AN ABSTRACT OF THE THESIS OF

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Title: AN EVALUATION OF THE USE OF TARIF TABLES IN SECOND GROWTH DOUGLAS-FIR

Abstract approved: ______________________
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The Washington State Department of Natural Resources' *Comprehensive Tree-Volume Tarif Tables* are a set of preconstructed local volume tables. This can increase "on plot" efficiency since only diameters are necessary to obtain volumes after the proper table for the given diameter/height relationship is accessed. The tables are accessed and indexed by a tarif number which is the cubic-foot volume to a 4-inch top of a tree of one square foot of basal area. With an increase in height for the same basal area there will be an increase in the cubic-foot volume and therefore, the tarif number. For this reason, this index is a measure of general tree form (i.e. diameter/height relationship). A sample of trees is taken in a stand and the average tarif number is found to index the local volume table for a particular stand. To find the tarif number, total stem cubic-foot volume and the diameter at breast height are needed for each sample tree. In this report, three volume equations that could be used to calculate tarif tested on an independent data set of sectioned young growth Douglas-fir

(Pseudotsuga menziesii (mirb.) Franco) trees for their accuracy to predict volume. The percent difference of the means and a modified chi-square test were used to evaluate the Weyerhaeuser, Bruce-DeMars, and British Columbia (immature) cubic-foot volume equations. It was found that the first two equations predicted volume well and gave very comparable results while the third consistently underestimated volumes. Error limits are reported so that each equation can be evaluated to see if it meets desired accuracy criteria. Graphical analysis was used to further look at the effects of measurement errors on the calculation of tarif numbers and eventually on volume estimates. Accuracy must be considered for each circumstance; however, in some cases measurements may not have to be as accurate as presently suggested. It was found that diameter measurements are not as important as height measurements. Also, measurements to obtain tarif must be much more accurate if Scribner volume is desired as compared to total stem cubic-foot volume. Finally, further research needs for realizing the full potential of the tarif system are discussed.

AN EVALUATION OF THE USE OF TARIF TABLES IN SECOND GROWTH DOUGLAS-FIR

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AN EVALUATION OF THE USE OF TARIF TABLES IN SECOND GROWTH DOUGLAS-FIR

INTRODUCTION

The purpose of this report is to evaluate the use of the Washington State Department of Natural Resources' (DNR) *Comprehensive Tree-Volume Tarif Tables* (Turnbull, Little and Hoyer, 1980) for determining volume in second growth, westside Douglas-fir *(Pseudotsuga menziesii (mirb.) Franco)* stands. The DNR comprehensive tarif system is a unique, convenient, statistically accurate and interrelated collection of preconstructed local volume tables (Turnbull and Hoyer, 1965) or volume tables needing only diameters to find tree volumes. These tables can be accessed for many species by a tarif number indexing system. After a literature review and discussion of the tarif system's use in the Pacific Northwest, this author considers the ability of three Douglas-fir cubic-foot volume equations, an important step in finding tarif numbers, to predict volume in an independent data set from western Oregon. Secondly, this report discusses the accuracy of field measurements.

The Tarif System

"Tarif" volume tables were derived in Britain by Dr. F. C. Hummel in 1955. The system was introduced in the United States by Turnbull, Little and Hoyer in their 1963 edition of the *Comprehensive Tree-Volume Tarif Tables* (Turnbull, et al., 1963). A second, revised edition was released in 1972 (Turnbull, et al., 1973) and a third edition with further corrections and revisions was released in 1980 (Turnbull, et al., 1980). In

1976, a supplement, *Comprehensive Log Scale Tree-Volume Tarif Tables for Douglas-fir*, was printed. This reported Scribner volume in 16- and 32-foot logs using the Scribner Log Scale Rule, where the other tables had utilized the Scribner formula for calculating volume. Tarif, as used here, should not be confused with the word "tariff" which refers to the "taxes placed by a government upon exports, or especially imports." (Webster, 1966).

Each local volume table in the system is identified by an individual tarif number. This number is the cubic-foot volume to a 4-inch top for a tree of 1.0 square foot of basal area (13.54 inches DBH[1/]) (Turnbull, et al., 1980). The tarif number represents the change in taper in each local volume table. If the DBH of a tree is held constant, the tarif number increases as the height increases and as the tree's form becomes better, i.e., taller for the same diameter or less flare in the base with more height. The taller tree would, of course, have more cubic-foot volume to a 4-inch top (CV4). This shows that the CV4 of a tree of 1.0 square foot of basal area changes with tarif number and therefore with each local volume table which the tarif numbers can index. On the other hand, if the height of a tree is held constant, the tarif number will decrease as the DBH is increased and the form of the tree becomes "poorer", i.e., more flare in the lower bole.

The basis for the tarif system is dependent upon two related facts. First, CV4 plotted against the basal area for a number of trees in a stand can be adequately represented by a straight line; and secondly, when trees

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1/ DBH is the diameter at breast height, which is taken by convention as 4.5 feet above the ground on the uphill side of a tree in the Pacific Northwest (Bruce, 1980).

of several stands are plotted in this way, all lines consistently cross the horizontal axis (basal area) where the volume is zero and the basal area is 0.087 square feet (4 inches diameter). These two features are shown in Figure 1.

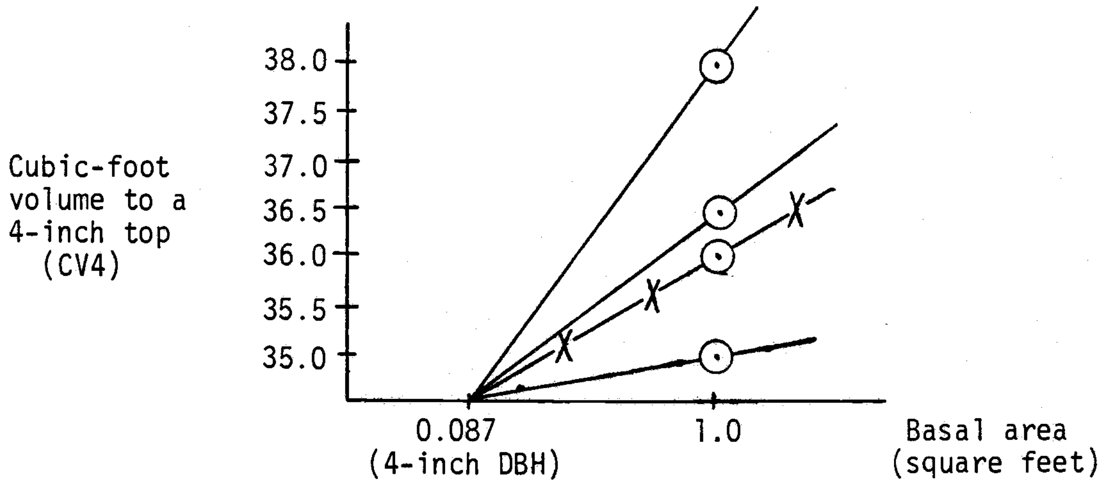


Figure 1. Fundamentals of the Tarif System (Turnbull and Hoyer, 1965)

The x's represent trees of different DBH's and volumes from a particular stand and the lines are plots of other stands. From Figure 1 it can be visually seen what a tarif number is. The o's would represent the tarif numbers for each of the four stands shown. For example, the tarif number for any tree along the line with the x's would be found by going horizontally from the point on the line above 1.0 square foot basal area to the vertical axis of CV4, which is 36.0 (the CV4 of a tree of 1.0 ft^2 basal area).

The tarif system has many attractive features. As will be discussed shortly, volume estimating procedures are simplified with reduced field work. Standardized curve forms are contained within the tarif system so the need for curve fitting of local volume is eliminated. This is an important consideration when estimating volume growth from remeasurements of permanent plots because the use of different methods of curve fitting can result in error. Another important feature of the tarif system is that volumes and volume/basal area ratios are given in several units of measure, to different minimum merchantable top limits, and it provides a simple, accurate means for usually difficult conversions between units of measure. This makes the system very appropriate for today's changing market standards and for organizations that do not have access to, or the facilities to utilize more complicated taper equations. This also makes the system equally convenient for fixed plot or variable plot (point) sampling (Turnbull, et al., 1980). A final feature that has become more attractive with the introduction of small, inexpensive "personal" computer systems is the fact that the tarif system is not limited to tables, which are good for field use, but also utilize formulas which are easily applied to computer use. A summary of the formulas and their use is given by Bell, Marshall and Johnson (in press) and are covered in detail by Brackett (1977), with later revisions given by Chambers and Foltz (1979).

Use of the Tarif System

To find the volume of a stand two basic pieces of information are normally needed: tree frequency and tree size. The number of trees are often found by diameter classes, using some sampling scheme such as fixed, variable plot or 3-P selection (see Dilworth, 1980). For some or all of these sample trees the size is found by measuring diameter, height and possibly other information such as the tree's form, or by directly finding volumes on a small sample. This could be done by felling and sectioning techniques, or by using instruments such as the Barr and Stroud optical dendrometer that can measure diameters along tree boles. With information on size, local volume tables can be constructed or existing tables can be localized by observing height/DBH relationships. With the tarif system a tree tally by DBH is still necessary but local volume tables are already available and applicable to a specific stand.

In order to access a particular local volume table for a certain stand, the tarif number of that stand must be determined. To do this, it is suggested that a sample of at least 20 trees representative of the range of DBH's in the stand be sampled for each species present. This sample involves the measurement of total height to the nearest two feet and DBH to the nearest 0.1 inch for each "tarif" sample tree. Access tables or equations are then entered with each tree's DBH and height to determine tarif numbers, which are then averaged for the stand to determine which local (tarif) volume table will be used to find volumes or volume/basal area ratios by knowing only diameters. Access tables have been published for many Pacific Northwest species by the DNR (1972). An example of the construction of such access tables and the use of the equations for determining tarif numbers for tarif sample trees is given by Bell, Marshall and Johnson (in press).

One such equation in the tarif system is that which calculates the tarif number. This equation is (Brackett, 1977; Chambers, et al., 1979; and Bell, et al., 1980):

```
TARIF = (CVTS * .912733)/                                    (1)
        (((1.033 * (1.0 + 1.382937
        * EXP (-4.015292 * (DBH/10.0))))
        * (BA + 0.087266)) - 0.174533)
```

where

EXP = exponential function
BA = square feet basal area = $.005454154\ DBH^2$
CVTS = cubic-foot volume including top and stump

As can be seen, to find a tree's tarif number, the DBH and CVTS must first be known. DBH is an easy parameter to measure in the field, but CVTS cannot be so easily directly determined. Normally, however, regression equations are utilized that predict CVTS from the independent variables of DBH, total height, and in some cases, a measure of tree form. It is easily seen that the ability of this equation to predict CVTS is directly related to the ability to determine a tarif number and get accurate measurements of stand volumes.

Comparison of Volume Equations

Currently there are two widely used equations for CVTS in second growth Douglas-fir. The purpose of this analysis is to test the ability of these two equations, and also a third equation that has not been used extensively in the tarif system, to predict volumes by DBH class from an independent data set from Western Oregon.

EQUATIONS

The two equations widely used are the British Columbia Immature Douglas-fir volume equation (Brackett, 1977):

$$CVTS = (10^{-2.658025})*(DBH^{1.739925})*(HT^{1.133187}) \qquad (2)$$

and the Weyerhaeuser Douglas-fir cubic volume equation (Brackett, 1977):

$$CVTS = 10^{[-3.21809 + 0.04948 \text{ LOG HT} * \text{LOG DBH} - 0.15664 (\text{LOG DBH})^2 + 2.02132 \text{ LOG DBH} + 1.63408 \text{ LOG HT} - 0.16185 (\text{LOG HT})^2]} \quad (3)$$

where LOG is the logarithm to the base 10 and HT is the total height. The other equation is the Bruce-DeMars second growth Douglas-fir volume equation (Bruce and DeMars, 1974), which has been used in the Hoskins levels-of-growing-stock study (Berg and Bell, 1979):

$$CVTS = (0.480961 + 42.46542/H^2 - 10.99643DBH/H^2 - 0.107809DBH/H - 0.00409083DBH) * (.005454154DBH^2H) \quad (4)$$

DATA

To test and validate models, an independent data set is necessary. In order to be able to compare predicted volumes with actual volumes for the above three equations, the data necessary was DBH, total height, and the actual CVTS. The best way to get a tree's CVTS (inside bark) is to use sectioning techniques. Trees from two different studies were used.

First, Dr. Walter Thies of the Pacific Northwest Forest and Range Experiment Station in Corvallis, Oregon, made available 146 live, non-forked, sectioned Douglas-fir trees. Dr. Thies' study is on the growth loss by individual Douglas-fir as a result of infection by *Phellinus (Poria) weirii (Murr) Gild.* (laminated root rot). The study tract was in a 45 year old Douglas-fir stand on International Paper Company land in Section 17 of Township 6 North, Range 3 West, Willamette Meridian in Clatsop County near Apiary, Oregon. The tract contained both infected and healthy trees. Trees within the plot were felled and whole-tree skidded from the plot. The DBH and total height were recorded. The diameter inside bark was measured at the stump, at breast height, at 8 feet, and at each log thereafter for the length of the stem to a 4-inch diameter, inside bark, top so that a minimum of 10 sections were measured (Thies, 1977).

The second data set was from thinning treatments of the Regional Douglas-fir Cooperative levels-of-growing-stock (LOGS) study near Hoskins, Oregon, Section 27, Township 10 South, Range 7 West, Willamette Meridian in Benton County. The study is maintained by the School of Forestry, Oregon State University, Corvallis, Oregon, on land owned by Starker Forests. In 1963, when the study began, the stand was 20 years old. The study is examining cumulative wood production, the size development, and growth-growing stock ratios as affected by eight different thinning regimes. After an initial calibration thinning in 1963, treatment thinnings were begun in 1966 with future thinnings being made whenever the average height of predesignated crop trees on all treatments increases 10 feet (Berg and Bell, 1979; Williamson and Staebler, 1971). Treatment thinnings were done between the 1966-1967, 1969-1970, 1970-1971, 1973-1974, 1975-1976 and the 1979-1980 growing seasons. Data used in this analysis were from the 1966-1967, 1970-1971, and 1979-1980 thinnings. Trees were measured for DBH, total height and sectioned at 4-foot intervals along the bole from which inside bark measurements were found.

For all sectioned trees, volumes were calculated for tree segments based on various cubic-foot volume rules (Dilworth, 1980). The sections that were within the first 20% of the tree's total height were assumed to be frustrums of a neiloid; therefore, the sub-neiloid rule formula was used. Demaerschalk and Kozak (1977) suggest that the infection point where the tree's form changes from a neiloid to a paraboloid ranges from 20% to 25% of the total height from the ground, regardless of species and size class. The remainder of the sections in the bole, including the last section, were considered to be frustrums of a paraboloid and the smalian rule was used. The CVTS is then found by summing the volumes for each section in a tree. The CVTS was already calculated for the trees provided by Dr. Thies in this manner. To calculate the CVTS from the LOGS sectioned trees, a program for the Hewlett-Packard 9830 computer was used (Marshall, 1980).

The data were divided into one inch diameter classes. It was hoped to get about 20 trees per class for the analysis, from 4 to 30 inches. There is, however, a noticeable lack of trees in the larger diameters. There were only 16 trees greater than the 20 inch class (all from Thies' study) and most less than 22.0 inches; therefore, no analysis was done above the 22 inch class. Table I shows the distribution of the trees by DBH class and by study. In appendix A, plottings of actual volume, height and tarif against diameter at breast height are found for the data set.

ANALYSIS

The first test used is the percent difference of the mean which is equal to the mean volume of the actual volumes of the sectioned trees minus the mean volumes of the predicted volumes from the volume equations divided by the mean volume of the actual volumes all multiplied by 100.

$$\frac{(\text{actual vol. mean - predicted vol. mean})}{(\text{actual vol. mean})} * 100 \qquad (5)$$

This gives a measure of accuracy of the mean of the predicted volumes

DBH CLASS* (Inches)	THIES DATA	LOGS DATA	TOTAL	AVERAGE (ft^3)	STANDARD DEVIATION (ft^3)	RANGE (ft^3)
4	0	6	6	2.120	0.402	1.610- 2.600
5	3	20	23	3.121	0.621	1.810- 3.540
6	6	31	37	4.935	0.887	3.183- 6.565
7	4	27	31	6.661	1.360	4.315- 10.268
8	4	29	33	9.285	2.254	6.350- 14.586
9	9	28	37	12.369	3.075	7.620- 18.175
10	3	20	23	14.753	2.777	9.756- 20.350
11	7	18	25	19.857	4.553	11.027- 27.848
12	8	15	23	24.340	5.333	16.760- 32.514
13	12	5	17	34.168	5.452	21.226- 44.886
14	12	5	17	41.582	6.041	26.774- 51.931
15	8	4	12	43.944	5.026	35.461- 52.180
16	8	4	12	53.898	8.538	41.262- 62.808
17	13	1	14	60.287	7.371	42.618- 68.527
18	15	1	16	66.751	9.493	40.530- 78.165
19	13	1	14	74.749	8.810	59.578- 94.689
20	5	0	5	81.584	5.576	75.438- 89.930
21	8	0	8	93.703	14.919	81.217-117.751
22	5	0	5	103.342	8.214	89.678-110.509
+22	3	0	3	115.017	28.050	85.887-141.846
TOTALS	146	215	361			

TABLE I. Distribution of trees by source and DBH class and class CVTS variation.

* 4-inch class is 3.6 to 4.5 inches

within each DBH class.

The second test is a chi-square test to determine the accuracy of the volume equation compared to the actual volumes of the sectioned trees. This test was proposed by Freese (1960) and later modified by Rennie and Wiant (1978). Chi-square volumes are calculated using the equation:

$$\chi^2_{(n,\alpha_1)} = \frac{\sum_{i=1}^{n} \left(x_i - \mu_i \right)^2}{\sigma^2} \qquad (6)$$

where

χ^2 is the calculated chi-square value with n degrees of freedom and a probability of α_1 (.05 here). (From Snedecor and Cochran, 1980).

x_i is the predicted volume of the ith individual using the volume equation.

μ_i is the actual volume of the ith sectioned tree.

σ^2 is the hypothesized variance (required accuracy).

and where

$$\sigma^2 = \frac{E^2}{Z^2} \qquad (7)$$

where

E is the error limit which includes $(1-\alpha_2)$ of the deviations between x_i and μ_i.

Z is the standard normal deviate for probability of α_2 (1.96 for this analysis).

To express the results in terms of accuracy, equation (7) is substituted into equation (6) and solved for the error limit E (equation (8)).

$$E = \left[\frac{Z^2 \sum_{i=1}^{n} (x_i - \mu_i)}{\chi^2(n, \alpha_1)} \right]^{1/2} \qquad (8)$$

The error limit can also be expressed as a percent of the true volume by equation (9).

$$E\% = \left[\frac{Z^2 \sum^{r} \left(\frac{x_i}{\mu_i} - 1\right)^2}{\chi^2(n, \alpha_1)} \right]^{1/2} * (100) \qquad (9)$$

The degrees of freedom (n) is equal to the number of values observed.

Paired t-tests are commonly used for the testing of accuracy. Freese (1960) suggests that this test is unsuitable because it will reject a technique that is precise but only slightly biased while accepting a technique that is not precise but is unbiased. Precision and bias are the two components of accuracy. Precision is the lack of variation of measurements while bias is when the "predicted" values are constantly or, by some mathematical function, different than the "true" values. Inaccuracy may be due to lack of precision and/or bias. The t-test accepts the variation among the individual differences between the predicted and the standard as an inherent characteristic of the population of these differences. The t-test uses the standard error of the mean difference in its denominator. If there is precision, the denominator of the paired t-statistic will be small, causing a small bias to be significant. On the other hand, if there is a large lack of precision (large variation among individual differences) the denominator will be large, causing even a large bias to be insignificant. The t-statistic for a paired t-test with (n-1) degrees of freedom is:

$$t = \frac{\overline{d}}{\sqrt{\dfrac{\sum_{i=1}^{n} d_i^2 - \dfrac{\left(\sum_{i=1}^{n} d_i\right)^2}{n}}{n(n-1)}}} \qquad (10)$$

where d_i is the difference between the true value of the ith observational unit and the estimated value, $\overline{d}$ is the average of the d_i's and n is the number of the observational units. The t-test, therefore, uses the precision part of accuracy to test for the freedom of bias and may give unacceptable results (Freese, 1960). The chi-square test will reject an inaccurate technique, regardless of the source of inaccuracy. For this reason a chi-squared test was chosen for this analysis. A major problem with the chi-square hypothesis is the need for specifying a goal for accuracy, which may change with time, or user. Rennie and Wiant (1978) modified Freese's test to an approach of confidence intervals which give test results as error limits, as demonstrated above in developing equations (8) and (9). This allows others to decide, by comparing error limits, if the procedure is within the accuracy needed.

For these analyses, a program was written in Fortran V on the Oregon State University Cyber CDC computer. Appendix B contains a sample hand calculation of the percent difference of the means and error limits. A listing of the program VOLEVAL (VOLume equation EVALuation) is found in

Appendix C, along with a sample and explanation of the input file and a sample of the output.

RESULTS

The average volumes for each diameter class are found in Table II. The percent difference of the means for the three volume equations compared to the section tree volumes are presented in Table II by diameter class. An examination of the signs of the percent difference of the means will indicate the bias tendencies. A negative value indicates that the mean of the actual volumes is less than the mean of the predicted volumes for that diameter class; or that the volume equation is overestimating the volume on the average. A positive value indicates that, on the average, the volume is being underestimated.

The general trend for all three equations is similar but different in magnitude. Predicted volumes are underestimated in the smaller diameters with the bias becoming less as the diameter increases, and in the case of the Weyerhaeuser and Bruce-DeMars equations, volumes are consistently positive (underestimating) in bias and are almost always more biased than the Weyerhaeuser and Bruce-DeMars equations which are very similar.

For the chi-square test, the confidence limit was set at 95%. For comparison purposes, two chi-square values are shown for each equation in Table IV. The first value expresses the number of cubic-feet within which 95% of the predicted volumes will differ from the actual volumes. The second value expresses the percent difference within which 95% of the predicted volumes will differ from the actual volumes. For example, the 0.64 cubic-foot and 27.71% error limits for the Weyerhaeuser equation in the

4-inch diameter class can be interpreted as (Rennie and Wiant, 1978):

1) It is expected that 95% of the deviations between the Weyerhaeuser equation predicted volumes and the sectioned tree volumes, in the 4-inch diameter class, will be within ± 0.66 cubic-feet of the actual sectioned tree volumes.

2) It is expected that 95% of the deviations between the Weyerhaeuser equation predicted volumes and the actual volumes, in the 4-inch class, will be within 27.71% of the actual volumes.

These error limits also show that the Weyerhaeuser and Bruce-DeMars equations are very comparable and tend to predict volumes better than the British Columbia equation with their narrower confidence limits in most of the diameter classes.

Although these data are from only two sources in Western Oregon and the height ranges in some of the diameter classes may be limited, the above two tests suggest that both the Weyerhaeuser or Bruce-DeMars Douglas-fir cubic-foot volume equations give similar results and both would be preferable to use over the British Columbia equation unless a simpler equation is necessary (e.g. in a handheld programmable calculator) and less accuracy is acceptable. The confidence limits in Table IV can be compared to see which equation(s) will meet the desired level of accuracy.

TABLE II. Average cubic-foot volume for each DBH class and volume equation.

DBH CLASS (Inches)	SECTIONED TREES	WEYERHAEUSER	BRITISH COLUMBIA	BRUCE-DEMARS
4	2.12	1.71	1.74	1.73
5	3.12	2.81	2.79	2.81
6	4.94	4.58	4.44	4.52
7	6.66	6.24	5.97	6.15
8	9.28	8.72	8.24	8.57
9	12.37	12.31	11.60	12.10
10	14.75	14.61	13.65	14.37
11	19.86	19.68	18.37	19.41
12	24.34	24.11	22.53	23.83
13	34.17	33.70	31.67	33.59
14	41.58	40.70	38.38	40.73
15	43.94	44.06	41.37	44.01
16	53.90	53.29	50.26	53.44
17	60.29	60.96	57.64	61.22
18	66.75	65.58	61.99	65.72
19	74.75	76.48	72.67	76.89
20	81.58	83.75	79.61	83.94
21	93.70	94.03	89.82	94.29
22	103.34	104.70	100.46	105.14

TABLE III. The percent difference of the means.

DBH CLASS (Inches)	WEYERHAEUSER	BRITISH COLUMBIA	BRUCE-DEMARS
4	19.41	17.81	18.19
5	9.82	10.54	10.07
6	7.35	10.18	8.52
7	6.31	10.38	7.74
8	6.12	11.20	7.71
9	0.44	6.23	2.16
10	0.98	7.47	2.58
11	0.92	7.49	2.27
12	0.93	7.44	2.08
13	1.38	7.31	1.69
14	2.12	7.69	2.05
15	-0.27	5.85	-0.16
16	1.13	6.75	0.85
17	-1.11	4.38	-1.55
18	1.75	7.13	1.54
19	-2.31	2.78	-2.87
20	-2.66	2.42	-2.89
21	-0.35	4.15	-0.62
22	-1.32	2.79	-1.74

TABLE IV. 95% error limits in percent and cubic-feet.

DBH CLASS (Inches)	WEYERHAEUSER		BRITISH COLUMBIA		BRUCE-DEMARS	
	ft	%	ft	%	ft	%
4	0.64	27.71	0.60	25.61	0.61	26.15
5	0.58	19.76	0.60	20.29	0.58	19.29
6	0.93	18.01	1.11	21.49	0.97	18.75
7	0.96	14.94	1.30	20.16	1.05	16.33
8	1.48	14.43	2.07	20.59	1.66	16.10
9	1.41	10.07	1.91	14.09	1.46	10.34
10	1.66	11.71	2.38	15.69	1.75	11.99
11	2.29	11.30	3.35	15.18	2.37	11.16
12	2.71	10.83	3.94	15.43	2.81	11.12
13	3.07	8.70	4.89	13.71	3.12	8.98
14	2.96	6.70	5.60	12.85	2.87	6.54
15	5.26	12.15	6.48	14.23	5.39	12.36
16	7.74	12.63	9.33	14.54	7.58	12.53
17	3.72	7.20	5.36	8.71	3.73	7.03
18	6.67	10.20	9.74	13.44	6.36	9.36
19	5.73	7.91	5.94	7.15	5.83	8.09
20	4.90	6.16	4.68	5.30	4.87	6.17
21	13.14	13.69	14.11	13.66	13.01	13.85
22	5.81	5.92	6.62	6.11	5.75	5.82

ANALYSIS OF FIELD MEASUREMENTS

When using the above equations to find the cubic-foot volume (CVTS) of a tree in order to calculate a tarif number using equation (1), measurements of diameter at breast height (DBH) and total height (HT) are necessary. The instructions to the *Comprehensive Tree-Volume Tarif Tables* (Turnbull, et al., 1980) suggests that the heights should be measured to the nearest even foot and diameters to the nearest 0.1-inch. Incorrect measurements of either of these variables will introduce further error into the calculation of tarif numbers and the volumes to be calculated from them. To investigate the effects of measurement errors on tarif and volume calculations, the Weyerhaeuser cubic-foot volume equation, discussed in part one, was used in conjunction with the interrelated equations of the tarif system (see Brackett, 1973, Chambers and Foltz, 1979 and summarized in Bell, et al. in press) to produce graphs by varying a certain variable (e.g. DBH) while holding the other(s) constant (e.g. HT) and calculating tarif numbers or volumes. Calculations were done and values plotted using programs written on the Hewlett-Packard 9830A with a plotter.

The effects of DBH and HT measurements on tarif calculations are first considered and then the effects of these resulting errors in tarif on volume and volume/basal area ratio are investigated.

TARIF NUMBER

Figures 2 and 3 show the relationship between DBH, height and tarif number. Both were constructed using the Weyerhaeuser volume equation (equation 2) and the tarif equation (equation 1). In Figure 2, HT was held constant at 50-, 100-, 150-, and 200-feet and DBH was increased at 2-inch increments with volume (CVTS) and tarif calculated for each DBH and HT. For Figure 3, the same process was used with DBH held constant at 10-, 15-, 20-, and 30-inches and HT increased at 5-foot increments.

To find the effects of height measurement errors on the tarif number, DBH was held constant at 10-, 15-, 20-, and 30-inches and for heights at every 5-feet starting at 30 feet, the volume and then the tarif number were calculated as described above for 2-, 4-, and 6-feet taller and shorter heights than the assumed "correct" total height. The percent difference in tarif number was calculated for each "error" in total height. It was found that there was little difference between low and high errors so these percent differences were averaged and plotted for each of the 3 "errors" in Figure 4 for each DBH. The curves for each DBH are the same.

The other component of calculating tarif numbers from a cubic-foot volume equation is DBH. To test errors in measuring DBH, graphs similar to those in Figure 4 for height were constructed in the same way by varying DBH by 0.1-, 0.2-, 0.5-, and 1.0-inches for 50-, 100-, 150-, and 200-foot heights. Unlike the heights, in this case there was a significant difference in the values of percent difference in tarif number for high and low (assumed "correct", DBH plus and minus the 4 "errors" respectively) measurement errors. In Figure 5 the average of these values are graphed, while in Figures 6 and 7 the values for high and low "errors", respectively, are graphed. The curves are the same for the heights.

From these four figures it is seen that more care must be taken in measuring smaller trees. Considering height (Figure 3) to be within $\pm$ 5% on tarif, a 40-foot tree can have a 2-foot error while a 140-foot tree can have up to a 6-foot error. The same generalization holds true for DBH.

Figure 2 indicates that as the DBH gets larger the accuracy in measurement may decrease (less slope) and that DBH measurements become much less important than measurements of tree height.

VOLUME

These above figures give some indication of the effects of different accuracy requirements and errors, but their full impact will be better realized by considering volumes. Figures 8 and 9 show the percent difference in volume for cubic-foot, including top and stump (CVTS), and Scribner board foot to a 6-inch top in 32-foot logs (SV632) for a 10-, 15-, 20-, and a 30-inch DBH and errors of 1, 2 and 3 tarif numbers. Again, DBH does not affect the curve form, although there is a difference between the cubic-foot and Scribner volumes. For a 5% error in tarif, there will be an approximately 5% error in CVTS for all tarif numbers. This is also approximate for volume/basal area ratios. By drawing a horizontal line across Figure 9 at 5% difference ("error") in volume, the line will cross over the 1 tarif error line at about a tarif number of 20 (5% of 20 is 1) and the 2 tarif error line at about a tarif number of 40 (5% of 40 is 2). Therefore, to keep cubic-foot volume to within 5% in a stand with a tarif of 40, the tarif can be measured to within 40 plus or minus 2 tarif numbers (or between 38 and 42). This error can be distributed between height and DBH measurements according to time and accuracy needs. These two figures were also constructed from the Weyerhaeuser and tarif equations and the equation for SV632 (Figure 9) given in Chambers and Foltz (1979) or Bell, et al. (in press). By assuming a "correct" tarif number and calculating its volume for a constant DBH, the percent difference in volume, or error, can be found by calculating the volume for a tarif number larger or smaller ("error") than the assumed "correct" tarif number. For example, if we assume a 15-inch DBH and a tarif of 60, by comparing the calculated volume (CVTS by rearranging equation 1) with the calculated volume for a tree with a DBH of 15-inches and a tarif of 61 the error in volume of overestimating tarif 60 by one can be found. For SV632, a 5% error in tarif would result in about 10, 7.5, and 6.5 percent errors in volume for a 20, 40 and 60 tarif number respectively. These numbers can be contrasted to the commonly used Form Class Tables (Girard and Bruce, 1976) where there is an approximately 3% error in board foot volume for each Form Class in the middle of the tables. This figure may be higher, such as 6% in the smaller Form Classes. The ability and accuracy of field measurements to define Form Class and tarif may help to determine which system can be used with more confidence.

Since the tarif tables are local volume tables, once they are accessed and the proper table found for a particular stand, only diameters are needed to find volumes. To get volumes, such as in a fixed plot cruise, diameters must be measured carefully, especially the smaller diameters, when Scribner board foot volume is desired, since errors substantially over 100% in volume can occur. Even up to 30 inches, errors as much as 6% can occur. However, when volume/basal area ratios (VBAR's) are desired, diameters are much less important. Figure 10 shows VBAR by DBH and tarif, for CVTS and SV632. This figure shows that diameter has very little influence on VBAR except in the smaller diameters and that using the proper tarif is much more important.

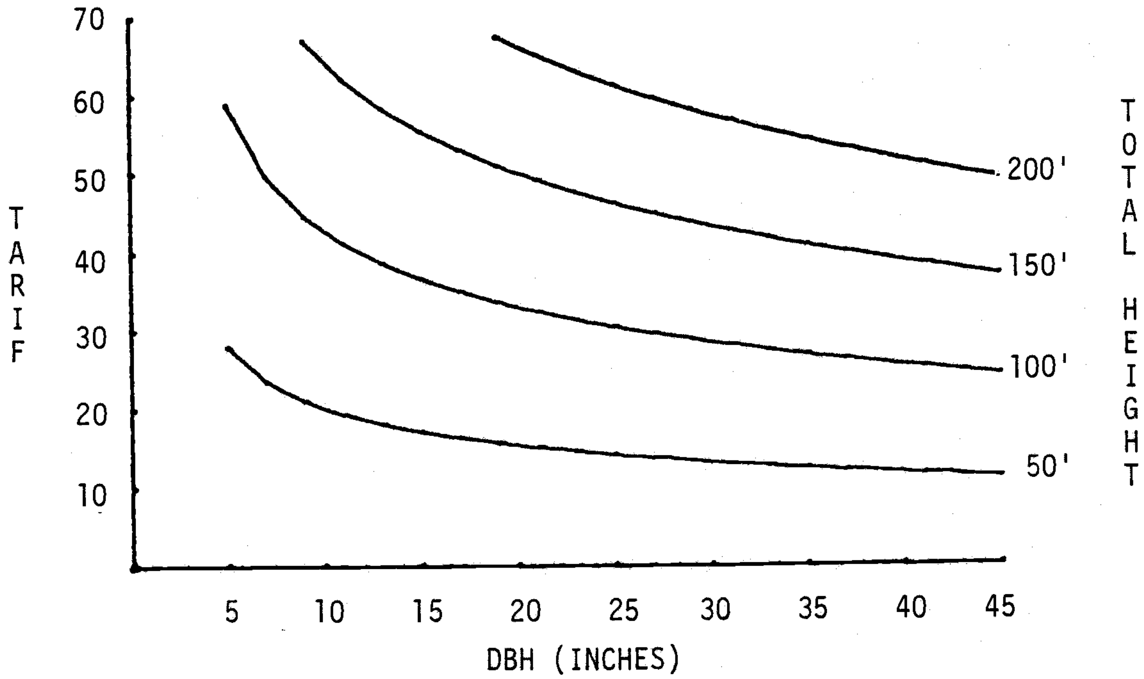


Figure 2. Tarif number vs. diameter at breast height.

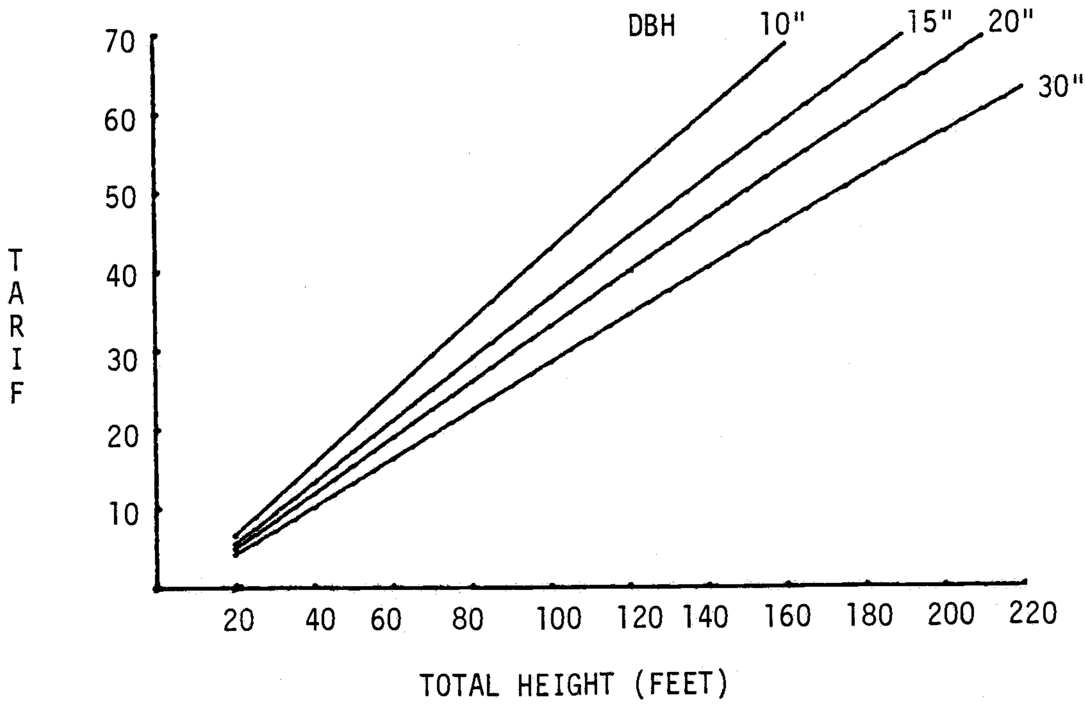
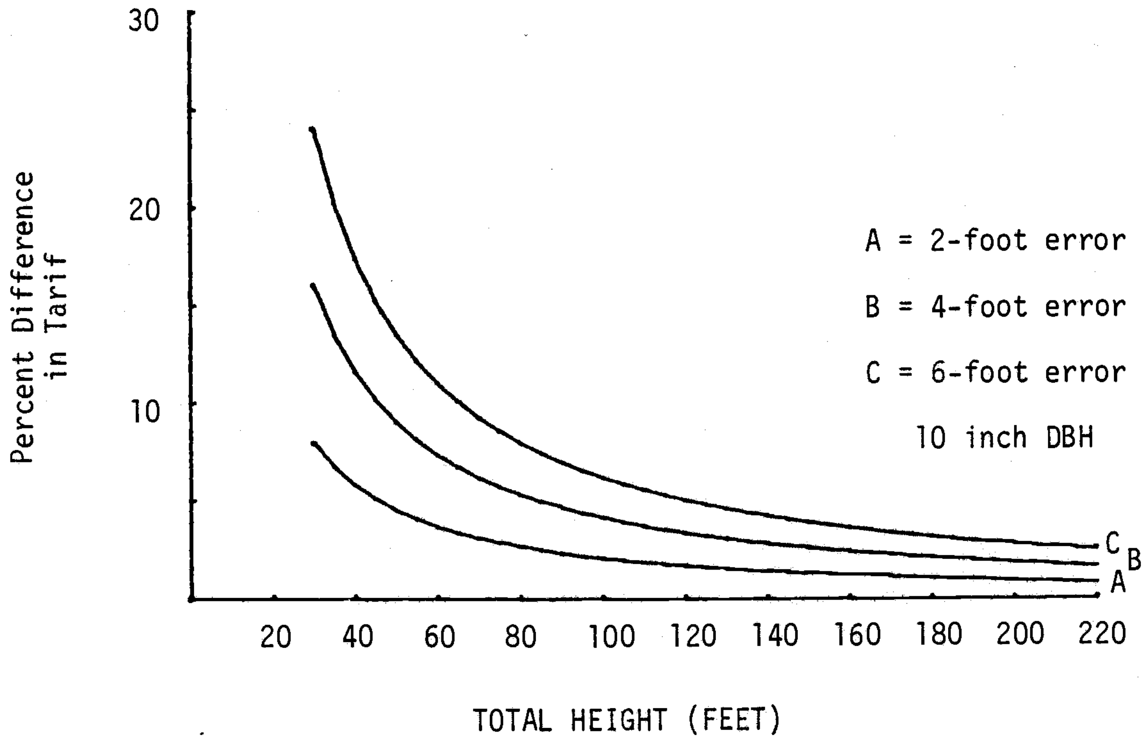


Figure 3. Tarif number vs. total height.



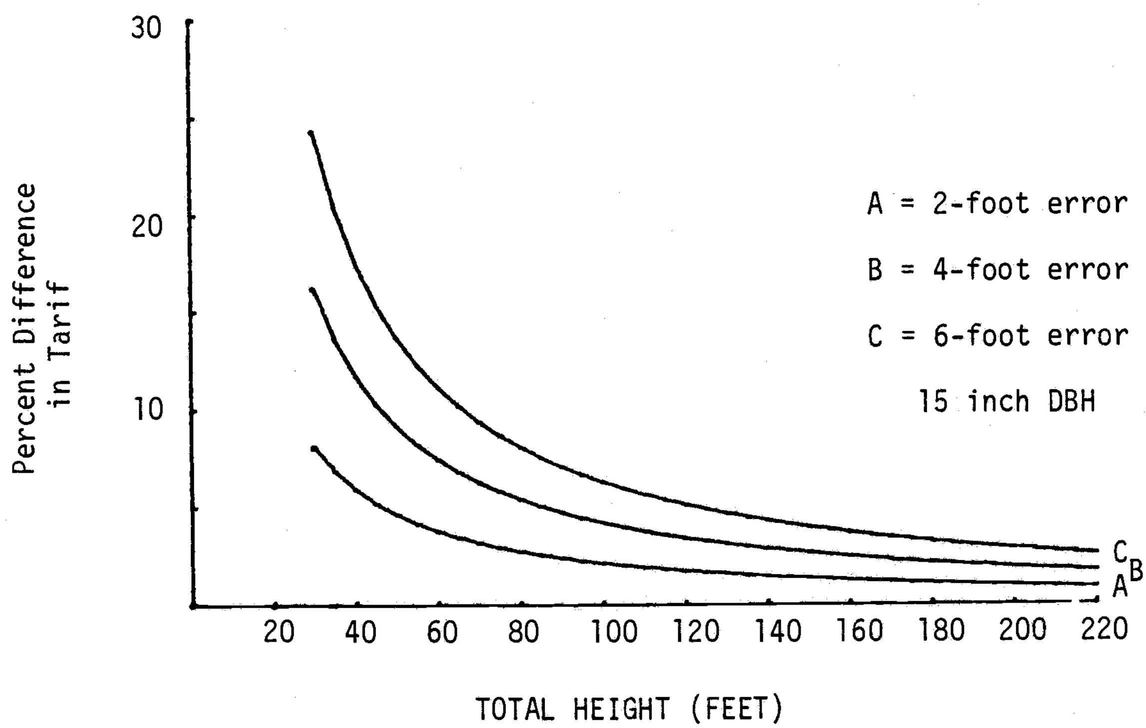
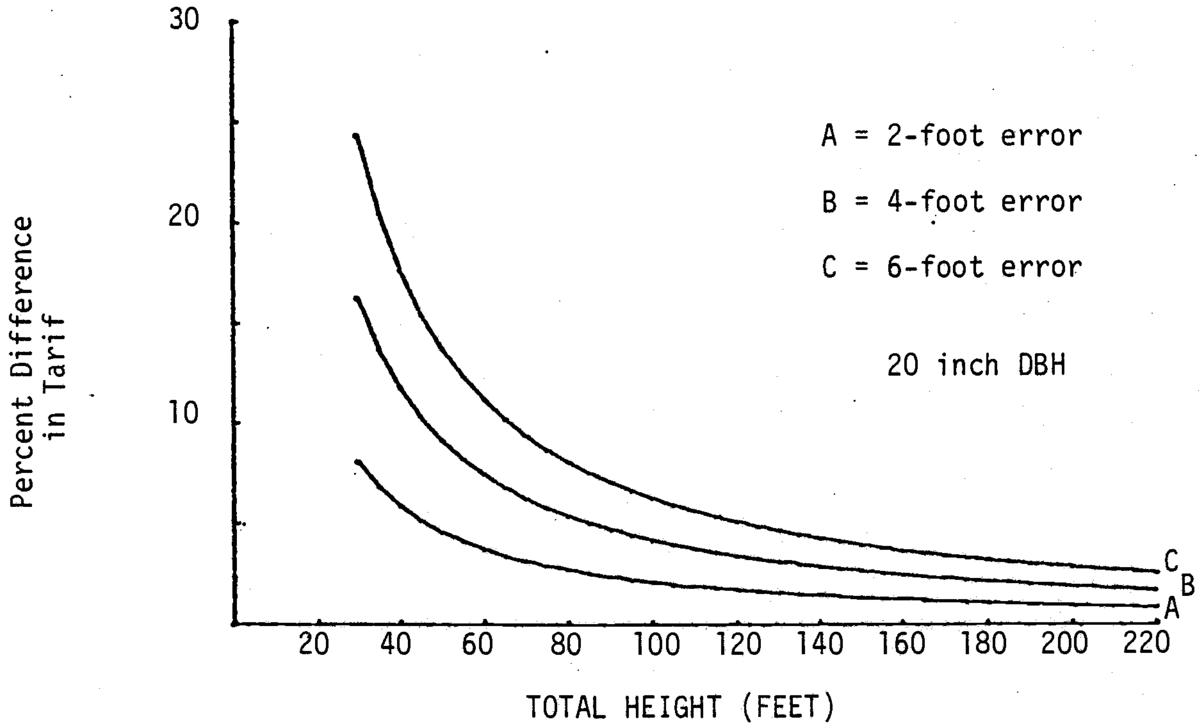


Figure 4. Effect of height measurement errors on tarif number for 10-, 15-, 20-, and 30-inch diameters at breast height.



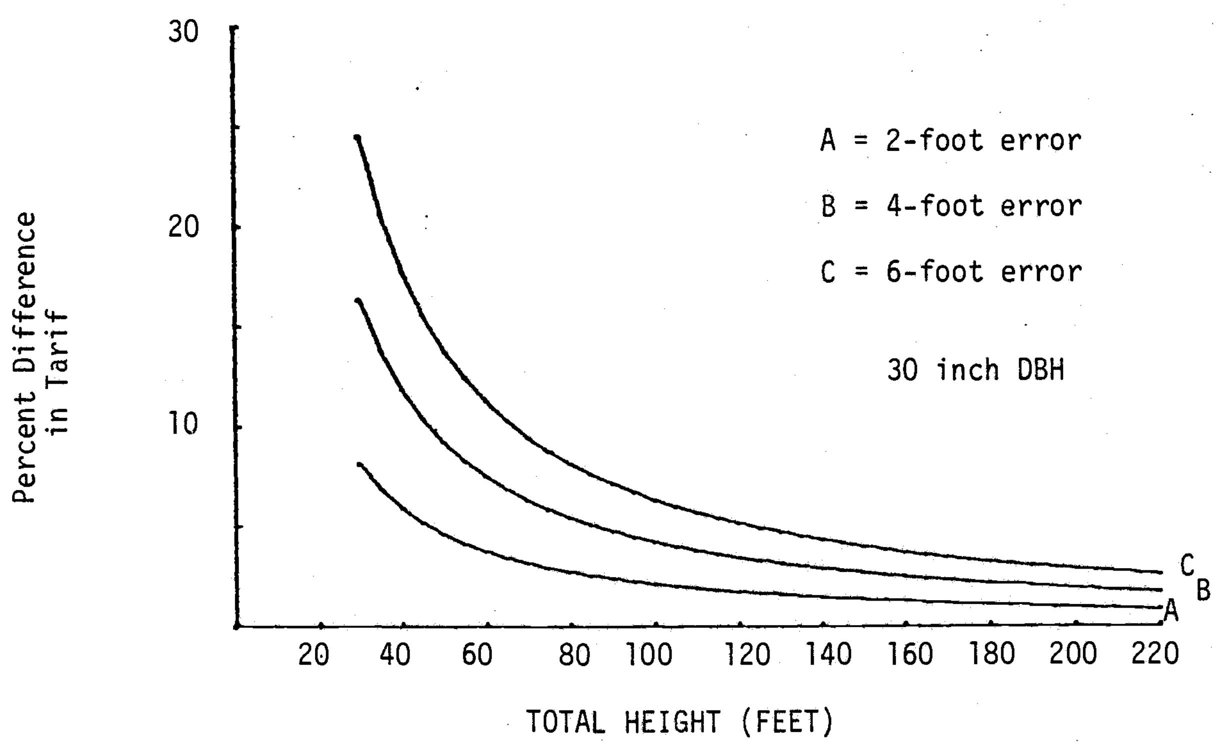
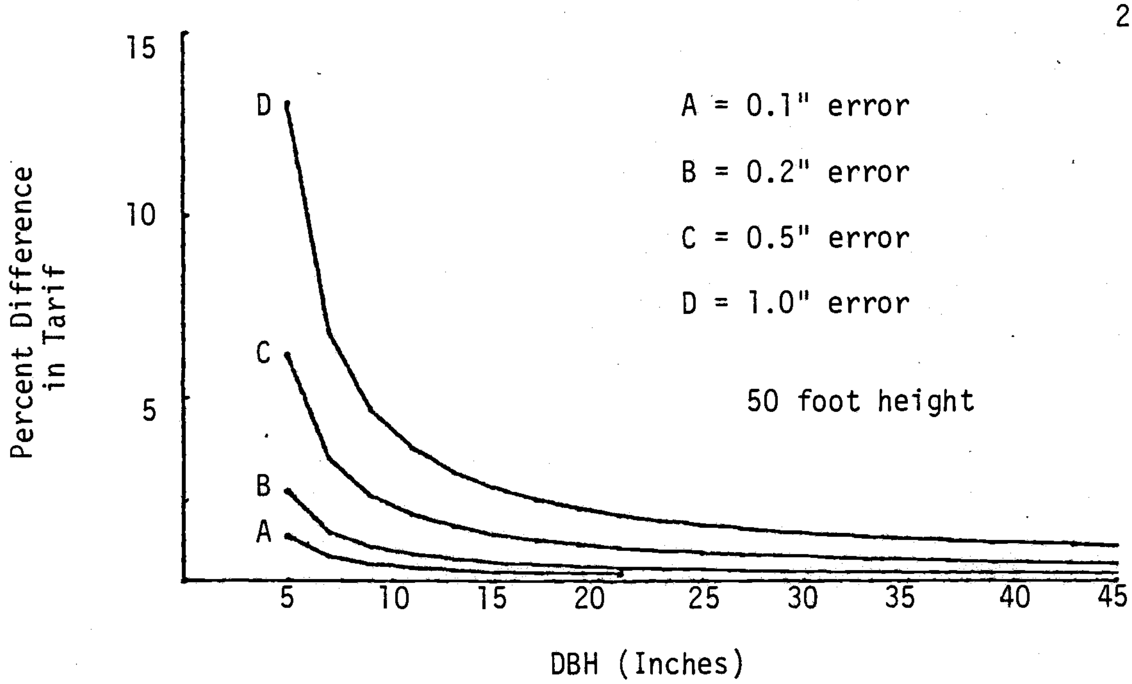


Figure 4. continued.



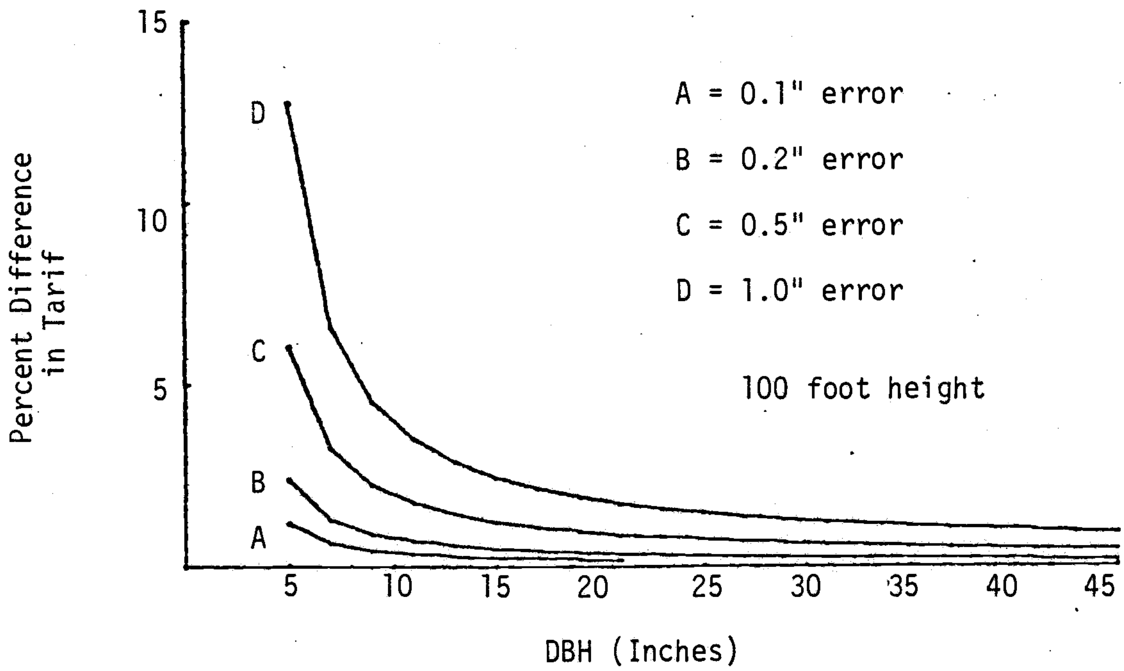
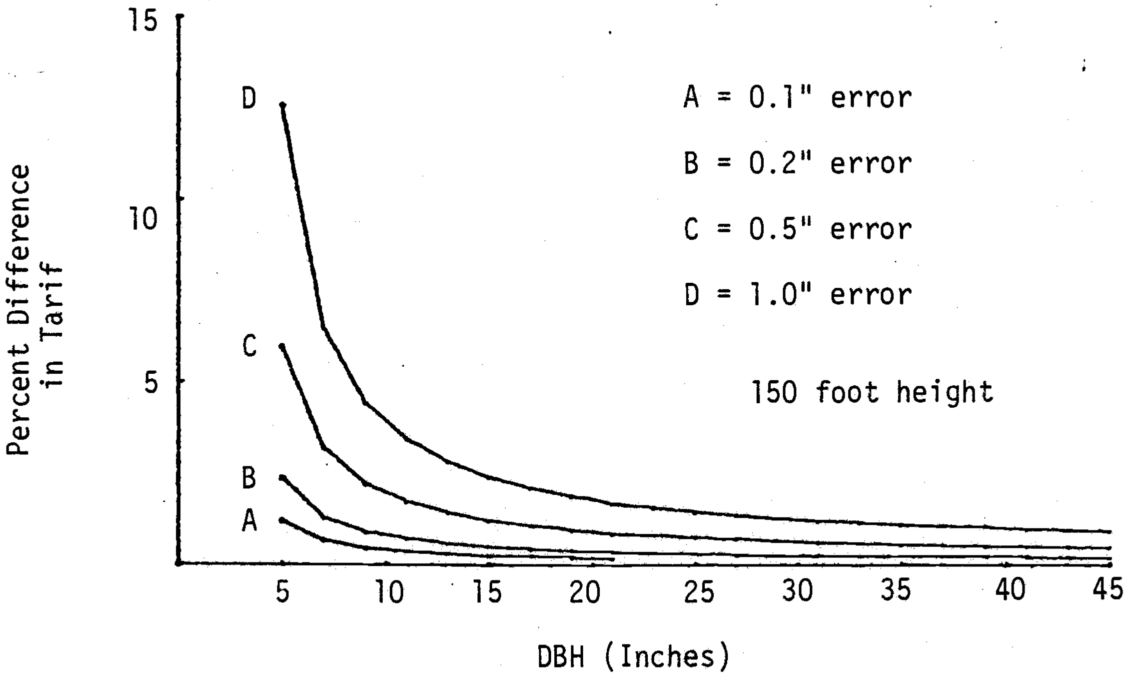


Figure 5. The average (of high and low) effect of measurement errors in DBH on tarif number for 50-, 100-, 150-, and 200-foot total heights.



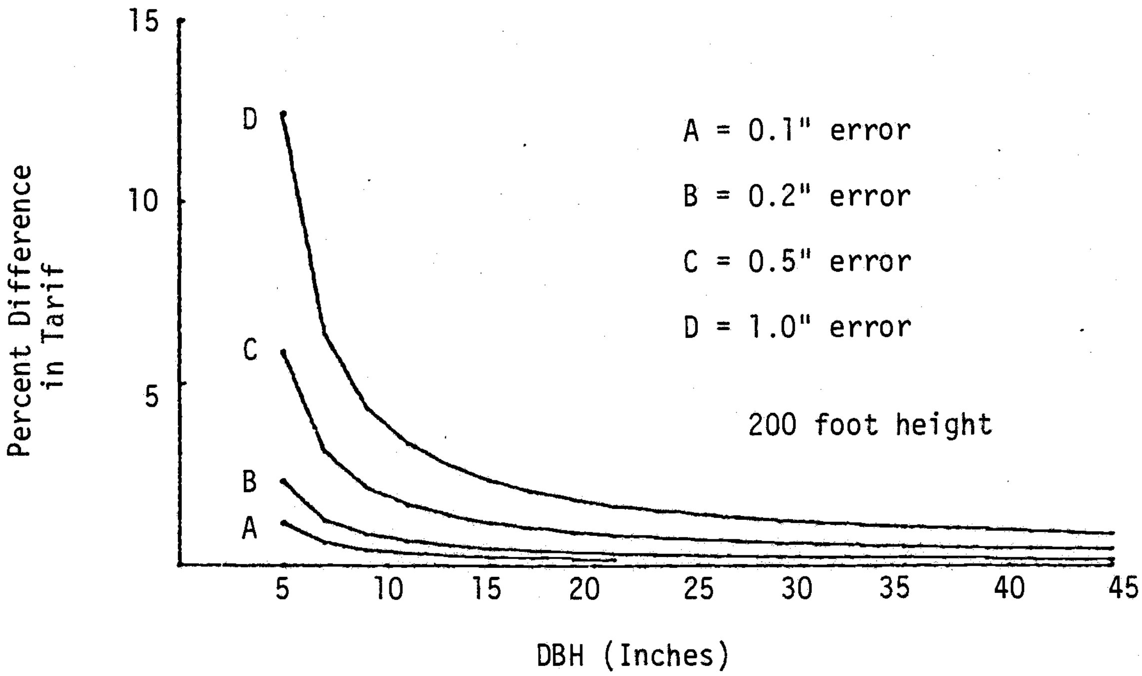


Figure 5. continued.

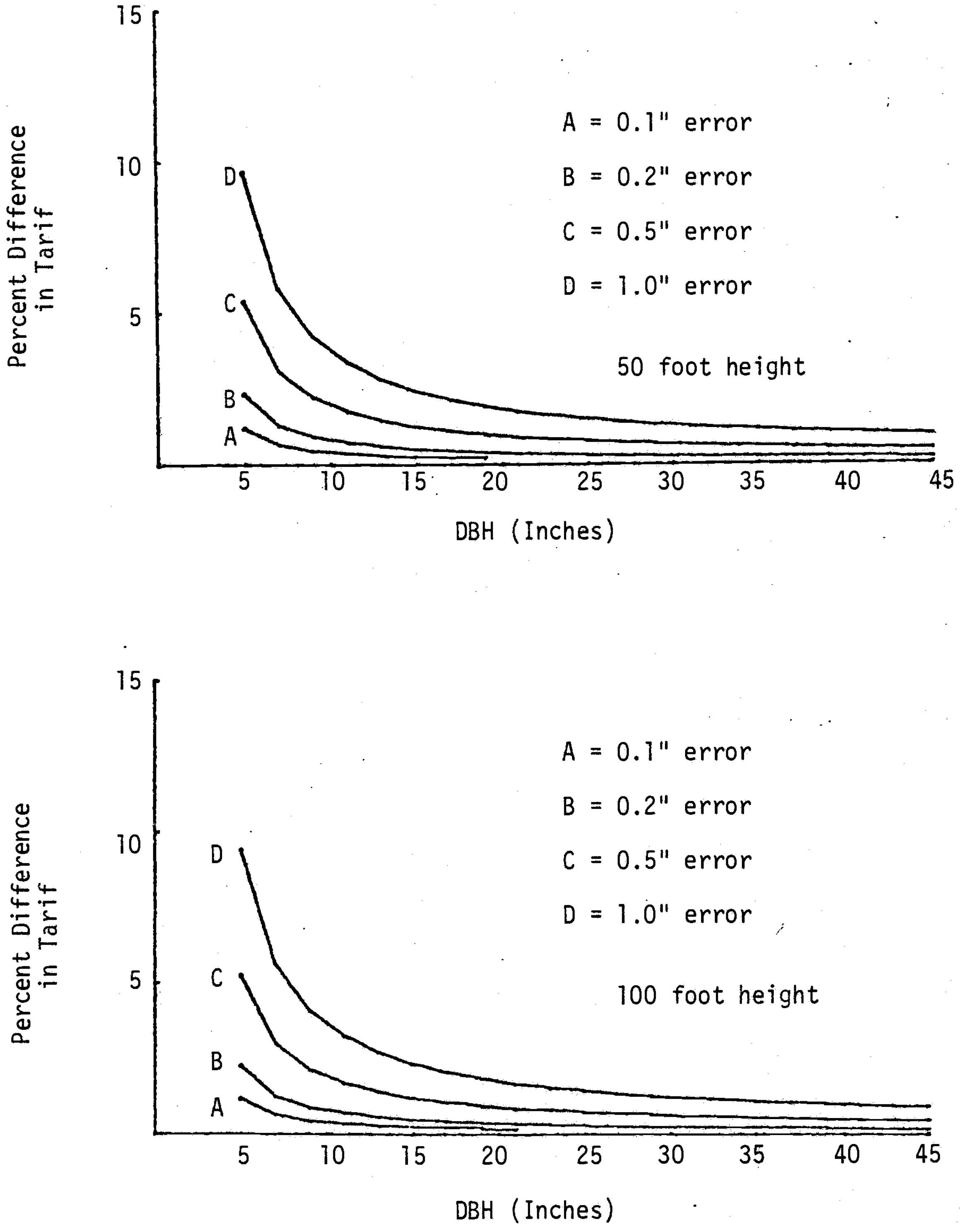
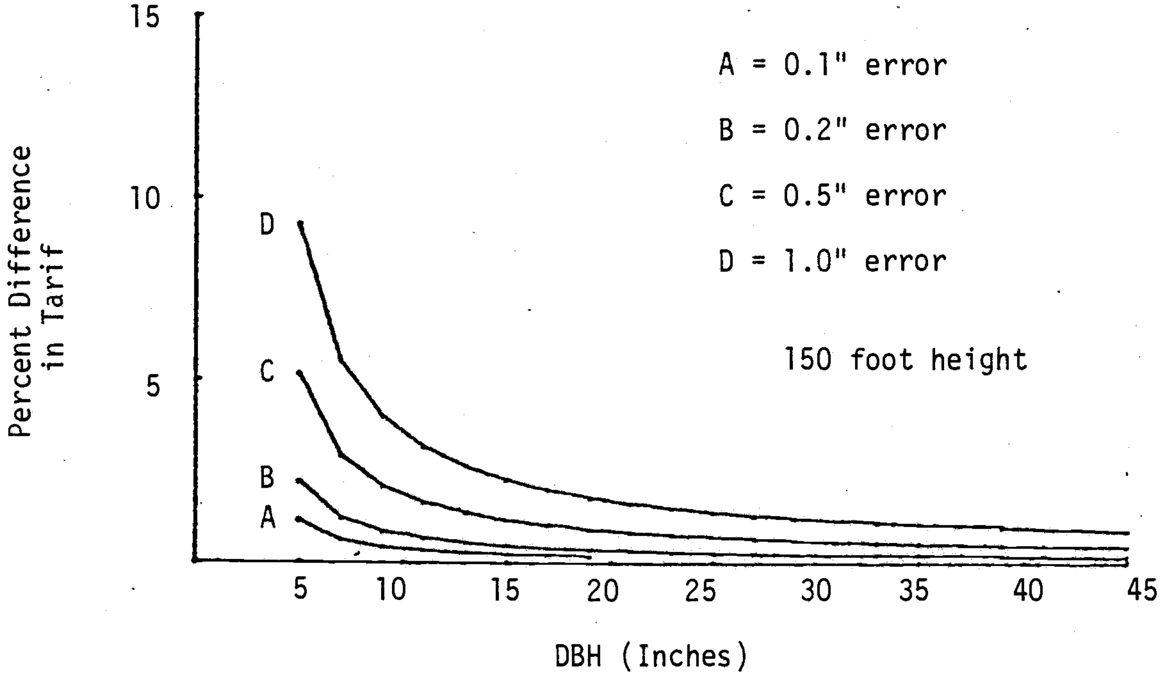


Figure 6. Effect of high DBH measurements on tarif number for 50-, 100-, 150-, and 200-foot total heights.



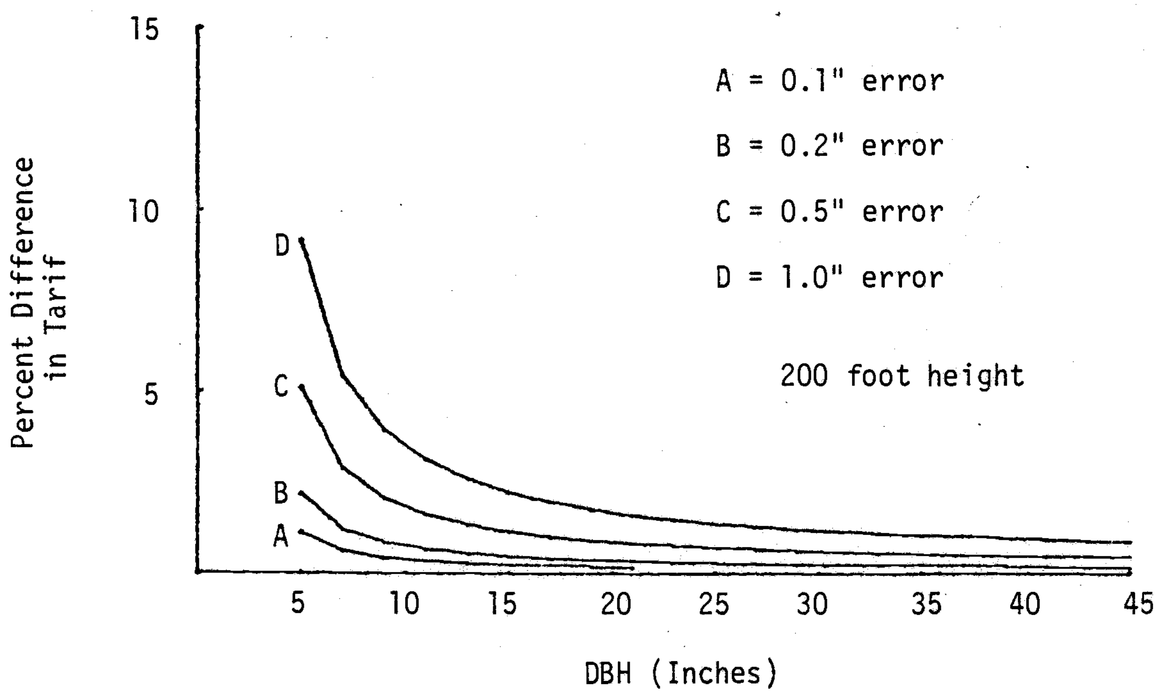


Figure 6. continued.

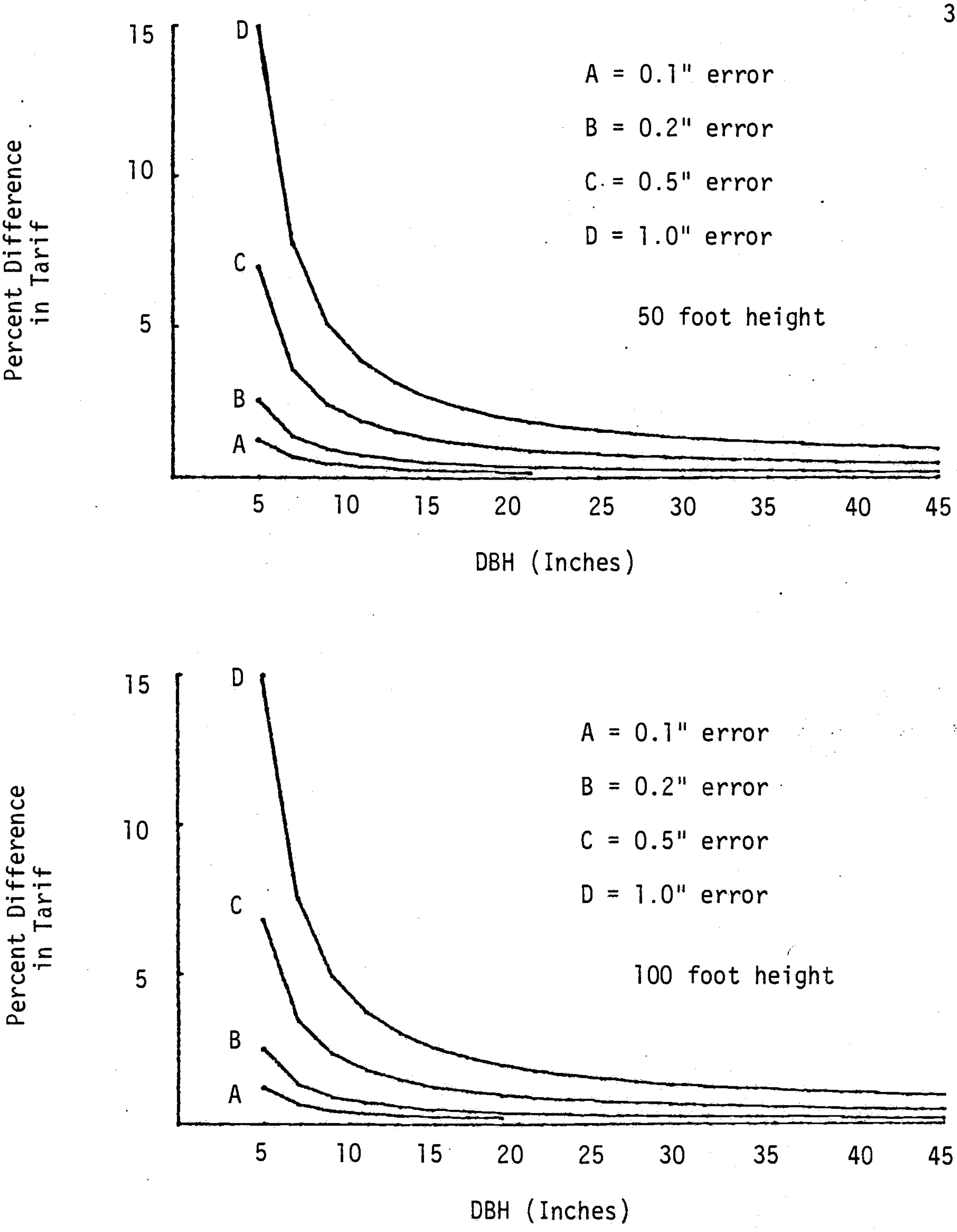
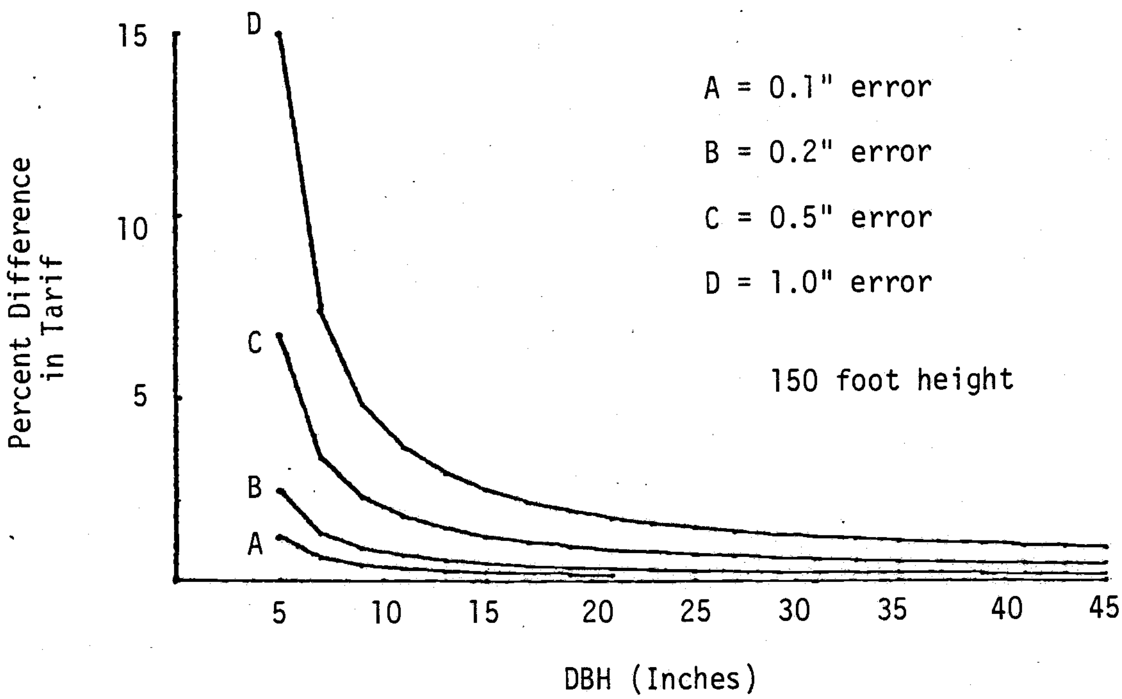


Figure 7. Effect of low DBH measurements on tarif number for 50-, 100-, 150-, and 200-foot total heights.



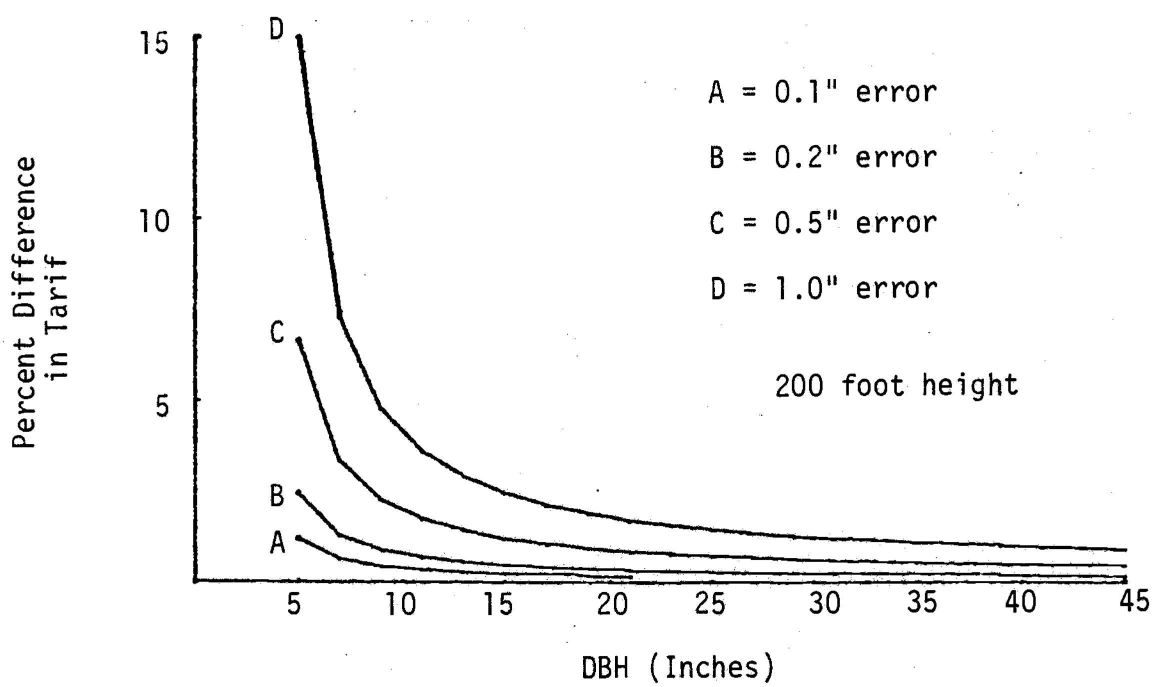
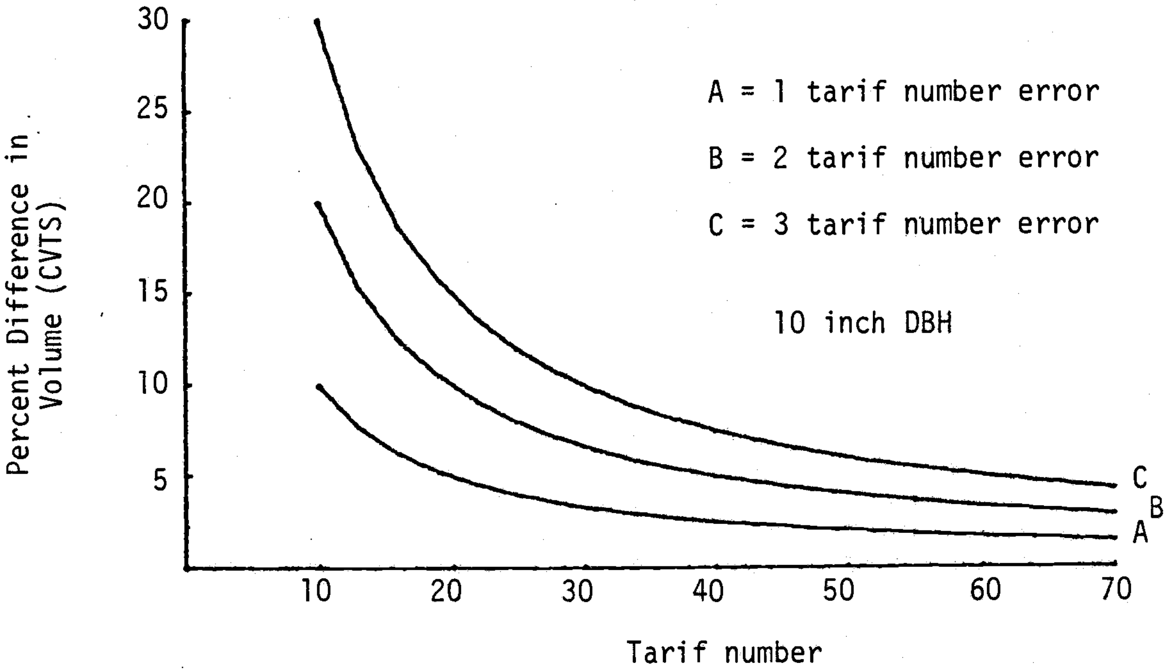


Figure 7. continued.



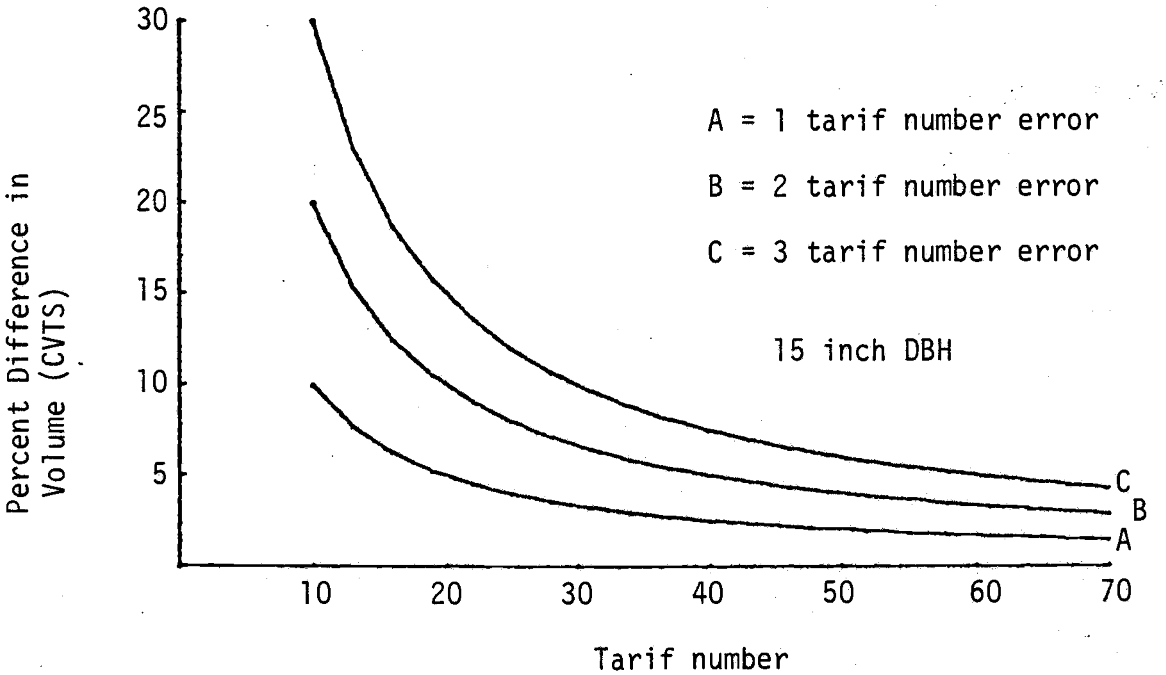
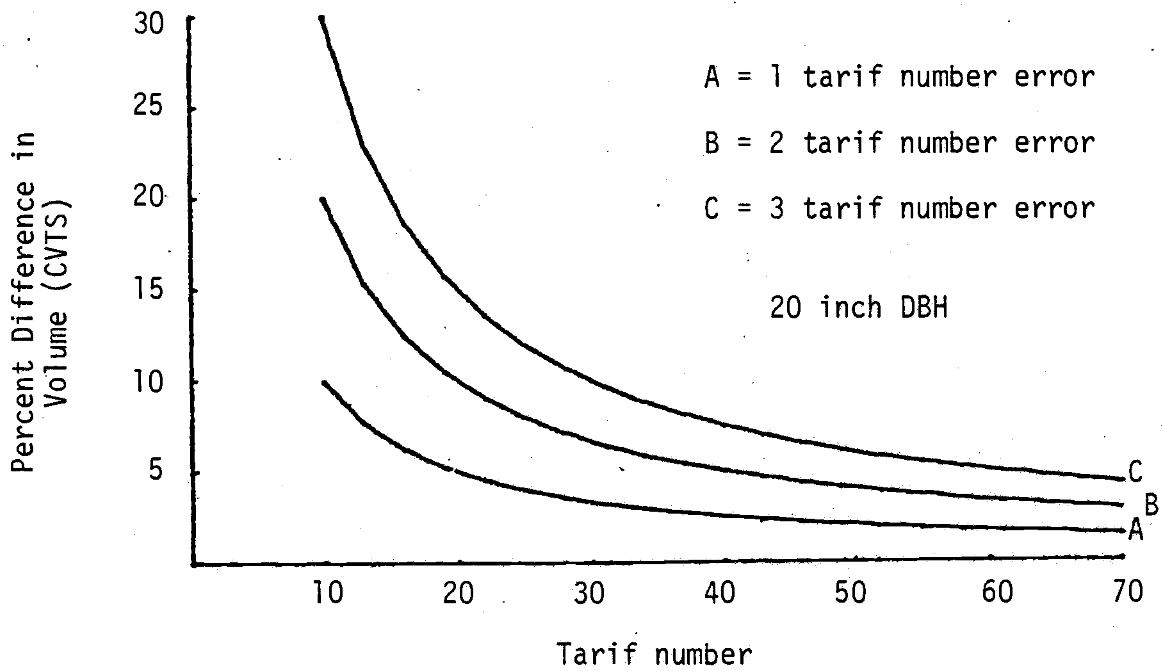


Figure 8. Effect of tarif errors on CVTS for 10-, 15-, 20-, and 30-inch DBH.



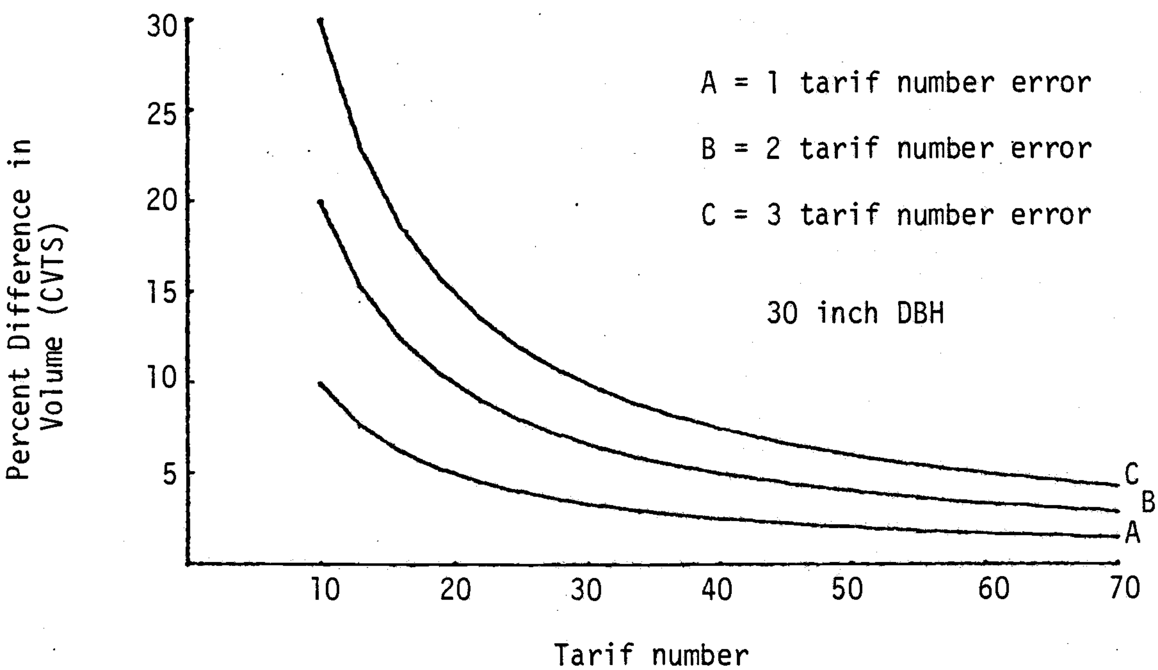
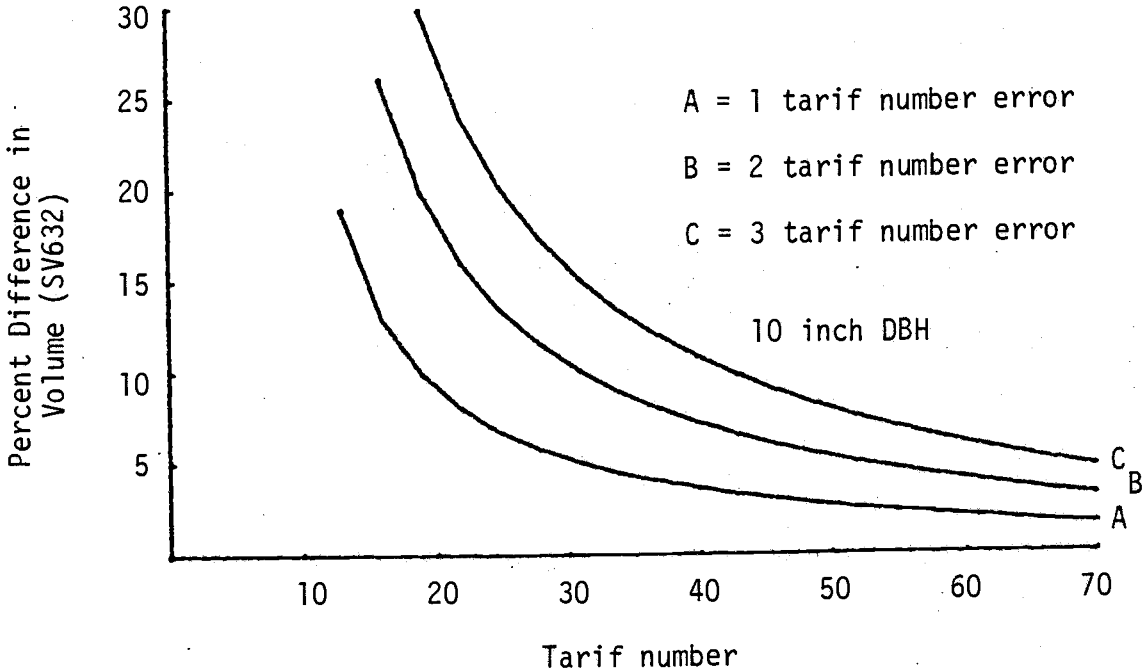


Figure 8. continued.



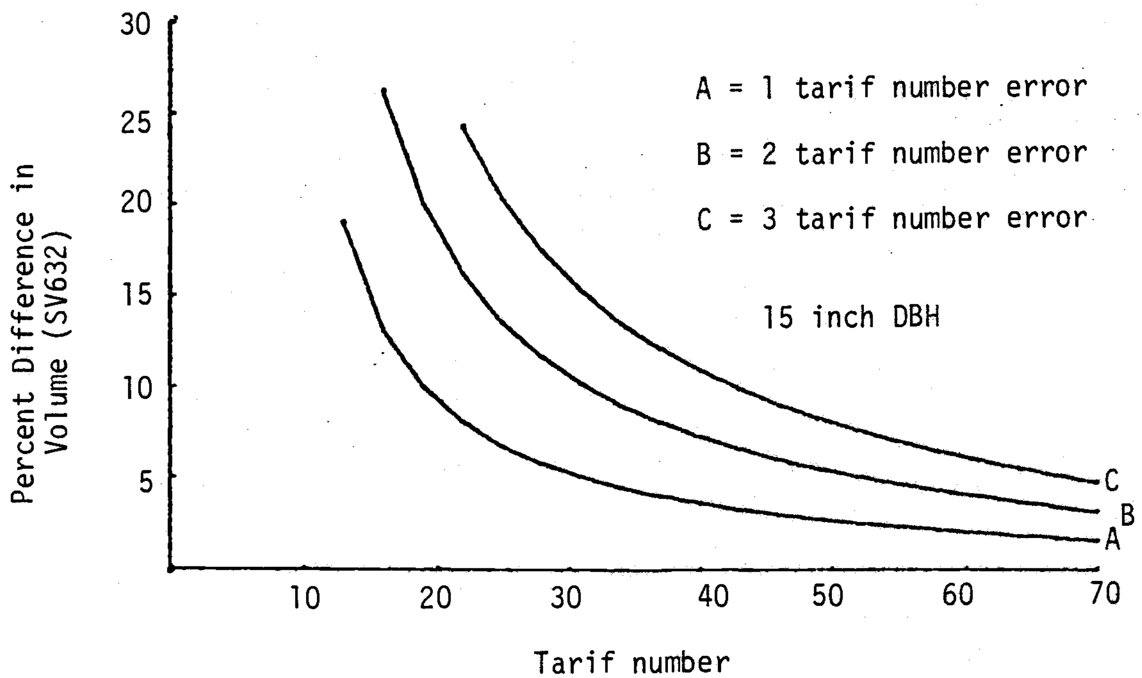
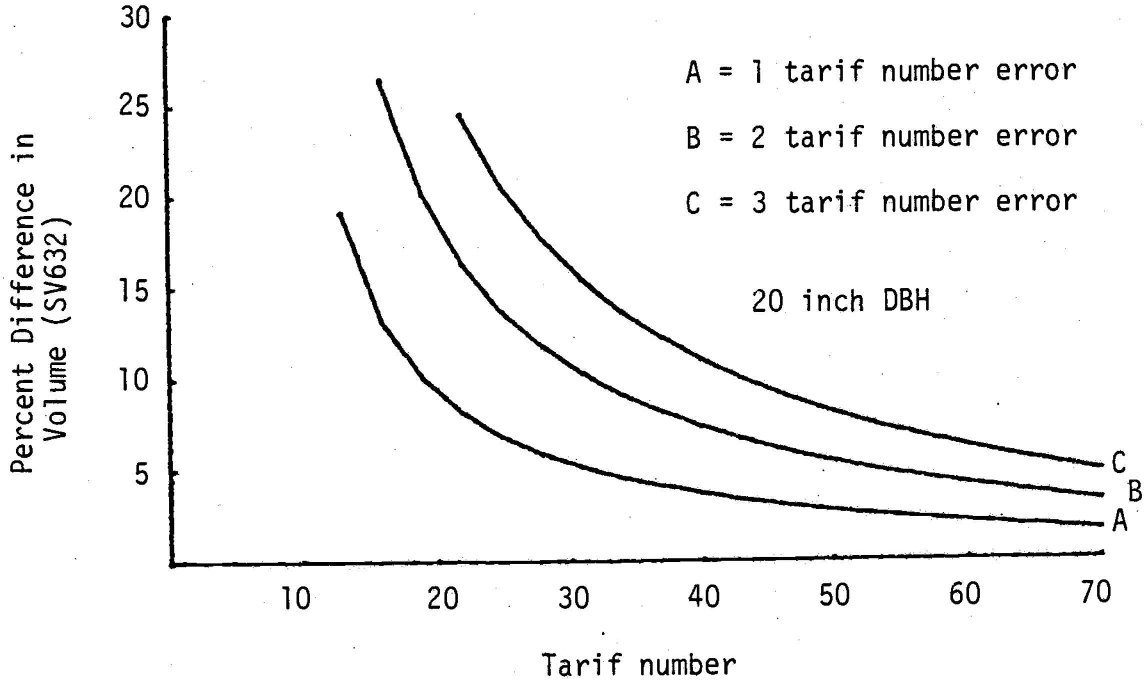


Figure 9. Effect of tarif errors on SV632 for 10-, 15-, 20-, and 30-inch DBH.



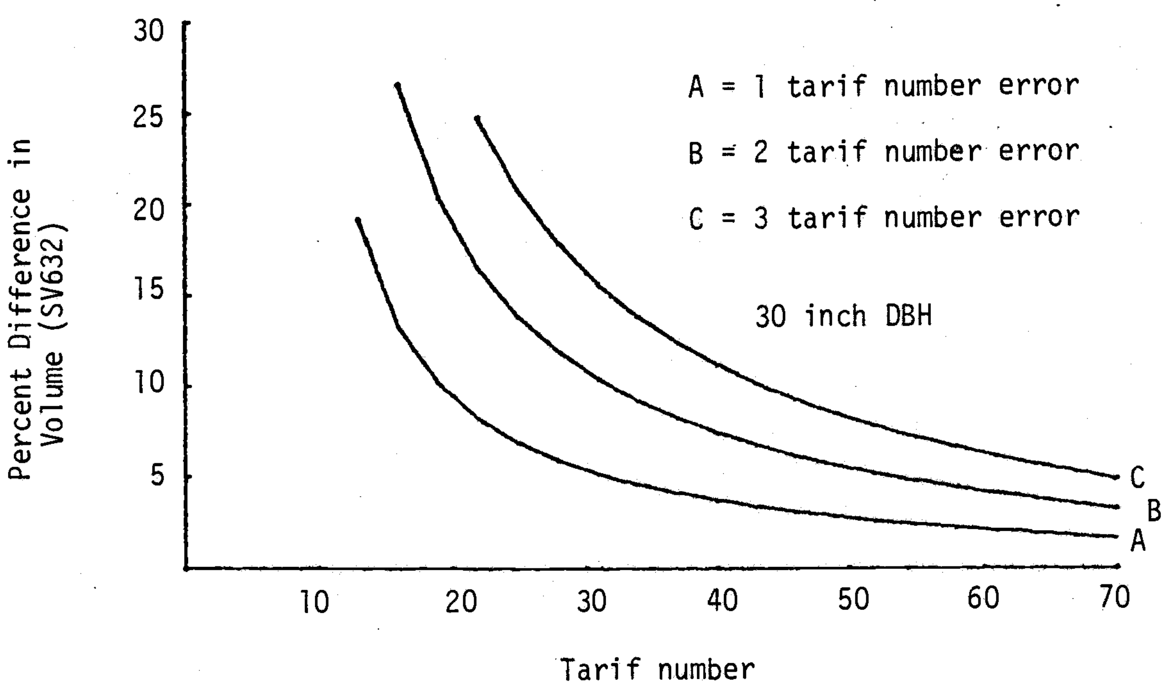
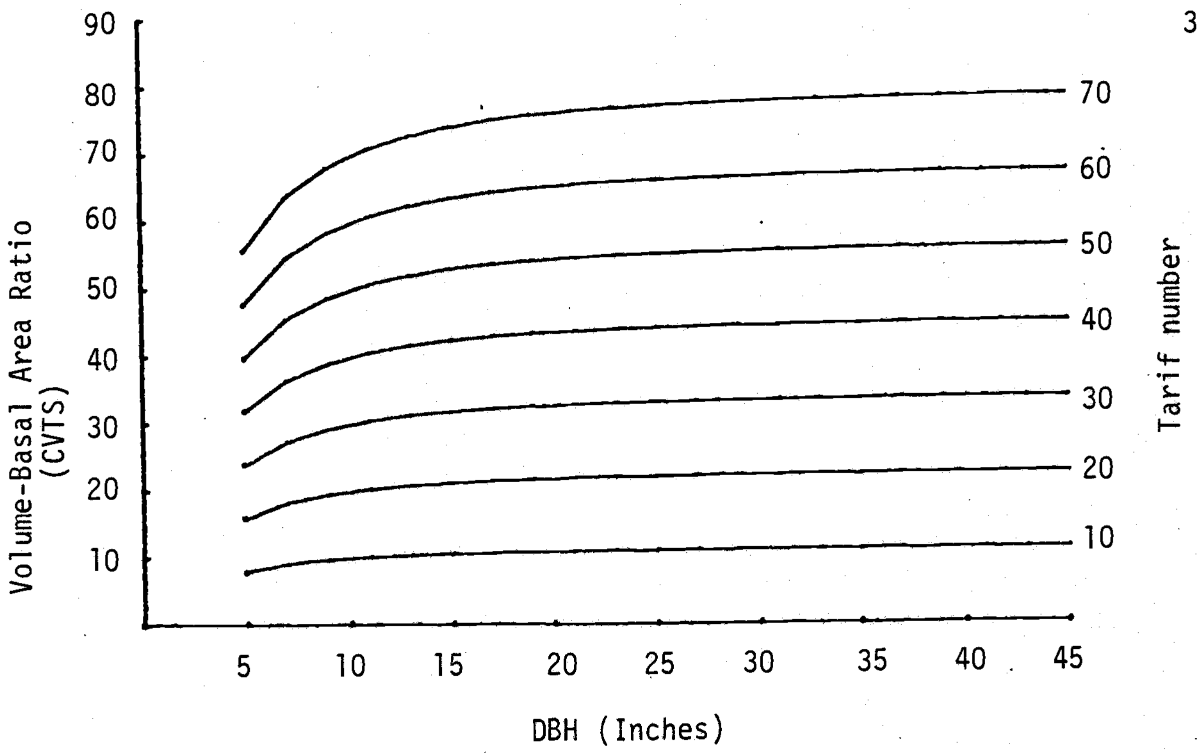


Figure 9. continued.



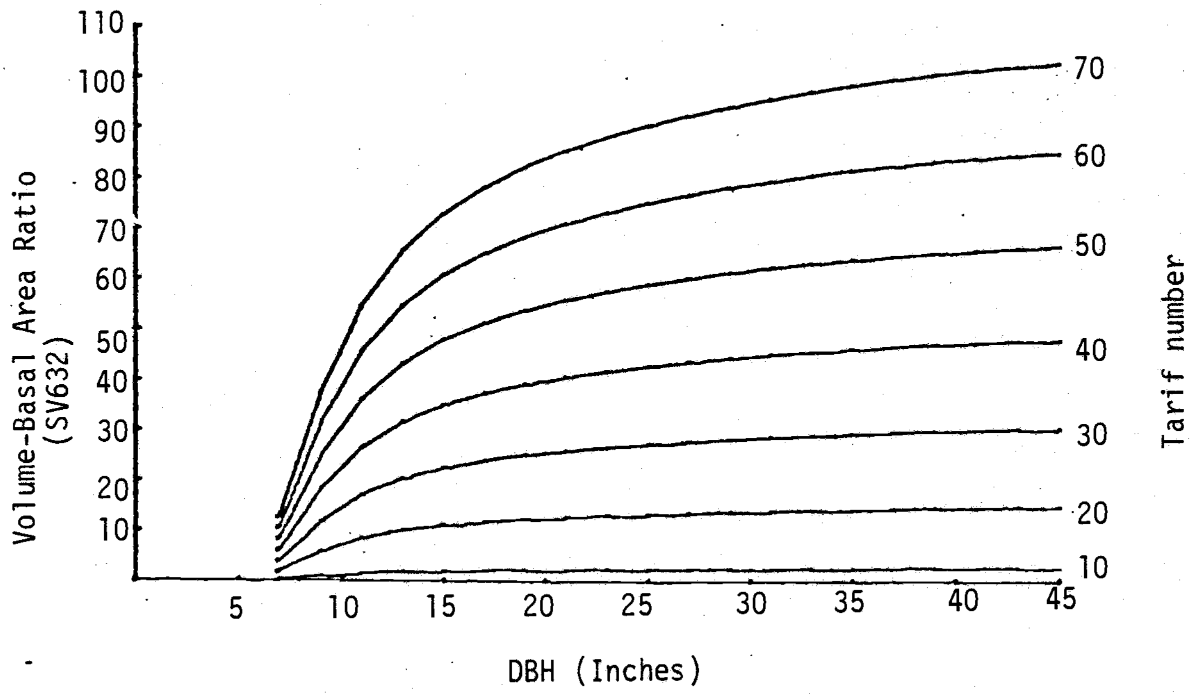


Figure 10. Effect of DBH and tarif on the ratio of volume-basal area (VBAR) for CVTS (top) and SV632 (bottom).

FURTHER CONSIDERATIONS AND STUDIES

The use of the tarif system for obtaining volumes is gaining more interest. Further research, however, is necessary to completely utilize its potential. Foltz and Chambers (1980) recently compared the accuracy of the tarif and form class volume estimation methods. They found that the tarif method equaled or exceeded the form class method, except for some bias in the smaller trees in which form class measurements would generally provide diameters near the bottom (DBH) and top (16 or 30 feet) of the only log in the tree, thus providing more accurate volumes. In considering the field standpoint, more work needs to be done to evaluate the differences in the two methods, in terms of both accuracy and time in measuring total height versus the diameter inside bark at 16 or 32 feet, and the need to only measure diameters once the tarif number is known.

Grading is another important factor that must be considered. The tarif system is not set up to grade individual logs. Quite often grading is done by determining the amount of the tree's volume in a certain grade by log position (Bell, et al., in press). These tables, however, tend to go to a variable top (Girard and Bruce, 1976). The error of using these tables to cruise trees to 6-inch or smaller to tops needs to be determined and if necessary, corrections made.

A final consideration for future research and further development of the tarif system should be to refine the sampling for the tarif number itself. Instructions suggest 20 trees distributed through the range of the diameters present (Turnbull, et al., 1980) in the stand concerned. However, better estimates for the purpose of volume determination might be obtained from random or biased (e.g. selecting more of the larger or smaller trees) sample rather than a more systematic sample. Berry and Wiant (1967) have suggested that a better estimate of volume may be obtained by selecting tarif measurement trees proportional to basal area. This might be done by selecting the first tree in on a variable plot cruise to measure for volume to determine tarif. In stands where there are trends in tarif with DBH (as is often the case in uneven-aged, old-growth or managed stands), this type of sampling may be advantageous. Another possible technique would be to use simple linear regression to fit an equation describing tarif as a function of DBH. This is particularly useful and will not require much additional time with the use of programmable calculators and computers. In this case, a systematic sample may be better. Either of these approaches may prove to be more practical in some cases rather than subdividing the sample by diameter and using two tarif numbers for calculations. The second part of this question is how many trees need to be sampled for tarif in a stand. This must take into consideration the variation of tarif in the stand which may be influenced by such things as tree spacing, distribution, size, stand age and the type of management practiced. The stratification of areas must also be considered when using tarif as well as form class.

CONCLUSION

The *Comprehensive Tree-Volume Tarif Tables* use a tarif number to index particular local volume tables. Local volume tables require only diameter measurement after they are accessed, thus simplifying and speeding volume determinations in the field and office. The tarif number, a measure of a tree's general form, is calculated for a tree by knowing the cubic-foot volume, including top and stump, and the diameter at breast height. To obtain the CVTS, volume equations are often used. Of the three equations tested, it was found that two, the Weyerhaeuser and Bruce-DeMars equations were very comparable and were generally better in results than the British Columbia equation for Western Oregon second growth Douglas-fir. The analysis did not specifically consider effects of management and considered trees from 4 to 22 inches from two different locations in Western Oregon. Using a chi-square test the equations can be compared to see if they meet the accuracy needed.

Through graphical analysis, the effects of measurement errors on tarif number determination and the effect of an error in the tarif number on volume were also investigated. Accuracy must be considered for each circumstance; however, height measurements do seem more important than diameter measurement, and in some cases measurements may not have to be as accurate as presently suggested. It was found that the tarif number must be found more accurately to get the same error in Scribner volume as for cubic-foot volume. Although more work is needed, the tarif system appears to be useful, quick, and a convenient way of obtaining tree or stand volumes.

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APPENDICES

APPENDIX A

PLOTTING OF THE DATA IN PART 1

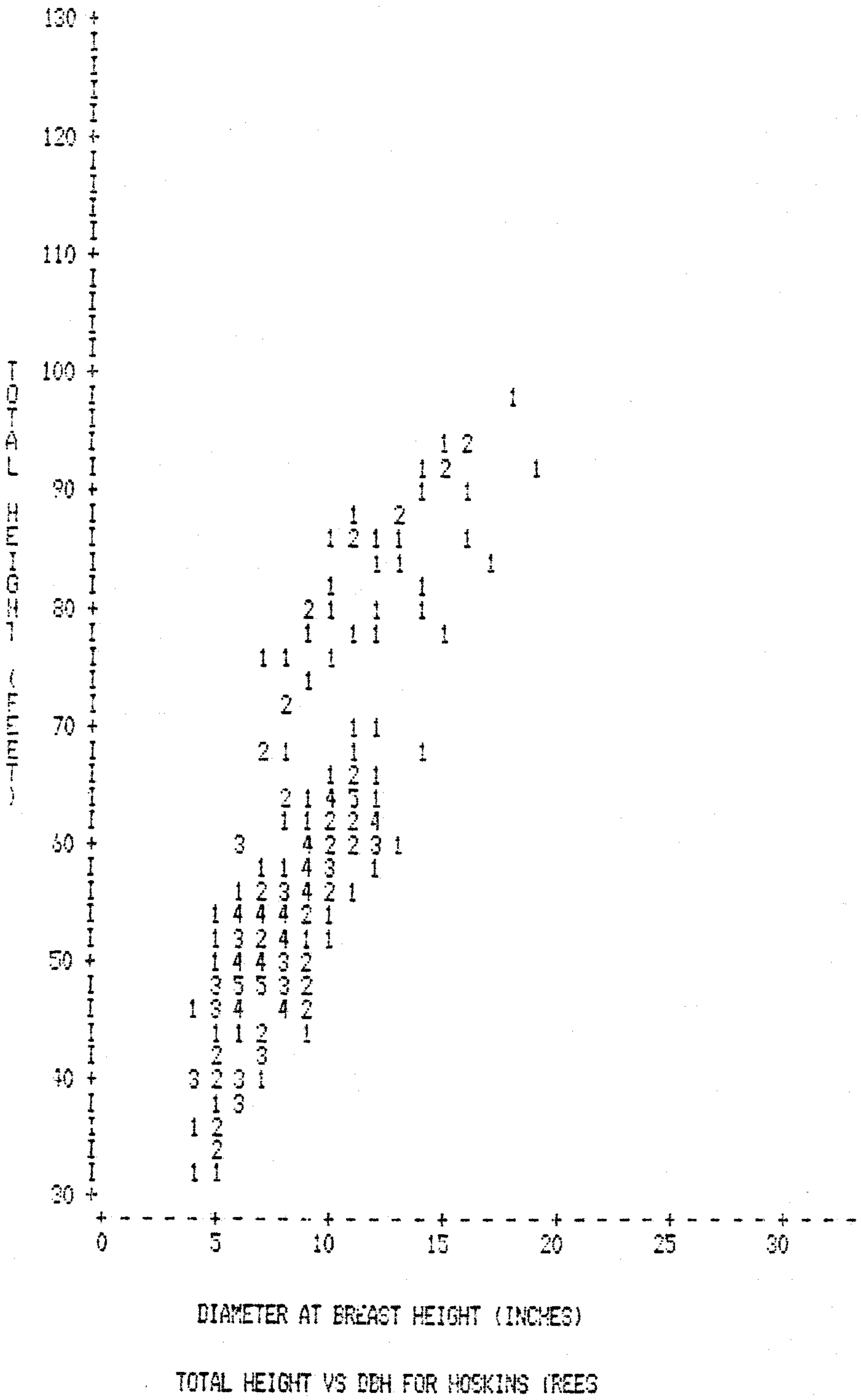

Figure A-1. Total height vs. DBH for Hoskins trees.

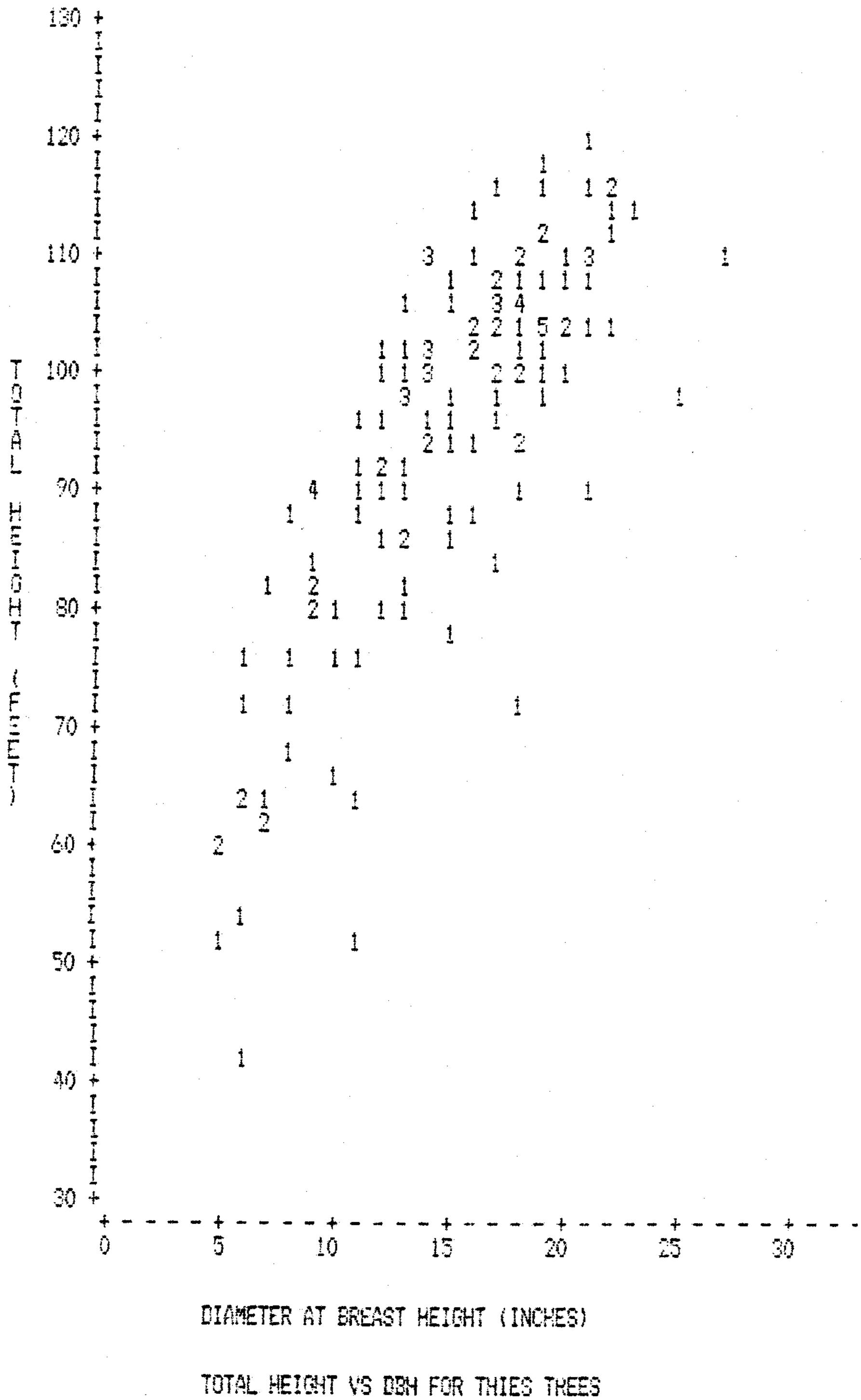

Figure A-2. Total height vs. DBH for Thies trees.

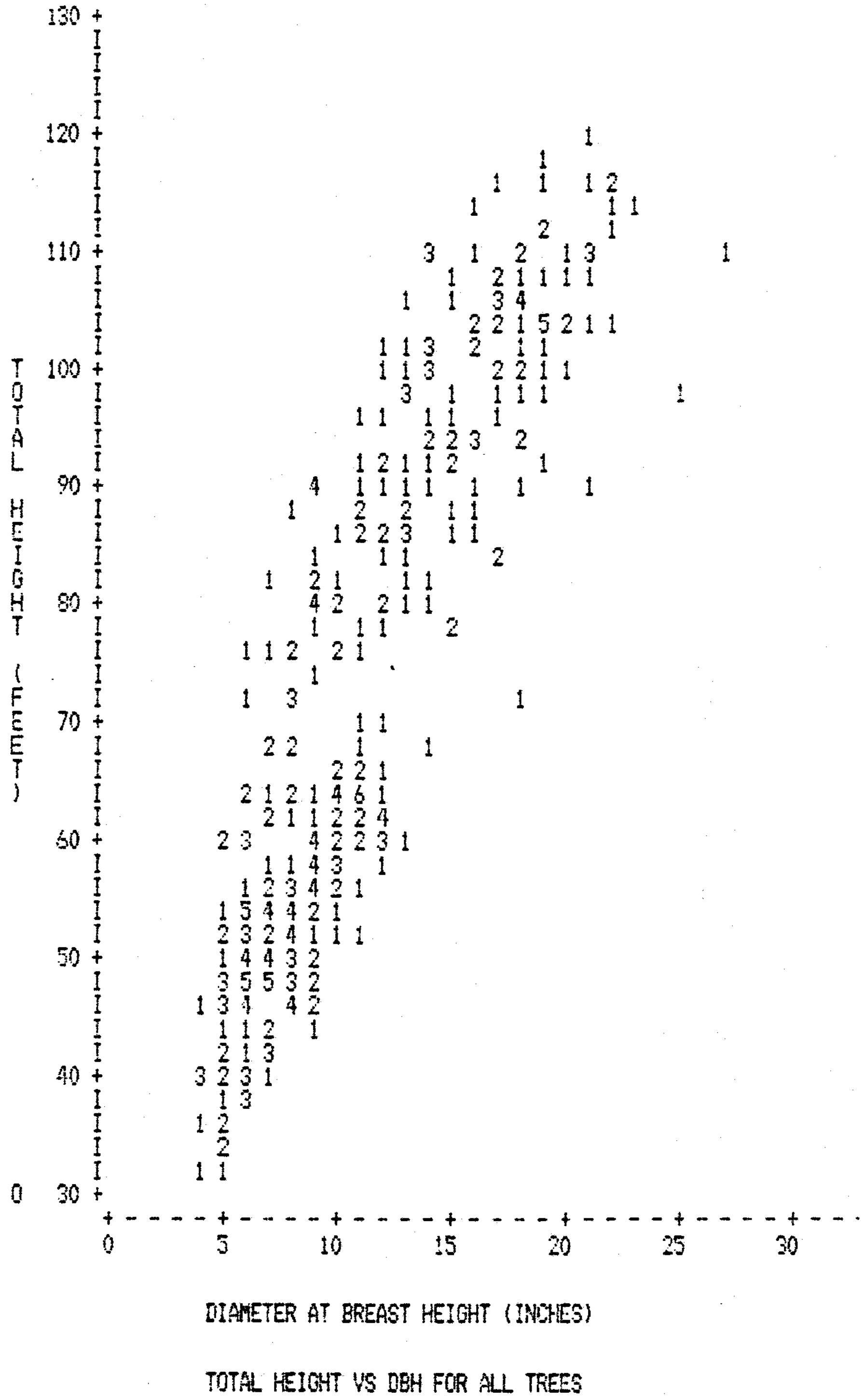

Figure A-3. Total height vs. DBH for all trees.

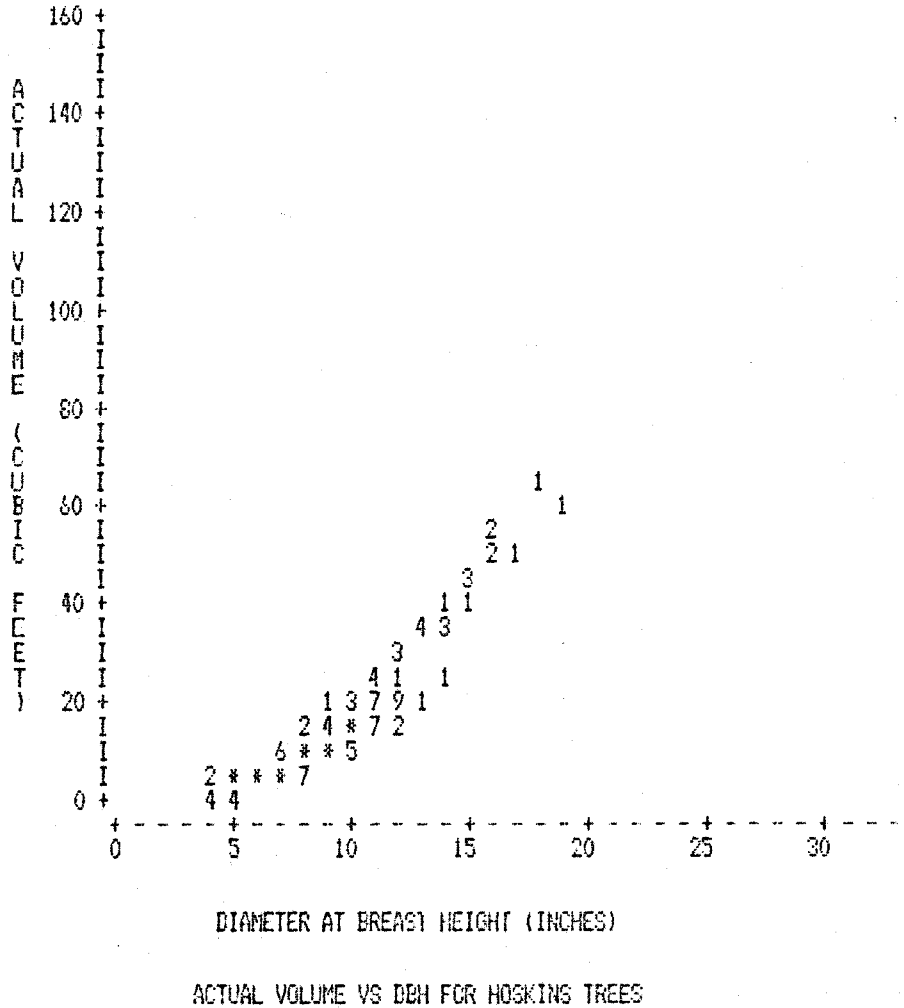

Figure A-4. Actual volume vs. DBH for Hoskins trees.

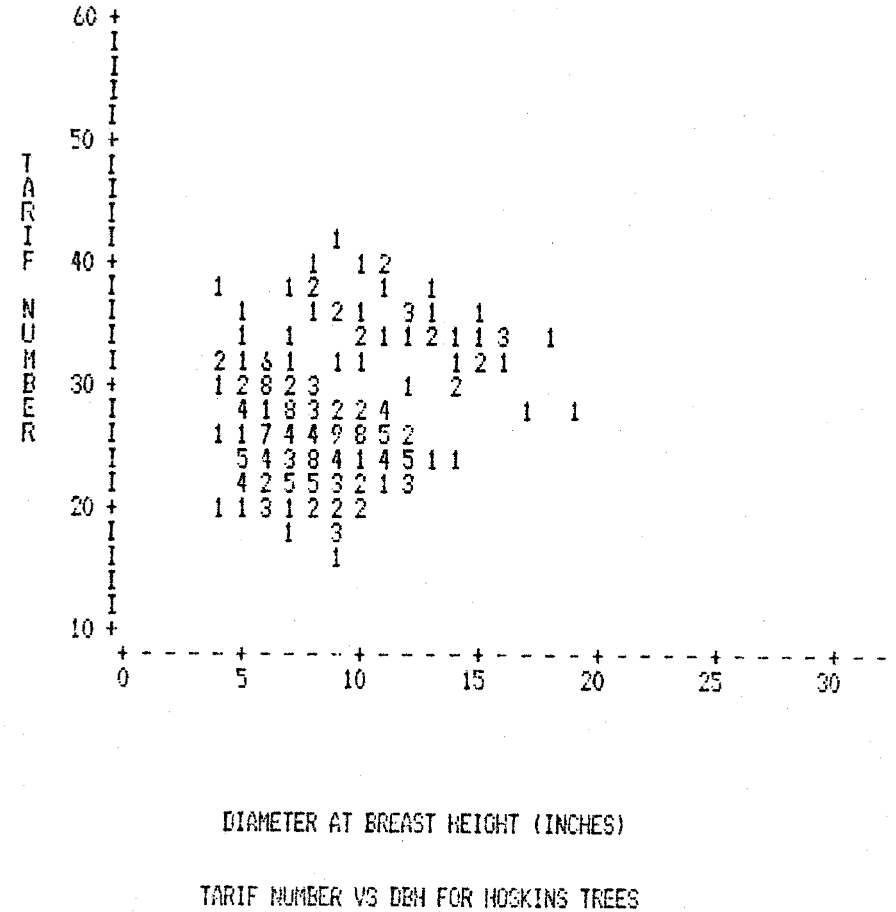

Figure A-5. Tarif number vs. DBH for Hoskins trees.

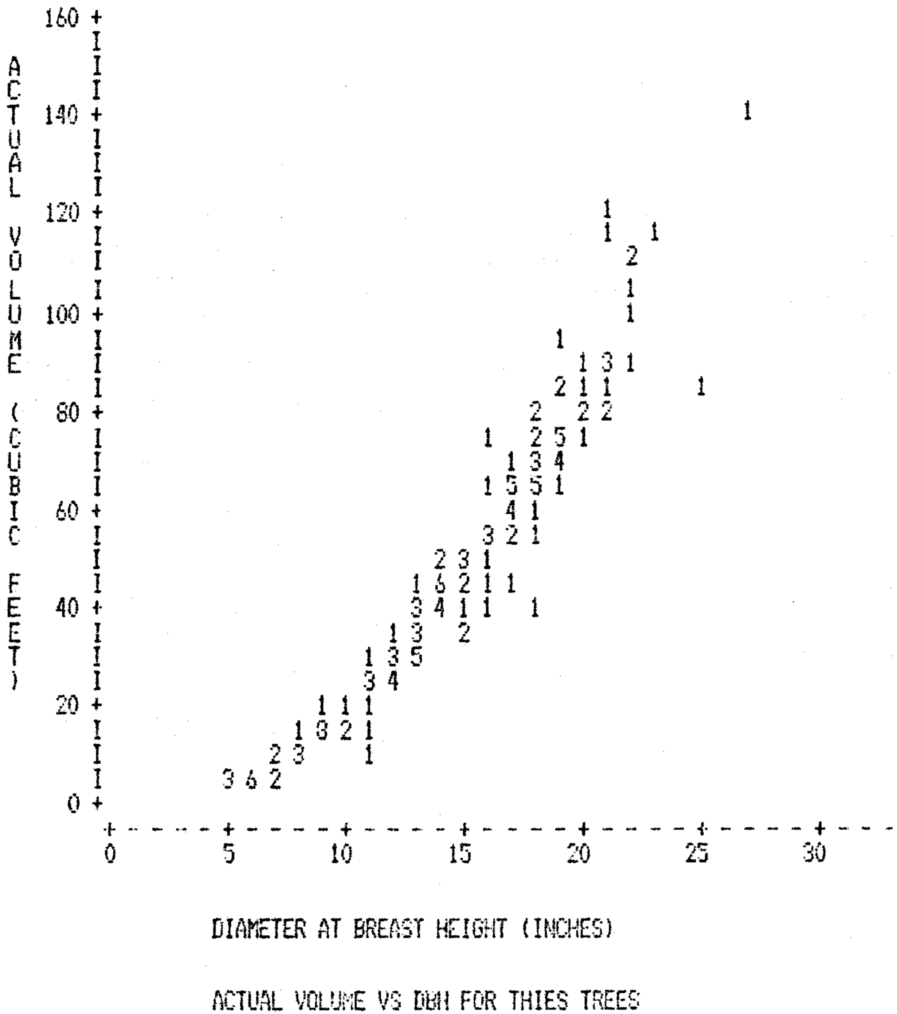

Figure A-6. Actual volume vs. DBH for Thies trees.

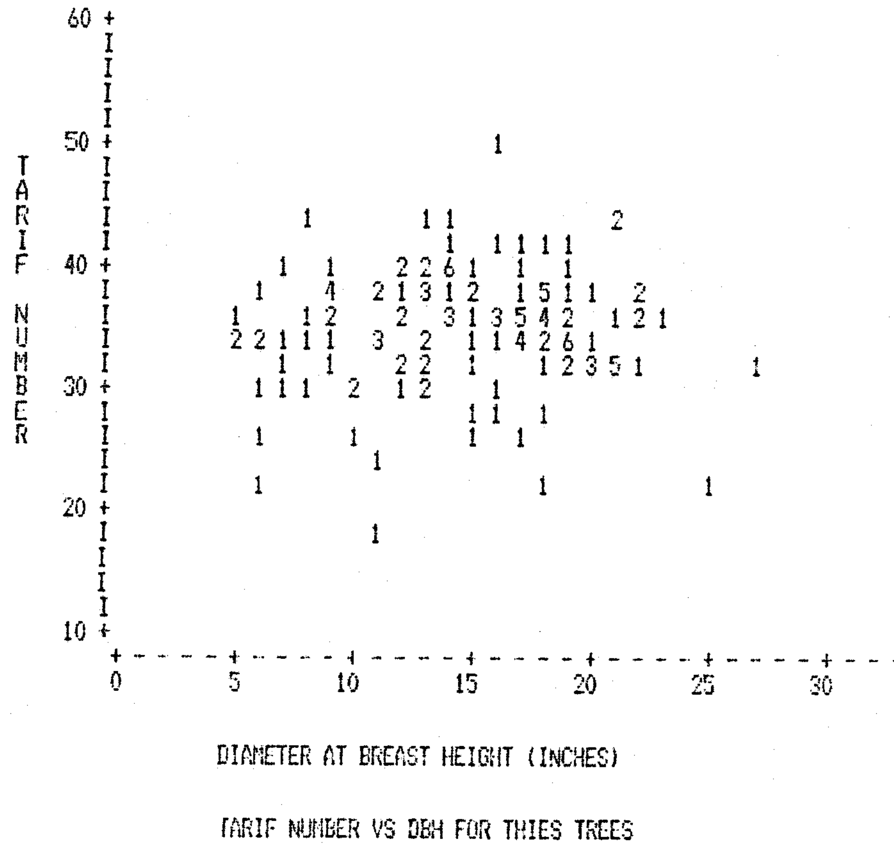

Figure A-7. Tarif number vs. DBH for Thies trees.

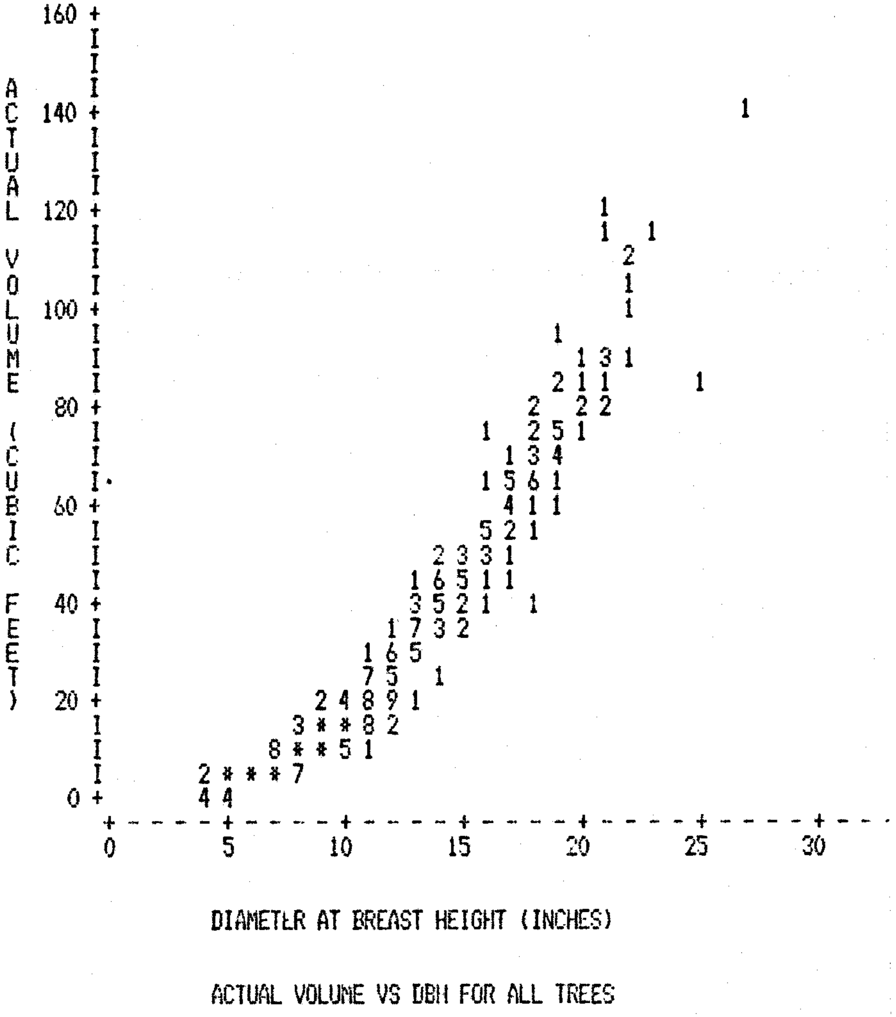

Figure A-8. Actual volume vs. DBH for all trees.

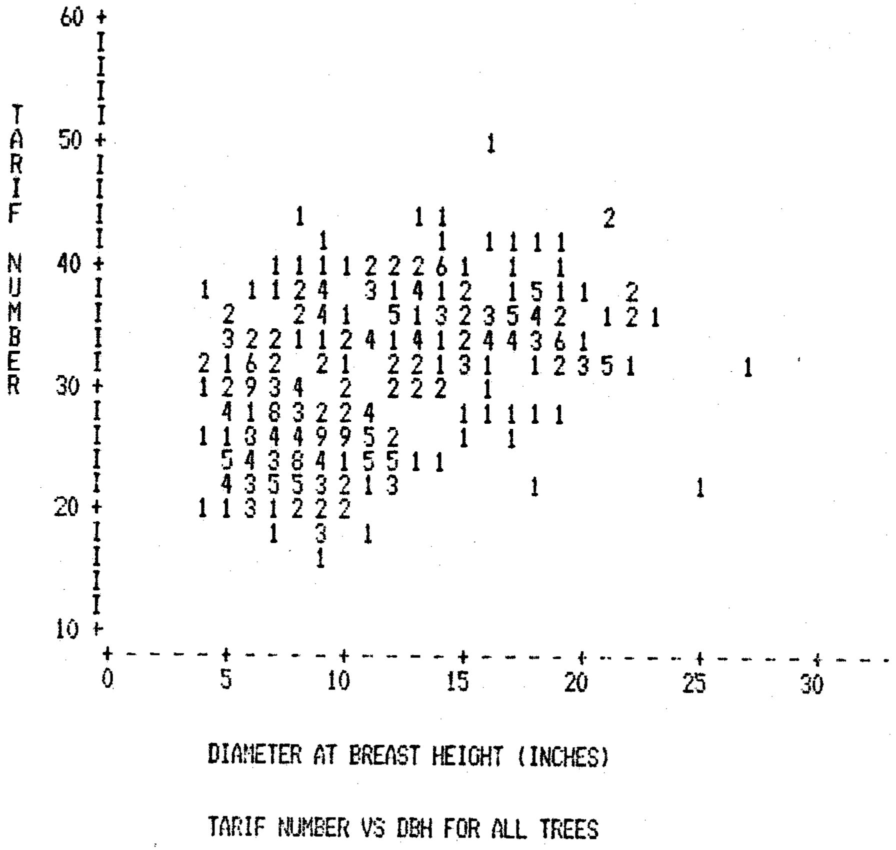

Figure A-9. Tarif number vs. DBH for all trees.

APPENDIX B

SAMPLE OF CALCULATIONS FOR VOLUME EQUATION COMPARISONS USING 15-INCH CLASS AND BRITISH COLUMBIA DOUGLAS-FIR EQUATION

DBH	HT	(μ) CVTS	(x) CVTS B.C.	$(x-\mu)^2$	$(\frac{x}{\mu} - 1)^2$
14.6	96.5	47.118	41.372	33.017	0.014872
14.6	91.7	38.667	39.047	0.144	0.000097
14.6	91.0	45.135	38.710	41.281	0.020264
14.9	97.1	48.889	43.164	32.776	0.013713
15.0	94.8	40.910	42.499	2.525	0.001505
15.0	105.5	52.180	47.974	17.690	0.006497
15.1	77.5	35.461	34.217	1.548	0.001231
15.2	108.7	47.562	50.784	10.381	0.004583
15.2	85.4	37.278	38.636	1.844	0.001327
15.2	78.4	42.839	35.068	60.388	0.032906
15.3	87.1	45.155	39.962	26.967	0.013226
15.5	94.9	46.137	45.048	1.186	0.000557
	TOTALS =	527.331	496.481	229.747	0.110778

PERCENT DIFFERENCE OF THE MEANS

$$\text{MEANS} = \frac{\Sigma x}{n} \qquad n = 12$$

$$\text{ACTUAL} \quad \frac{527.331}{12} = 43.94$$

$$\text{PREDICTED} \quad \frac{496.481}{12} = 41.37$$

$$\%\ \text{DIFF} = \left(\frac{\text{Act. mean} - \text{Pred. mean}}{\text{Act. mean}}\right) * 100 = \left(\frac{43.944-41.373}{43.944}\right) * 100 = \underline{\underline{5.85}}$$

CHI SQUARE

$n = 12 \qquad Z = 1.96 \quad (\text{For } \infty = .05)$

$\chi^2_{(12,105)} = 21.03$ (Snedecor and Cochran, 1980)

$$E = \left(\frac{(Z^2)\,\Sigma\,(x_i-\mu)^2}{\chi^2}\right)^{1/2} = \left(\frac{(1.96)^2\ (229.747)}{21.03}\right)^{1/2} = \underline{\underline{6.48}}$$

$$E\% = \left(\frac{(Z)^2\,\Sigma\,(\frac{x}{\mu}-1)^2}{\chi^2}\right)^{1/2} * 100 = \left(\frac{(1.96)^2\ (0.110778)}{21.03}\right)^{1/2} * 100 = \underline{\underline{14.23}}$$

APPENDIX C

LISTING OF PROGRAM FOR VOLUME EQUATION EVALUATION (VOLEVAL) WITH SAMPLE INPUT AND OUTPUT (FORTRAN V)

LISTING OF PROGRAM VOLEVAL

```
      PROGRAM VOLEVAL (INPUT,OUTPUT,TAPE3=INPUT,TAPE8=OUTPUT)
      DIMENSION CVTS(100),DBH(100),HT(100),CVTSX(100,4),
     $A(8),AVE(4),SUMX(4),DIFF(100,4),PRCTDIF(4),E(4),EPRCNT(4),
     $SUMA(4),SUMB(4),LS(100)
C     ****************************************
C     PROGRAM VOLEVAL WAS WRITTEN BY DAVID MARSHALL
C     TO USE A MODIFIED CHI-SQUARE TEST (RENNIE AND
C     WIANT,1978,BLM RESOURCE INVENTORY NOTES. NO.14)
C     TO TEST THREE DOUGLAS-FIR VOLUME EQUATIONS.
C     ****************************************
      DO 1 J=1,3
       SUMX(J)=0.0
       SUMA(J)=0.0
       SUMB(J)=0.0
    1 CONTINUE
      READ(3,3000) A
 3000 FORMAT(8A10)
      READ(3,*) CHISQR,ALPHA,Z,N
      DO 2 I=1,N
      READ(3,*) LS(I),DBH(I),HT(I),CVTS(I)
    2 CONTINUE
  100 N=I-1
      IDF=N
      SUMCVTS=0.0
      DO 3 I=1,N
       SUMCVTS=SUMCVTS +CVTS(I)
    3 CONTINUE
      ACTAVE=SUMCVTS/N
      DO 5 I=1,N
       DO 4 J=1,3
        CALL VOLUME(CVTSX(I,J),DBH(I),HT(I),J)
    4  CONTINUE
    5 CONTINUE
      WRITE(8,8000)
 8000 FORMAT(1H ,/,/,/,/,/)
      WRITE(8,8001) A
 8001 FORMAT(1H ,8A10)
      WRITE(8,8002)
      WRITE(8,8003)
 8002 FORMAT(1H ,@STUDY@,2X,@DBH@,3X,@HT@,4X,@CVTS@,1X,3(4X,@CVTSX@,5X,
     $@DIFF@))
 8003 FORMAT(1H ,33X,@WEYCO@,15X,@BC@,16X,@B-D@)
      DO 7 I=1,N
       DO 6 J=1,3
         DIFF(I,J)=CVTS(I) - CVTSX(I,J)
         SUMX(J)=SUMX(J) + CVTSX(I,J)
    6  CONTINUE
       WRITE(8,8004) LS(I),DBH(I),HT(I),CVTS(I),(CVTSX(I,J),DIFF(I,J),
     $J=1,3)
 8004 FORMAT(1H ,2X,I2,2X,F4.1,1X,F5.1,1X,F7.3,3(3X,F7.3,2X,F6.2))
    7 CONTINUE
      DO 9 I=1,N
       DO 8 J=1,3
        A1=(CVTSX(I,J) - CVTS(I))**2.
        B=((CVTSX(I,J)/CVTS(I))-1.)**2.
        SUMA(J)=SUMA(J) + A1
        SUMB(J)=SUMB(J) + B
    8  CONTINUE
    9 CONTINUE
      Z2=Z**2.
      DO 10 J=1,3
       E(J)=((Z2*SUMA(J))/CHISQR)**.5
```

LISTING (continued)

```
      EPRCNT(J)=(((72*SUMB(J))/CHISQR)**.5)*100.
      AVE(J)=SUMX(J)/N
      PRCTDIF(J)=((ACTAVE - AVE(J))/ACTAVE)*100.
   10 CONTINUE
      WRITE(8,8005)
      WRITE(8,8006)
 8005 FORMAT(1H ,20X,@***** FINAL VALUES *****@)
 8006 FORMAT(1H ,22X,@ACTUAL@,4X,@WEYCO@,4X,@B.C.@,6X,@B-D@)
      WRITE(8,8007) ACTAVE,(AVE(J),J=1,3)
      WRITE(8,8008) (PRCTDIF(J),J=1,3)
 8007 FORMAT(1H ,12X,@AVE@,/,13X,@CVTS@,3X,4(3X,F6.2))
 8008 FORMAT(1H ,12X,@% DIFF@,/,13X,@OF MEAN@,9X,3(3X,F6.2))
      WRITE(8,8009) (E(J),J=1,3)
      WRITE(8,8010) (EPRCNT(J),J=1,3)
 8009 FORMAT(1H ,12X,@E@,15X,3(3X,F6.2))
 8010 FORMAT(1H ,12X,@E%@,14X,3(3X,F6.2))
      WRITE(8,8011)
      WRITE(8,8012) CHISQR,ALPHA,Z,IDF,N
 8011 FORMAT(1H ,/,19X,@CHISQR@,4X,@ALPHA@,6X,@Z@,6X,@DF@,4X,@OBS@)
 8012 FORMAT(1H ,17X,F8.4,4X,F4.3,4X,F4.2,4X,I3,4X,I3)
      WRITE(8,8013)
 8013 FORMAT(1H ,/,13X,26(@- @))
      END
      SUBROUTINE VOLUME(VOL,D,H,J)
      GO TO (1,2,3),J
    1 VOL=-3.21809 + .04948*ALOG10(H)*ALOG10(D)
     1 -.15664*ALOG10(D)**2. + 2.02132*ALOG10(D)
     2 +1.63408*ALOG10(H) - .16185*ALOG10(H)**2.
      VOL=10.0**VOL
      RETURN
    2 VOL=10.0**(-2.658025)*(D**1.739925)*(H**1.133187)
      RETURN
    3 VOL=(.480961 + 42.46542/(H**2.) - 10.99643*(D/H**2.)
     1 -.107809*(D/H) - .0040983*D)*.005454254*(D**2.)*H
      RETURN
      END
```

NOTE: The @ character represents a single quote mark.

SAMPLE INPUT DECK FOR PROGRAM VOLEVAL
(15-inch DBH class)

CARD

1. Cover card [1/]

2. User number and password

3. Charge number and project number

4 & 5. Getting and executing the binary version of VOLEVAL.

6. EOI (End-of-record) - Multipunch 7/8/9 in column 1.

7. Run title (up to 80 columns)

[2/]8. X^2, α , Z, n

[2/]9. Volume (actual), DBH, HT

LAST CARD. EOI (End-of-information) - Multipunch 6/7/8/9 in column 1.

```
FRLBOX.
USER,______,______.
CHARGE,______,______.
GET.BEVAL.
BEVAL.
&
                RUN FOR 15 INCH CLASS
21.03,.05,1.96.12
2 14.6 96.5 47.118
1 14.6 91.7 38.667
1 14.6 91.0 45.135
2 14.9 97.1 48.889
2 15.0 94.8 40.910
2 15.0 105.5 52.180
2 15.1 77.5 35.461
2 15.2 108.7 47.562
2 15.2 85.4 37.278
1 15.2 78.4 42.839
2 15.3 87.1 45.155
1 15.5 94.9 46.137
#
```

1/ This cover card is set up to run at the OSU Forest Research Laboratory RJE (Remote job entry) terminal.

2/ Free-field format.

SAMPLE OUTPUT FOR PROGRAM VOLEVAL
(15-inch DBH class)

RUN FOR 15 INCH CLASS

STUDY	DBH	HT	CVTS	CVTSX WEYCO	DIFF	CVTSX BC	DIFF	CVTSX B-D	DIFF
2	14.6	96.5	47.118	43.941	3.18	41.372	5.75	44.007	3.11
1	14.6	91.7	38.667	41.643	-2.98	39.047	-.38	41.582	-2.92
1	14.6	91.0	45.135	41.307	3.83	38.710	6.43	41.228	3.91
2	14.9	97.1	48.889	45.833	3.06	43.164	5.72	45.925	2.96
2	15.0	94.8	40.910	45.220	-4.31	42.499	-1.59	45.246	-4.34
2	15.0	105.5	52.180	50.566	1.61	47.974	4.21	50.916	1.26
2	15.1	77.5	35.461	36.901	-1.44	34.217	1.24	36.394	-.93
2	15.2	108.7	47.562	53.380	-5.82	50.784	-3.22	53.853	-6.29
2	15.2	85.4	37.278	41.431	-4.15	38.636	-1.36	41.163	-3.89
1	15.2	78.4	42.839	37.797	5.04	35.068	7.77	37.305	5.53
2	15.3	87.1	45.155	42.798	2.36	39.962	5.19	42.576	2.58
1	15.5	94.9	46.137	47.941	-1.80	45.048	1.09	47.968	-1.83

***** FINAL VALUES *****

	ACTUAL	WEYCO	B.C.	B-D
AVE CVTS	43.94	44.06	41.37	44.01
% DIFF OF MEAN		-.27	5.85	-.16
E		5.26	6.48	5.39
E%		12.15	14.23	12.36

CHISQR	ALPHA	Z	DF	OBS
21.0300	.050	1.96	12	12

- -