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A program that uses taper functions to calculate volume to any merchantability standards that you desire.
The Author

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Cover photo: The PINEVOL title screen that introduces the program

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Abstract
Taper functions describe a model of the actual geometric shape of a tree. When this shape is assumed to be known, volume by any log rule and to any merchantability standard can be calculated. PINEVOL is a computer program for calculating the volume of the major southern pines using species-specific bole taper functions. It can use the Doyle, Scribner, or International ¼-inch log rules or calculate solid wood volume inside or outside of bark. This document describes the methods used in volume calculation in PINEVOL and is a program user’s guide.

Keywords: Loblolly pine, longleaf pine, shortleaf pine, slash pine, stem profile equations, taper functions.

Introduction
Tree volume is an important determinant of timber value. Information about tree volume is also important to those who evaluate alternatives to cutting and important forest characteristics like carbon sequestration. Volume growth information, which is based on volume calculations, can be more than just a measure of investment potential; it can describe the cumulative effects of the environment on trees since the bole develops and persists over time.

There are many ways to calculate tree volume. These range from tables like those presented in Miscellaneous Publication 50 (U.S. Department of Agriculture Forest Service 1976) to stem profile functions of the form suggested by Bennett and others (1978), which are used in this program. The form of stem profile function chosen works well and several authors who will be mentioned below have used it for a variety of species of southern pines. However, using a stem profile function to calculate volume is mathematically intensive. PINEVOL is a Visual Basic® program that performs all of the necessary calculations to calculate volume by several log rules to any desired merchantability limits.

Model Design and Assumptions
PINEVOL is based on the taper function developed by Bennett and others (1978). This model has been applied to most of the major southern pine species. A list of these species and the authors who prepared the models is presented in table 1.

This taper model allows volume calculation for any portion of a tree simply by integrating the function over height for any given upper and lower height. Volumes can also be calculated using a piecewise method if the upper and lower diameters of each piece are known.

Bennett and others (1978) provided one set of parameters for inside bark taper and another for outside bark taper. In order to increase the accuracy of these taper functions, each parameter set was further subdivided into three crown ratio classes, resulting in six sets of parameters for taper (Dell and others 1979, Feduccia and others 1979). A function for converting outside bark diameter at breast height in inches to inside bark diameter at breast height in inches was also calculated for each species and crown ratio class.

Base Taper Function
Bennett and others (1978) derive the following taper function:

\[
d(h) = \begin{cases} 
D(h/4.5)^b & \text{if } h_1 \leq h \leq 4.5 \text{ feet} \quad (1) \\
\frac{D(H-h)}{(H-4.5)} + b_1(h+h-4.5)/H^2 + b_2D(h-4.5)/H^2 + b_3D^2(h-4.5)/H^3 + b_4(H-h)(2H-h-4.5)/H^4 & \text{if } 4.5 \text{ feet} \leq h \leq H
\end{cases}
\]

where

\[d_i = \text{estimated regression parameters}\]
\[d = \text{predicted stem diameter (inches) at height } h\]
\[D = \text{diameter at breast height (inches)}\]
\[h = \text{height above breast height (inches)}\]
\[H = \text{total tree height (feet)}\]
\[h_i = \text{stump height above groundline (feet)}\]
Cubic Volume Calculation

Integrating equation (1) with respect to height of the base and top of the piece provides one means to estimate piece volume (Bennett and others 1978). Bennett and others (1978) divided this integral to predict volumes for parts above and below D (if both parts are included, simply add the partial volumes together).

\[
\text{VOL} = \left[ R_0 (h_v - h_l) + R_0 \cdot R_1 (h_u - h_l) \right] \frac{\Pi 4.5 - 2b_1 - b_3(b_v - b_l) - b_u(b_u - b_l)}{576(2b_2 + 1)} \quad \text{if } h_l \leq h_v < h_u \leq 4.5
\]

(2a)

\[
\text{VOL} = \left[ \frac{1}{3} (R_2^2 + 2R_0 \cdot R_2) (h_v^3 - h_l^3) + \frac{1}{2} (R_0 \cdot R_1 + R_2 \cdot R_1) (h_u^3 - h_l^3) \right.
\]

\[
+ \frac{1}{3} (R_2^2 + 2R_0 \cdot R_2) (h_v^5 - h_l^5) + \frac{1}{3} R_1 \cdot R_2 (h_u^5 - h_l^5)
\]

\[
\left. + \frac{1}{7} R_1^2 (h_u^7 - h_l^7) \right] \quad \text{if } 4.5 \leq h_l < h_u \leq H
\]

(2b)

where

\[
R_0 = \frac{DH}{H - 4.5} \left[ \frac{4.5b_1 + 9b_4 - 4.5b_3 \cdot D - 4.5b_3 \cdot D^2}{H} + \frac{20.25b_4}{H^2} \right]
\]

\[
R_1 = \left[ - \frac{D}{H - 4.5} + \frac{b_1 + 2b_4 + b_3 \cdot D + b_3 \cdot D^2}{H} \right]
\]

\[
\frac{4.5b_1 + 9b_4 + 4.5b_3 \cdot D + 4.5b_3 \cdot D^2}{H^2} - \frac{20.25b_4}{H^3}
\]

\[
R_2 = \frac{b_1 - 3b_4 - b_2 \cdot D - b_3 \cdot D^2}{H^2}
\]

\[
R_3 = \frac{b_1}{H^3}
\]

and \(h_l\) and \(h_u\) are the lower and upper piece heights, respectively. The \(R\) variables are used just to make equation (2b) more tractable. Volume could also be obtained numerically by quadrature, but this method is not discussed here.

Board Foot Volume Calculation

Some forest products are not measured in ways that are simply geometrical. For these, the taper function can be used to find the diameter at various heights. In turn, this information can

Table 1—Descriptions and limits of the models used for taper functions in PINEVOL. In many cases these limits were not shown by the original authors so the average of the remaining models was used for limits and these limits are shown in parentheses

<table>
<thead>
<tr>
<th>Citation</th>
<th>Species</th>
<th>Location</th>
<th>D.b.h. range</th>
<th>Height range</th>
<th>Crown ratio range</th>
<th>Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baldwin and Polmer</td>
<td>Planted longleaf pine (Pinus</td>
<td>Central Louisiana</td>
<td>1 – 21</td>
<td>12 – 90</td>
<td>(14 – 89)</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>palustris Mill.)</td>
<td>and east Texas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dell and others 1979</td>
<td>Planted slash pine (P. elliottii</td>
<td>West Gulf</td>
<td>(1 – 23)</td>
<td>(8 – 105)</td>
<td>(14 – 89)</td>
<td>3,784</td>
</tr>
<tr>
<td></td>
<td>Engelm.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farrar and Murphy 1987</td>
<td>Natural longleaf pine (P. e.</td>
<td>West Gulf</td>
<td>1 – 26</td>
<td>8 – 107</td>
<td>16 – 86</td>
<td>342</td>
</tr>
<tr>
<td></td>
<td>Mill.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feduccia and others 1979</td>
<td>Planted loblolly pine</td>
<td>West Gulf</td>
<td>(1 – 23)</td>
<td>(8 – 105)</td>
<td>(14 – 89)</td>
<td>100</td>
</tr>
</tbody>
</table>

*This represents the number of upper stem taper measurements since the number of trees was not given.*
be used to assemble product volumes as if one were physically scaling the tree. For instance, PINEVOL can determine tree volumes using Doyle, Scribner, and International ¼-inch rules. Doyle and Scribner are based on 16-foot logs with a trim allowance of 0.3 feet added for each 16-foot log. The International ¼-inch rule is based on 4-foot sections with the same trim allowance added every 16 feet.

For Doyle and Scribner rules, PINEVOL performs the following steps:

1. Sets the saw-log height utilized (HSAW) to the stump height and calculates the height of the tree (MERHT) to the specified minimum diameter for saw logs
2. Finds the minimum of the unused log (MERHT- HSAW) or a standard log (16 feet) and calls it the new piece
3. Sets the length of the new piece to be an even 2-foot interval equal to or lower than its current length
4. Checks whether the top of this piece with trim allowance added is still less than MERHT, and subtracts 2 feet if it isn’t
5. Calculates the new HSAW as the sum of the previous HSAW plus the new piece length plus the trim allowance and finds the scaling diameter at the top of this piece
6. Calculates the volume of this piece using the appropriate volume equation [equation (3) or (4)] and adds it to the total volume

The actual volume equations used are from the “Forestry Handbook” (Wenger 1984):

\[
\text{Doyle Volume} = (d_s - 4)^2 \frac{L}{16} \tag{3}
\]
\[
\text{Scribner Volume} = \frac{(0.79 d_s^2 - 2 d_s - 4) L}{16} \tag{4}
\]

where
\[d_s = \text{the scaling diameter (inches) of the piece}\]
\[L = \text{its length (feet)}\]

7. Loops back to step 2 until there is not at least a 2-foot section remaining below MERHT

The process for calculating the volume by the International ¼-inch rule is slightly different; PINEVOL

1. Sets the saw-log height utilized (HSAW) to the stump height, calculates the height of the tree (MERHT) to the specified minimum diameter for saw logs, sets the number of pieces (NPiece) to one, and sets the length of a piece (LPiece) to 4 feet
2. Finds the new HSAW by either adding LPiece and a trim allowance to the existing saw-log height if NPiece is a multiple of four (16-foot log) or the last possible piece on the tree or by just adding LPiece if it is in the middle of the log—increments NPiece by one
3. Calculates the scaling diameter at HSAW
4. Calculates the volume of this piece using the appropriate mathematical volume equation [equation (5)] and adds it to the total volume

\[
\text{Int ¼-inch Volume} = 0.049762Ld_s^2 + 0.00622L^2d_s - 0.185476Ld_s + 0.000259L^3 - 0.011592L^2 + 0.042222L \tag{5}
\]

5. Increments NPiece by one and sets LPiece to 4 feet
6. Determines if HSAW plus LPiece plus trim allowance will fit below MERHT and if not reduces LPiece by 2 feet—repeats this until LPiece is < 2 feet in length
7. If LPiece is at least 2 feet in length loops back to step 2

Program Operation

System Requirements

PINEVOL is a Windows® program so some version of Microsoft Windows 95 or higher is necessary. At least 10 MB of hard disk space for installation of the program and help files will be required. When running, the program uses 7 MB of RAM. The minimum screen resolution for this program is 1024 X 768. Lower resolutions do not prevent the program from running, but several of the screens will not fit entirely on the monitor.

Installation

PINEVOL is a standard Windows® program complete with an installation package packed in a Zip™ file. This Zip™ file is available at http://www.srs.fs.usda.gov/4111/techtrans.htm or by request from the author. To perform the installation a user has to open the Zip™ file, double click on setup.exe, and follow the prompts. Administrative privileges are not required to install PINEVOL. On some systems, such as Windows 2000®, there might be a warning about the possible need for administrative privileges but they are not necessary since PINEVOL does not change your system settings in any significant way. PINEVOL can be removed from a system via the Add/Remove Programs icon in the Windows® Control Panel.

Usage

If installed with the installation program, PINEVOL can be selected and run from the Start menu. This will produce the title screen shown in figure 1.
The title screen remains for up to 5 seconds. Click on the box labeled PINEVOL and the Volume Parameters screen (fig. 2) will appear immediately.

This screen is used to specify the parameters that affect what trees and what parts of those trees will be included in volume. PINEVOL assumes that total volume is always from groundline to the tip of the crown. However, merchantable and saw-log volumes can have variable stump heights, minimum breast height diameters, or minimum inside or outside bark top diameters.

PINEVOL looks for stored volume parameters in the file VOLUME.PRM in the install folder of this program. If PINEVOL fails to locate VOLUME.PRM, it applies a set of changeable default values. To replace the existing VOLUME.PRM file or create a new one, check the box “Save for future runs” before continuing.

The next screen (fig. 3) presents the user with a choice of modes of operation. PINEVOL can operate in either batch or interactive mode. The batch mode reads a data file for multiple stems and creates a new file containing volume estimates, whereas the interactive mode allows the user to input the parameters for individual trees.

Output

Whether the batch mode or the interactive mode is chosen, PINEVOL calculates the same information. Only the format differs. The first variable calculated is crown ratio. This is very important because the mathematical models used in this program rely on crown ratio to determine which taper parameters will be used. Next, PINEVOL shows which of the three crown ratio classes is actually used. Crown ratio class 1 is for crown ratios < 36 percent, crown ratio class 2 is for crown ratios from 36 to 50 percent, and crown ratio class 3 is for crown ratios that exceed 50 percent. Girard form class, or the percentage ratio of the inside bark diameter at the top of the first log to d.b.h. outside bark, is presented. Merchantable height is the height to the diameter specified for merchantable volume, and height to a saw-log top is the height to the diameter specified for sawtimber volume.
Figure 3—The Mode of Operation screen lets the user choose to process a file in batch mode or use the program as an interactive volume calculator.

Figure 2—The Volume Parameters screen is used to customize the calculated volume standards and also provides a save option for later use.
When a tree with a given saw-log height is actually broken into logs with trim allowance, usually the full height to a saw-log top cannot be used. Saw-log height actually utilized is the part that can. Total cubic-foot volume inside bark and total cubic-foot volume outside bark are volumes from the base to the tip of the tree. Merchantable volume inside bark and merchantable volume outside bark are volumes in cubic feet from stump height to the height of the specified merchantable diameter. The stump height used depends on the size of the tree. The saw-log stump height is used for trees that are large enough to have saw-log volume, and merchantable stump height is used for smaller trees. Saw-log volume inside bark and saw-log volume outside bark are the volumes in cubic feet from the saw-log stump height to the saw-log height actually utilized. Note that one can calculate the pulpwood harvest by subtracting saw-log volume from the merchantable volume in cubic feet. Volume by the Doyle rule, volume by the Scribner rule, and volume by the International ¼-inch rule are volumes in board feet by the most commonly used log rules. All of the volumes calculated are independent. This means that total tree volume includes merchantable tree volume. To calculate the unmerchantable portion of a tree, one can subtract merchantable volume from total volume.

**Batch Mode Operation**

Once batch mode is selected, the user is prompted to identify the data file (fig. 4). By default, only files with a .dat extension are shown. However, other specific extensions (such as .txt) can be used. PINEVOL input files must be ASCII text files and must contain at least a tree identification, a species code, a stand origin indicator (0 = natural, 1 = planted), a d.b.h. in inches, a total height in feet, and a height to the base of live crown in feet. Several arrangements of these variables are possible in delimited files or any arrangement is possible in a fixed-column format file. There is an example in figure 5. Most application-specific files like Word®, Excel®, or WordPerfect® have invisible formatting characters embedded in them that this program cannot read. Your file can have headers or footers since the starting line and number of lines to process are selected at run time. Comments and data cannot be intermixed unless each block of data is processed in a separate run. Acceptable species codes and stand origin values are listed in table 2.

After an input file is selected, an output file must be identified (fig. 6). By default, only files with the extension .txt are listed, but all files can be shown. PINEVOL creates an ASCII text file with a header line and one line for each tree processed (fig. 7). In addition to presenting the calculated variables described above, each output tree line begins with tree identification information followed by the species code, d.b.h., height to the base of the live crown, and total height.

The next screen displays the full path of your input and output files and the first 100 lines of the input file (fig. 8). There is no limit to the number of trees that can be processed, but the file display is limited to 100 lines to save memory. To continue, select the format of your data using the combo box beneath the file display. Several delimited formats and fixed-column format are available.
In delimited formats, the input variables must be separated by nonnumeric characters (spaces or commas are preferred for readability). All characters to the left of the required numeric data are considered tree identification information, and this is copied to the output file. The length of the tree identification information in the output file is determined by its apparent length in the first record processed.

If the fixed-column format is used, the input file columns that contain the required information will have to be specified. In

Table 2—Species codes, species names, and the taper models available in this program

<table>
<thead>
<tr>
<th>Species code</th>
<th>Species name</th>
<th>Models available</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>Shortleaf pine</td>
<td>0 = Natural (Farrar and Mill.)</td>
</tr>
<tr>
<td>111</td>
<td>Slash pine</td>
<td>1 = Planted (Dell and others 1979)</td>
</tr>
<tr>
<td>121</td>
<td>Longleaf pine</td>
<td>0 = Natural (Farrar 1987)</td>
</tr>
<tr>
<td>131</td>
<td>Loblolly pine</td>
<td>0 = Natural (Farrar and Murphy 1988)</td>
</tr>
</tbody>
</table>

In delimited formats, the input variables must be separated by nonnumeric characters (spaces or commas are preferred for readability). All characters to the left of the required numeric data are considered tree identification information, and this is copied to the output file. The length of the tree identification information in the output file is determined by its apparent length in the first record processed.

If the fixed-column format is used, the input file columns that contain the required information will have to be specified. In
Figure 7—An example of the output file produced by a batch-mode run of PINDEVOL. The first few columns are the information selected as a plot description. The columns with headers are species, planting indicator, d.b.h., height to the base of the live crown, total height, crown ratio, crown ratio class, form class, merchantable height, saw-log height, height of saw logs actually used when saw-log volume is calculated, total cubic-foot volume inside bark, total cubic-foot volume outside bark, merchantable volume inside bark in cubic feet, merchantable volume outside bark in cubic feet, saw-log volume inside bark in cubic feet, saw-log volume outside bark in cubic feet, saw-log volume by the Doyle log rule, saw-log volume by the Scribner rule, and saw-log volume by the International ¼-inch rule. If there are warnings or errors, a message is appended to the line. This output corresponds to the input file from figure 5.
this format column numbers can be entered if they are
known, but PINEVOL does have a tool to determine these
column numbers. The procedure is best explained by a video
in the help file. Basically, this tool allows the user to select
variables in the input file preview, and the first and last
columns as well as the line in the file are displayed immedi-
ately beneath the box. Transfer buttons are available to copy
these values to the input boxes for each variable. The row in
the file is always displayed but is primarily used to specify a
starting row beneath any header information. For complete-
ness, there is also a last row to process option. There is no
transfer button for this function since, in most cases, this row
will not appear within the first 100 rows. The value defaults
to the last line in the file, but can be changed by the user.

In fixed-column format, whatever columns might constitute
tree and plot information can be selected, or even the entire
observation can be selected. These data are simply copied to
the output file and can include spaces and overlap the real
numeric variables.

When all of the columns and rows have been filled in, a click
of the calculate volumes button will start the calculation
process. If a line of data cannot be interpreted as tree data an
error box will pop up and calculation will be stopped so that the input file can be fixed. If any individual variable cannot be read as a number, it is set to zero. If any of the numeric data would result in a failed calculation (for example, 0 for d.b.h., height to base of live crown, or total height or an invalid species code) that line is marked as an error, and all output volumes will be set to zero, but calculation continues with the next tree. An error message will be written into PINEVOL.LOG (fig. 9). If the d.b.h. or total height or height to base of live crown is outside of the range used to develop these taper functions, the user will be warned, but the calculation will proceed. The warnings will indicate which variable was out of range. A summary box will appear indicating the number of records processed. After PINEVOL completes its calculations, exit the program and use any text editor to review the results or stay in the program and pick a new file to process.

**Interactive Mode Operation**

If interactive mode is chosen, the screen shown in figure 10 will appear. In interactive mode species selection is presented as option buttons, and the d.b.h. (in inches), total height (in feet), and height to the base of the live crown (in feet) are entered manually in text boxes. After this data is entered, clicking on the calculate button will calculate volume. Changes to any of the input tree parameters after volume has been calculated produces a warning that the calculated numbers shown on the screen are no longer applicable to the current tree (fig. 11).

The interactive mode screen also has a button to change volume calculation parameters. This button returns the user to the screen where stump height, minimum d.b.h., and minimum top diameter for merchantable and saw-log trees is specified. The results can be printed by clicking the “Print” button.

**Troubleshooting**

PINEVOL uses the standard Windows install routine. This can fail on some systems. If it does, the PINEVOL.CAB file can be unpacked with “EXTRACT/E PINEVOL.CAB” and PINEVOL.EXE can be run. Doing this will not set up the directory in the Program Files directory or add the program to your Start menu, but the program should run. But it is also possible that the .DLL files might have to be registered with Windows. The basic syntax for doing that is “REGSVR32 FILENAME.DLL” for each of the .DLL files in the .CAB file. Neither of these corrective actions should be necessary.

When PINEVOL is running, anticipated errors will generate warning or error messages. In batch mode the user is warned that there may be errors and each line of output is flagged for errors, but the actual error messages are contained in a file called PINEVOL.LOG located in the same directory as the output file. These messages indicate the line number of the input file on which the error occurred as well as some explanation of what caused the error. An example log file is shown in figure 9.

The equations used in these volume models were developed for a specific range of data. The user is allowed to specify trees that are not within the recommended ranges, but a warning message will be printed if this is done. Warnings in
Figure 10—The Interactive Data Entry screen requires the selection of a species and entry of a d.b.h., total height, and height to base of live crown for the tree of interest. Limits are shown for the selected species and all calculated volumes are shown on the lower portion of the screen.

the output file for batch mode are appended to the end of output lines and just indicate the tree parameter that is out of range. Examples of warnings and errors are shown in the example output file (fig. 7). The user can choose to ignore these messages or find a more suitable model for these special cases. In interactive mode the warnings are similar and the program will refuse to calculate results if attempting to do so would result in a mathematical error.

Conclusion

PINEVOL is a handy program for calculating the volume of southern pine trees. It has been used internally for a number of years, but has now been repackaged for the general public. Visual Basic source is also available upon request.

Acknowledgments

I want especially to acknowledge the contributions of Paul Murphy (Southern Research Station, deceased) who wrote the original FORTRAN version of this program. I would also like to thank Michael Shelton, Les Groom, James D. Haywood, Don Bragg, Kelly Peterson, and Jeff Goelz (all of the Southern Research Station), and Chi-Leung So (Louisiana State University) for their valuable suggestions on program development and documentation. I would like to further thank Kelly Peterson and Don Bragg for their helpful reviews of this publication.
Figure 11—Once volume has been calculated and any tree specification has been changed the results of the previous calculation are changed to red and a warning is printed that these are no longer the correct results. The previous volume results are not cleared so that the user can observe volume changes when the Calculate button is clicked.

**Literature Cited**


Taper functions describe a model of the actual geometric shape of a tree. When this shape is assumed to be known, volume by any log rule and to any merchantability standard can be calculated. PINEVOL is a computer program for calculating the volume of the major southern pines using species-specific bole taper functions. It can use the Doyle, Scribner, or International ¼-inch log rules or calculate solid wood volume inside or outside of bark. This document describes the methods used in volume calculation in PINEVOL and is a program user’s guide.

Keywords: Loblolly pine, longleaf pine, shortleaf pine, slash pine, stem profile equations, taper functions.
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