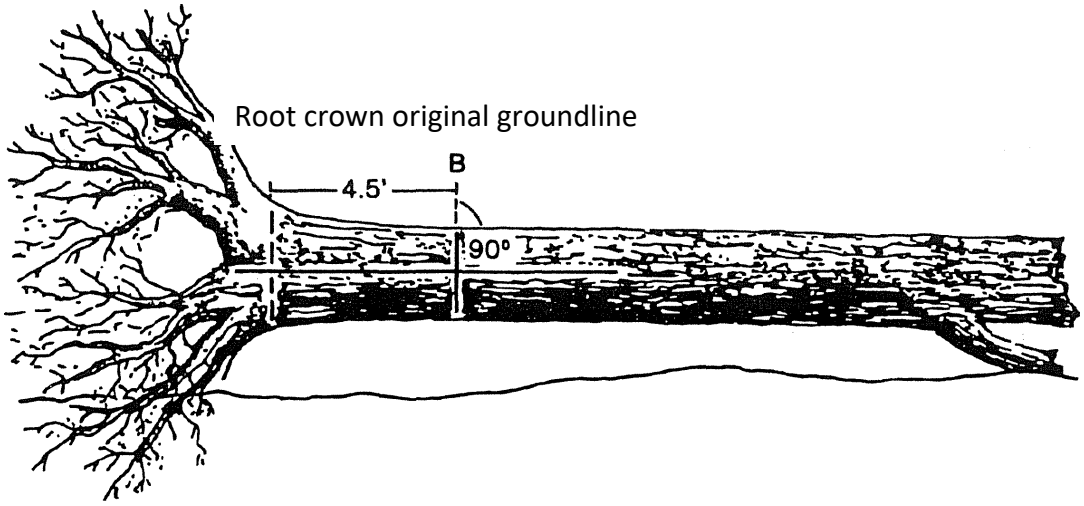


14.12i - Down Trees

On down trees measure DBH at 4.5 feet above original high side ground line at right angles to the center line of the bole B. Measure normally using calipers or diameter tape. If necessary, dig under bole, to pass the tape through.

14.12i – Exhibit 01

Measuring DBH on down trees



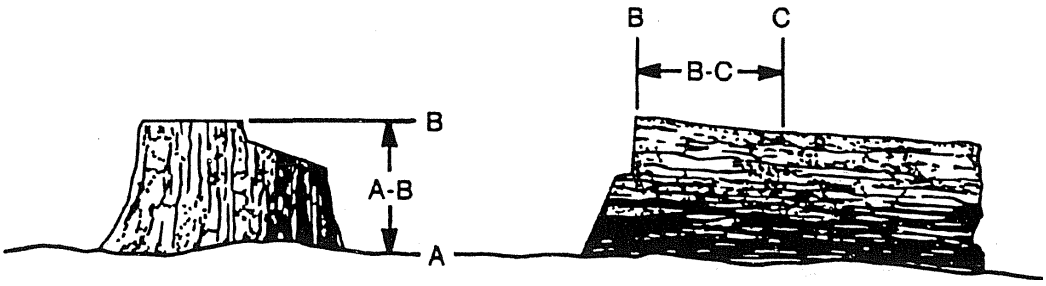
14.12j - Severed, Down Trees

Measure from the ground on the high side to the saw cut on the stump, height B and then from the saw cut on the end of the log up the bole to point C to determine where 4.5 feet above the

ground would be (ex. 01). Measure diameter at this point, normally using calipers or diameter tape. If necessary, dig under bole, to pass the tape through.

14.12j – Exhibit 01

Measuring DBH on severed trees

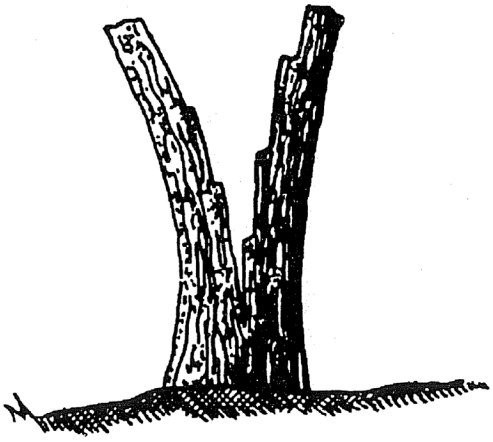


14.12k - Split Trees

Measure DBH with calipers or use the one-half diameter technique described in section 14.12c.

14.12k – Exhibit 01

Measuring DBH on split trees



14.12l- Trees Having a Large Catface

Use the most appropriate of the following procedures when measuring trees abnormally formed by a catface at 4.5 feet:

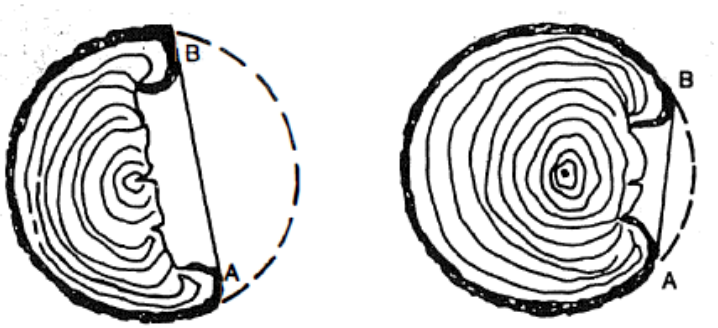
1. Use calipers. Measure DBH at right angle to catface.

2. Use a diameter tape. Adjust the tape to a normally rounded position to allow for the catface portion missing. If the tape is not adjusted but is pulled tight, the tape will be straight across the missing portion and the diameter read will be less than it should be (ex. 01).

3. Use the one-half diameter technique described in section 14.12c.

14.12l – Exhibit 01

Measuring DBH on trees with large catface



14.12m - Trees Without Bark

Volume estimation procedures assume Diameter Breast Height (DBH) will be measured outside bark. The DBH measurement for trees with no bark or only partial bark at 4.5 feet must be increased to reflect the contribution of the missing bark.

If a tree has no bark at 4.5 feet, add two times the average bark thickness (developed using data from trees with bark, of the same species, size, and geographic location) to the tree's DBH. If a tree has a partial bark covering at 4.5 feet, the individual making the measurement must use their best judgment in determining an accurate DBH.

14.13 – Diameter at Root Collar (DRC)

For species requiring DRC, measure the diameter at the ground line or at the stem root collar, whichever is higher (ex. 1). For these trees, treat clumps of stems having a unified crown and common rootstock as a single tree; examples include evergreen oaks, mesquite, juniper, and mountain mahogany. Treat stems of deciduous oak/maple woodland species (gamble oak and bigtooth maple) as individual trees if they originate below the ground.

14.13 - Exhibit 1

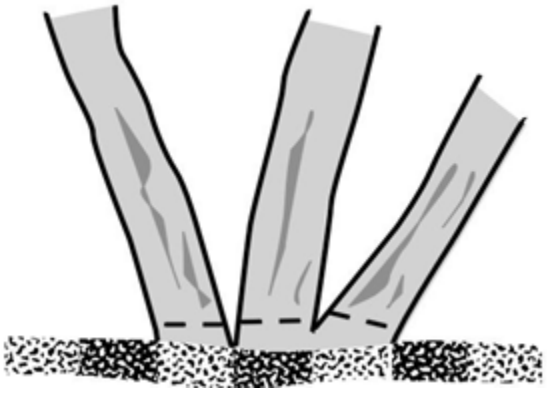
Measure diameter at ground line or at the stem root collar

For multi-stemmed trees, measure all stems with a diameter of 1.0 inch and greater (ex. 2). DRC is computed as the square root of the sum of the squared stem diameters.

14.13 - Exhibit 2

Measuring Multiple Stems

$$DRC = \sqrt{\sum (Stem\ Diameters^2)}$$



14.2 - Measuring Tree Heights

Most volume estimation procedures require accurate tree heights to provide an accurate estimate of tree volume. An error in tree height can result in an erroneous tree volume and by extension an erroneous sale volume.

The procedures described in this section apply to all height measuring instruments.

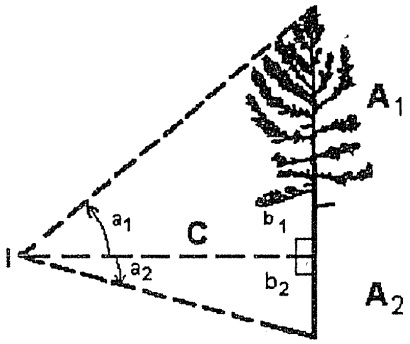
Heights of standing trees are calculated using measurements of baseline distance, elevation angle, and depression angle. An error in any one of these measurements will result in the calculation of an erroneous tree height.

The calculation of tree height is based on the "Law of Sines" which states, in part, for any triangle, if two angles and one side are known, then the remaining angle and two sides of the triangle may be found. The known side of the triangle is the baseline distance. The known angles are the right angle formed where the baseline intersects the tree bole and the measured elevation/depression, angle. Determine the length (height) on the tree bole from the baseline intersection to the sight point used for the elevation/depression angle (ex. 01).

14.2 - Exhibit 01

Measuring tree heights

C = Baseline distance.
a_1 = Elevation angle.
a_2 = Depression angle.
b_1,b_2 = Right angles (90°).
Tree height = Length A_1+A_2
l = Point at which measurements are taken.



It is usually more accurate to measure height from a point uphill from the tree or on the same contour line as the tree. Avoid measuring height downhill from the tree whenever possible.

Measure tree height to the tip of the tree and/or to specified reference heights, such as total merchantable height, or sawlog height. Depending on the volume estimation procedures used, a standard stump height may or may not be considered as part of the total or reference height measurement.

1. Total tree height. Measure from the base of the tree on the high ground side to the tip of the tree leader. Record total tree height to the nearest foot.

2. Reference heights. Measure using one of the following:

    a. To a specified diameter. Measure from the base of the tree on the high ground side to a specific reference diameter (minimum DIB or DOB).

b. To a merchantability limit. Measure from the base of the tree on the high ground side to a point above which the bole is too small or defective to meet the specified product utilization standards.

14.21 - Baseline Distance

Baseline distance is the horizontal distance from the face of the tree to a manufacturer's specified point on the height (angle) measuring instrument. Many instruments used to measure tree height are calibrated for specific baseline distances, such as the clinometer and the relaskop.

When using a tape to measure baseline distance, attach the tape at a convenient height on the tree and back off the required distance, pulling the tape tight. With a clinometer or releskop, find the percent slope of the tape going back to the tree. If the slope is over 10 percent, an adjustment to the measured slope distance is necessary to prevent a bias in the height calculation. Calculate the slope distance by multiplying the desired baseline distance by the slope correction factor (ex. 01). Back off the slope distance and measure the tree height from this distance, the desired baseline distance.

Example:

Initial measured base distance (desired horizontal distance) = 66 feet.

Percent slope to tree = 25.

Indicated slope distance for 66 feet = 68 feet (66 x 1.03).

This adjustment is necessary to ensure the desired horizontal distance is maintained.

14.21 – Exhibit 01

Slope correction factor (Corrects horizontal to slope distance)

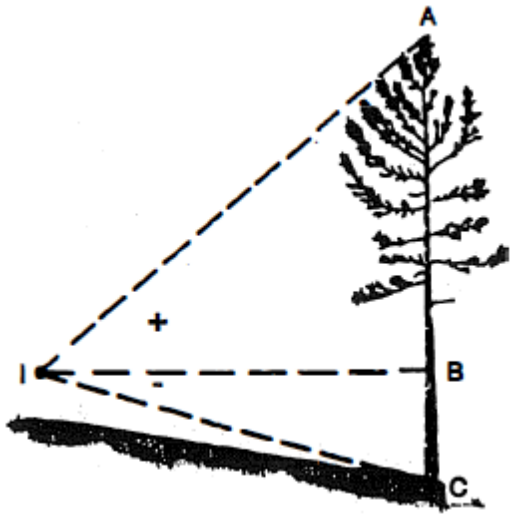
Slope Correction Factor			
Percent of Slope	**Slope Correction Factor**	**Percent of Slope**	**Slope Correction Factor**
0 to 9	1.00	70	1.22
10 to 17	1.01	71 to 72	1.23
18 to 22	1.02	73 to 74	1.24
23 to 26	1.03	75	1.25
27 to 30	1.04	76 to 77	1.26
31 to 33	1.05	78 to 79	1.27
34 to 36	1.06	80	1.28
37 to 39	1.07	81 to 82	1.29
40 to 42	1.08	83	1.3
43 to 44	1.09	84 to 85	1.31
45 to 47	1.10	86	1.32
48 to 49	1.11	87 to 88	1.33
50 to 51	1.12	89	1.34
52 to 53	1.13	90 to 91	1.35
54 to 55	1.14	92	1.36
56 to 57	1.15	93 to 94	1.37
58 to 59	1.16	95	1.38
60 to 61	1.17	96 to 97	1.39
62 to 63	1.18	98	1.4
64 to 65	1.19	99 to 100	1.41
66 to 67	1.20	101	1.42
68 to 69	1.21		

14.22 - Vertical Trees

Measure the height of a vertical tree whenever possible from either level ground or from the uphill side. Use elevation and depression angle measurements from horizontal to get the height. In exhibit 01, the elevation angle from the horizontal line to the tree top is shown by a (+); the depression angle from the horizontal to the ground by a (-).

14.22 - Exhibit 01

Measured on level ground or from the uphill side



If the two angles from horizontal have different signs (if measured from level or up-slope position), add the absolute values of the two height measurements to determine tree height. If both angles from horizontal have the same sign (if measured from the down-slope position), take the absolute values of the heights and subtract the smaller height reading from the larger one to get tree height.

Examples:

1. Tree measured from up-slope position:

   Instrument elevation to tree top, point A = +40 feet.

   Instrument elevation to ground, point C = -10 feet.

   Tree height= 40 ft. + 10 ft. = 50 feet.

2. Tree measured from down-slope position:

Instrument elevation to tree top, point A = +65 feet.

Instrument to ground, point C = +15 feet.

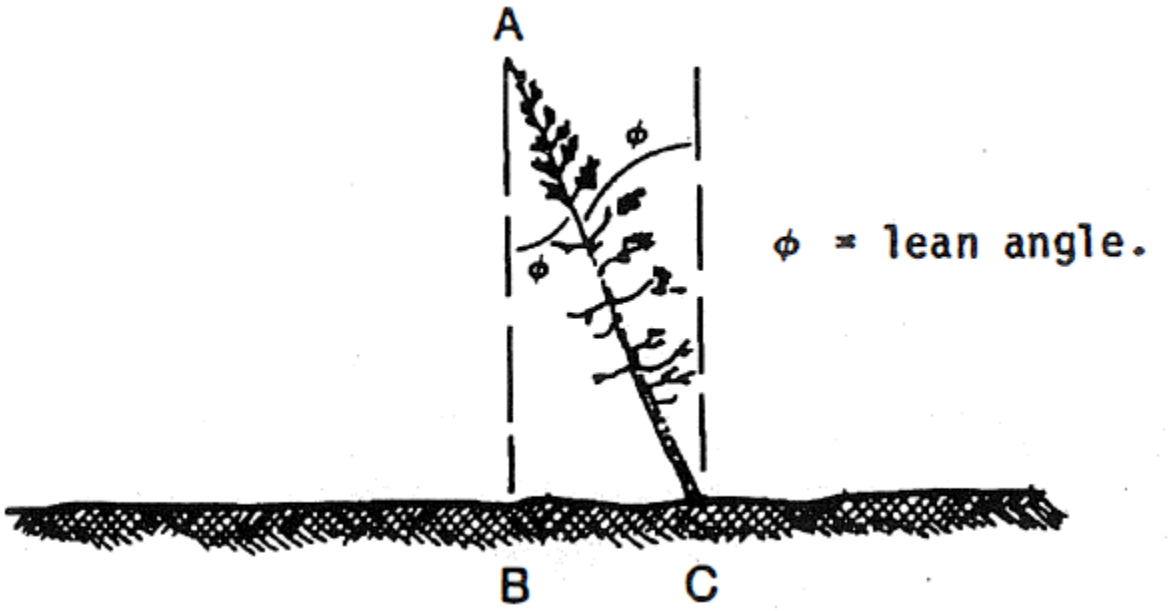
Tree height= 65 ft. – 15 ft. = 50 feet.

14.23 - Leaning Trees

Trees leaning 25 percent (about 15°) or more from vertical require the following special height measuring technique. See exhibit 01. The angle formed by the intersection of line AB and line BC must be a right (90°) angle.

14.23 - Exhibit 01

Measuring height of leaning trees



1. Determine vertical distance from the ground to the tip of the tree (AB).

2. Determine horizontal distance by measuring from the tree bole to a point directly under the tip of the leaning tree (BC).

3. Determine length of the bole (actual tree height, AC) using the Pythagorean theorem for right triangles where

$$\text{Tree height (bole length)} = \sqrt{\text{AB}^2 + \text{BC}^2}$$

Or use table 1 in chapter 90.

Example:

Vertical distance, ground tip (AB) = 65 feet.

Horizontal distance, stump to point under tip (BC) = 26 feet.

$$\text{Tree Height} = \sqrt{\text{AB}^2 + \text{BC}^2}$$

$$= \sqrt{65\text{ft.}^2 + 26\text{ft.}^2}$$

$$= \sqrt{4901\text{sqft.}}$$

$$= 70 \text{ feet.}$$

Alternatively, use the angle-of-lean method:

1. Measure Vertical Distance (AB)
2. Determine tree lean angle (θ in percent or degrees). The lean angle can be measured in degrees rather than percent, but then a trigonometric table or a scientific calculator is necessary to find the secant of the measured angle.
3. Multiply Vertical Distance by slope correction factor (sec. 14.21) to obtain bole length or the leaning tree height.

Example:

Lean percent = 40%, Slope Factor = 1.08.

(Lean angle = 22° Secant = 1.08)

Vertical Distance = 65 feet.

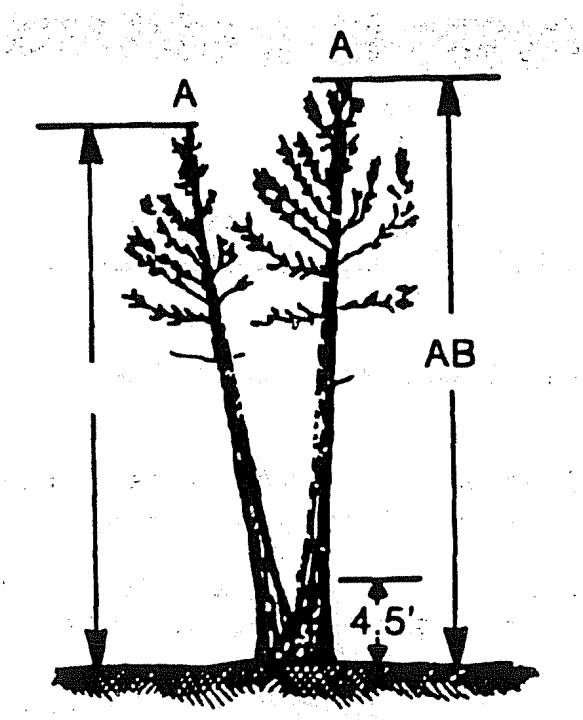
Leaning tree height = 65 ft. x 1.08 = 70 feet.

14.24 - Forked Trees

If trees fork below DBH, treat as two trees and measure height of each stem from base of tree to tip of tree.

14.24 – Exhibit 01

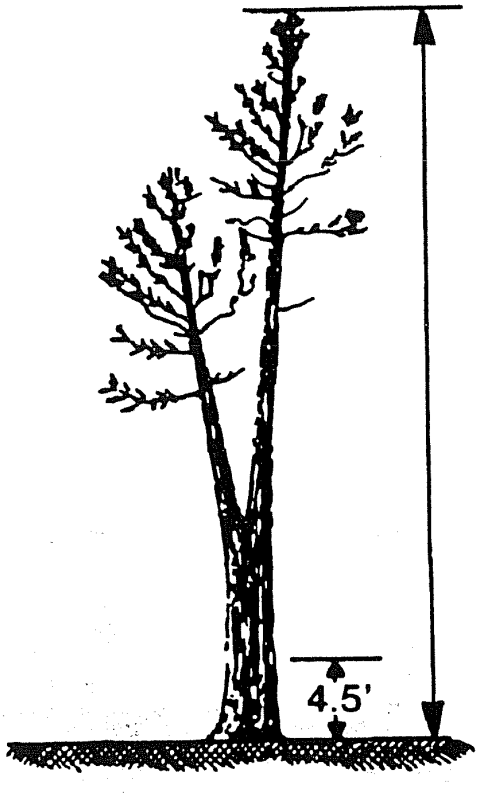
Height of trees forked below DBH



If the fork crotch occurs at or above 4.5 feet on high ground side, the tree is treated as a single tree. Measure height of the best fork.

14.24 – Exhibit 02

Height of trees forked above DBH



14.25 - Trees Having a Broken or Missing Top

Measure according to the following examples:

1. Total height of trees with broken top lying on the ground (ex. 01):

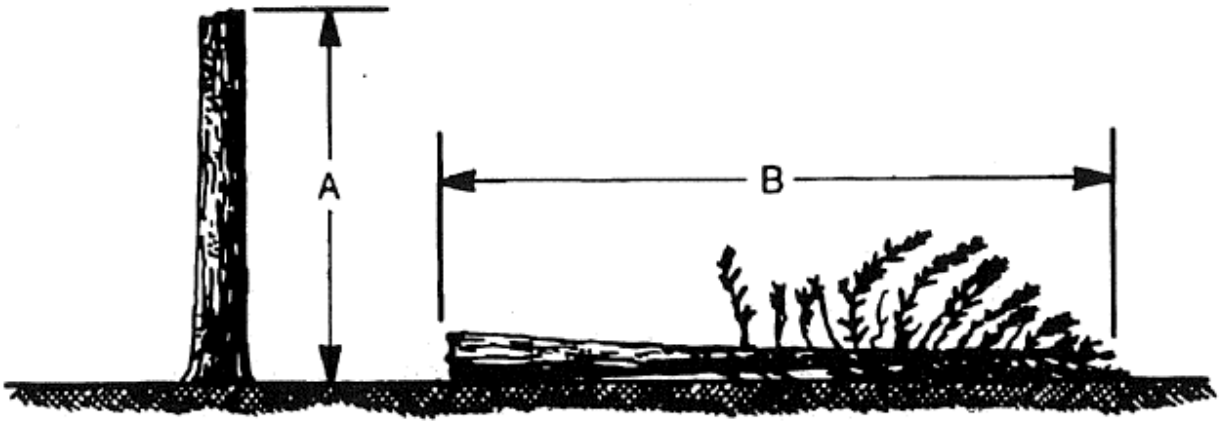
    a. Measure height of the stub (A).

    b. Measure length of the piece on the ground (B).

    c. Add the two measurements to obtain total height (A + B).

14.25 – Exhibit 01

Height of trees with broken top



2. Total height of trees with broken top attached (ex. 02). If distance to the break is short, measure tree height using procedures in paragraph 1. If distance to the break is great, measure tree height using the following procedures:

    a. Measure height to break (A).

    b. Measure ground distance from tip to stump (C).

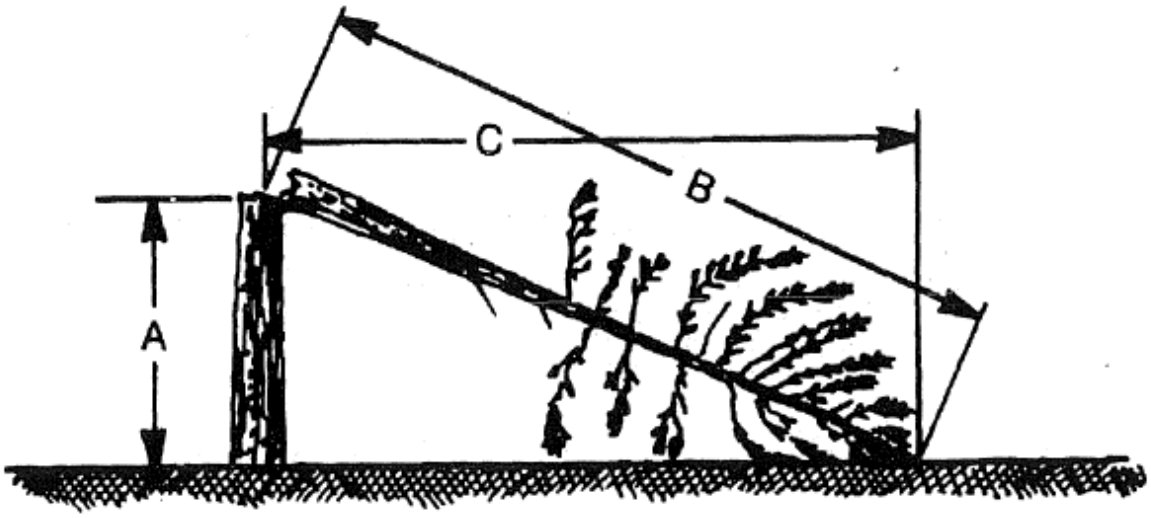
    c. Calculate length of the broken piece (B) using the Pythagorean theorem for right triangles where:

$$\text{Height B} = \sqrt{A^2 + C^2}$$

    d. Add the two height measurements to obtain total height (A + B).

14.25 – Exhibit 02

Height of trees with broken top attached.



3. Total tree height when top is missing. Locate three trees of the same species, with similar DBH measurements and diameter measurements at a convenient point up the tree, such as 16 feet, 32 feet, or other height. Measure total height of the three comparison trees and use their average height as the total height measurement. Some volume estimation models can determine the volume of a tree with a broken top by measuring the height and diameter where the break occurs. Check Regional and Forest directives for additional guidelines.

14.26 - Measurement Point is Hidden

There are many instances where height to be measured such as merchantable height cannot be measured directly. Dense foliage or foliage from an adjacent tree may obscure the measurement point. In these instances, obtain an average height from three comparison trees.

Example of comparison tree method for merchantable height (reference height):

	Tree 1	Tree 2	Tree 3	Average	Tree being Measured
Total Height	100 ft.	110 ft.	105 ft.	105 ft.	108 ft.
Merch. Height	81 ft.	87 ft.	84 ft.	84 ft.	to be estimated
DBH	16 in.	18 in.	18 in.	17.33 in.	17 in.

Average height ratio = 84 ft./105 ft. = 0.80

Reference height (tree being measured) = 108 ft. x 0.80 = 86.4 ft. = 86 ft.

14.3 - Tree Form Class

A measure commonly used as an independent variable along with DBH and height is Girard form class.

$$\text{Girard Form Class} = \left(\frac{\text{DIB at top of butt log}}{\text{DBH}}\right) \times 100$$

Specify the length of the butt log used for this purpose since form class may be expressed for either a 16-foot or 32-foot butt log. (Normally the DIB of the butt log is recorded at 17 or 33 feet above the ground to allow for a 1-foot stump.)

An alternate method of determining Girard form class is to use the Wiant f-c wedge, available from forestry supply houses. Match the wedge to the form of the butt log.

14.3 – Exhibit 01

Wiant F-C Wedge (reduced size)