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FOREST MENSURATION HANDBOOK

by G. J. Hamilton, MSc

FORESTRY COMMISSION

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A. C. Miller undertook most of the computer programming required to produce the tables and was responsible for establishing some form height/top height and tariff number/top height relationships, and for development work in connection with assortment tables and the measurement of stacked timber.

R. O. Hendrie prepared the single tree tariff charts and analysed various data concerning timber density, stacked timber, and bark.

M. D. Witts established most of the form height/top height and tariff number/top height relationships and investigated bark thickness in the major conifers.

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Forest Mensuration Handbook

INTRODUCTION

Measurement of timber is required for several purposes. The most obvious of these, perhaps, is the need to quantify forest produce for sale. Measurement of timber is also required in management, notably for planning purposes and for control of resources.

There are many different ways in which timber can be measured, some being more appropriate for one purpose than others. In addition the choice of method may be influenced by the size and quantity of produce, its value and possibly by the local conditions and facilities available.

This publication is intended to provide the information necessary to meet the needs of measurement for most purposes and conditions in British forestry. The main components are, first, a *key* (front inside cover) which enables the user to choose the measurement procedure most appropriate for the purpose intended. The principles involved in producing this key, together with explanatory notes, are given in Part I, immediately following. Secondly, detailed measurement procedures are given separately for felled and standing timber in Part III, page 20 and Part IV, page 44. Essential background information is given with each of the procedures which are individually numbered. The tables required to carry out some of these procedures are produced at the back of the book in Part VI, page 201.

Miscellaneous aspects of measurement, together with conversion factors, abbreviations, etc are brought together to form Part V, page 117.

PART I GENERAL ASPECTS OF MEASUREMENT

Expression of Quantity

Timber quantity can be expressed in terms of solid volume, stacked volume, green weight, dry weight, length, number of pieces, etc. Traditionally timber quantity has mostly been expressed in terms of solid volume and there are good reasons why this should be so. In the first place, many timber products, following conversion, are sold by solid volume. Sawn timber is an obvious example. Just as important, however, is the fact that solid volume can be relatively easily assessed for both felled and standing timber. Alternative measures which sometimes have a more direct bearing on the requirements of the consumer, such as dry weight for pulp manufacture, are generally restricted in their use on account of the practical difficulties in assessing them. For example the measurement of the weight of dry matter in timber is a complex process. Furthermore, weight measurements of any kind are impossible in standing timber. Even when parameters other than solid volume are assessed, for example stacked volume or weight, these are frequently converted to solid volume estimates for management purposes.

In general, therefore, the traditional measure of solid volume remains the basic reference quantity in timber measurement.

The Need for Conventions

A characteristic feature of measurement in forestry is that by the nature of the products, very precise measurement is rarely practicable and one is invariably dealing with volume *estimates*. There are many different ways of estimating timber volume with inevitable differences in the estimate arrived at. Even the smallest log can be measured in several different ways. It is thus a fundamental necessity to describe the method of measurement and the *measurement conventions* used when ascribing volumes to timber in order to convey the full meaning of such estimates. Standard measurement conventions are described in Part II, page 17.

Cost/benefit Aspects of Measurement

Given that an estimate of quantity is required for a particular purpose, a decision has to be made about the degree of precision which should be sought. Virtually any forest product may be measured to varying degrees of precision and to arrive at an appropriate level it is necessary to consider the costs and benefits associated with these different levels of precision.

In the first place greater precision generally costs more per unit volume. For example, the volume of a single log may be estimated as the product of its length and its mean cross-sectional area. The mean cross-sectional area may be estimated from one measurement taken at the mid point of the log. A more precise estimate of the mean cross-sectional area may be determined by taking the average of a number of measurements taken at regular intervals along the length of the log. The more frequent the measurements, the more precise will be the estimate. A second example might be, say, finding the mean diameter of a stand by sampling. The more trees sampled, the more precise will be the estimate of mean diameter. In both of these examples greater precision involves more work and hence costs more per unit of volume.

In broad terms also, greater precision produces greater benefits. As an example, consider the situation of a prospective buyer of timber confronted by two lots, of say, 500 logs. In one lot the volume of each individual log has been measured, whilst the volume of the second lot has been derived from a 5% sample of randomly selected logs. Depending on how accurately the sample represents the total population of logs, the true volume may be greater than, less than, or exactly equal to the volume estimated from the sample. Although the chances of an underestimate of volume are equal to the chances of an overestimate, the risk of a shortfall in volume may be one which the buyer is unwilling or unable to accept. The elimination of the element of risk is consequently of some value to him and the lot of logs where measurement is complete consequently becomes a more attractive proposition. This will be reflected in his willingness to pay a slightly higher price for this lot. The difference between the two prices could be regarded as an insurance premium against the risk of loss. Thus it follows that increases in price may be expected with increasing precision.

The relationship of price to precision, however, will be rather different from the relationship of cost of measurement to precision. Figure 1 depicts what might be regarded as the typical situation. The error of estimate can be regarded here as a standard error or as confidence limits at a specified level of probability (see page 123 for further explanation). Whereas cost rises rapidly as the error approaches $\pm 0\%$ the price curve tends to level out in the same area. An optimum level of precision can then be identified at the point where the difference between the two curves is greatest. In practice the establishment of a price/precision curve can rarely be based on factual information, but the generalised shape will apply in most situations.

There are two further important factors to be considered here which influence the shape of these curves and hence the optimum level of precision applying in a given situation. The first of these is the value of the product per unit of volume. For a given quantity and method of measurement the cost/precision curves may be similar for high and low value products but the price/precision curves may be expected to vary. In the case of a low value product the financial risk is clearly lower than with high value products at a given level of precision (other than $\pm 0\%$). The net result is a relatively lower 'insurance premium' against loss, and consequently a rather flatter price/precision curve as shown in Figure 2. With lower timber values the optimum level of precision becomes lower also.

The same principles apply where measurement is carried out for purely management purposes. In these cases the 'price' becomes a value considered by management as appropriate for the purpose. The critical factor here however is again the rate of change of this value with changing precision, bearing in mind here that the 'risk' attached to varying levels of precision is a risk to management. For purposes like inventory for production forecasting,

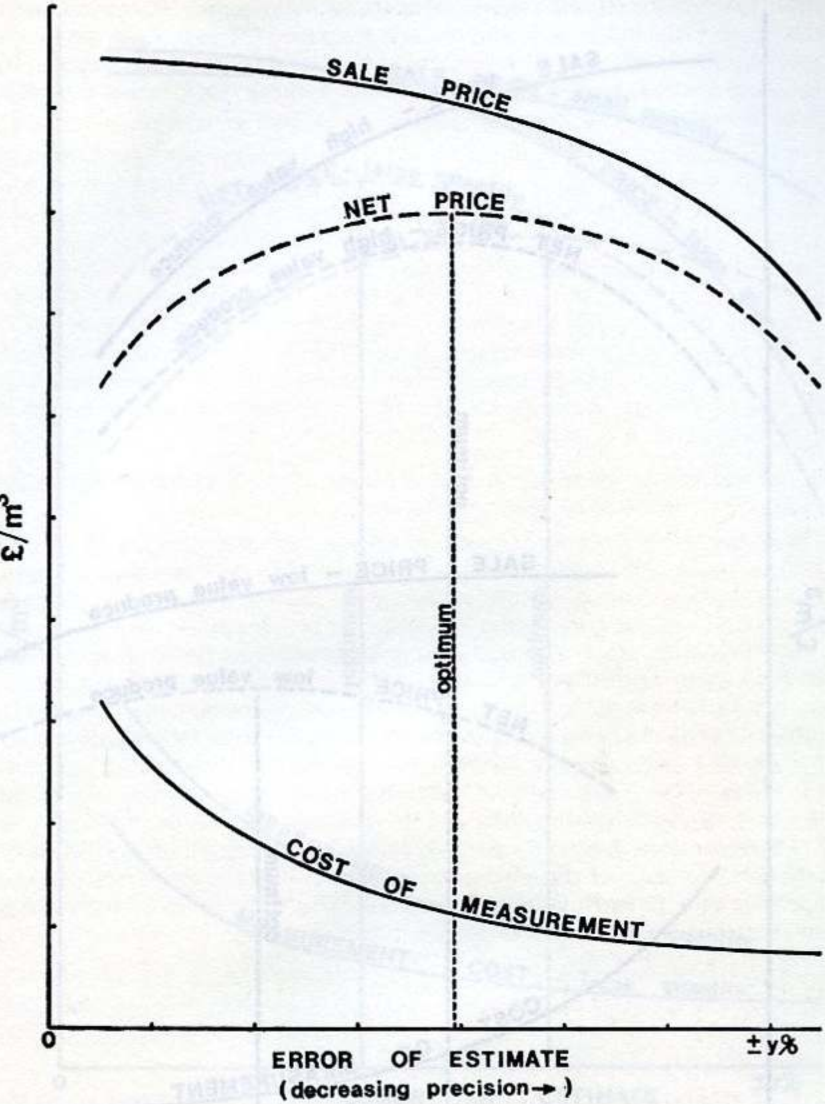
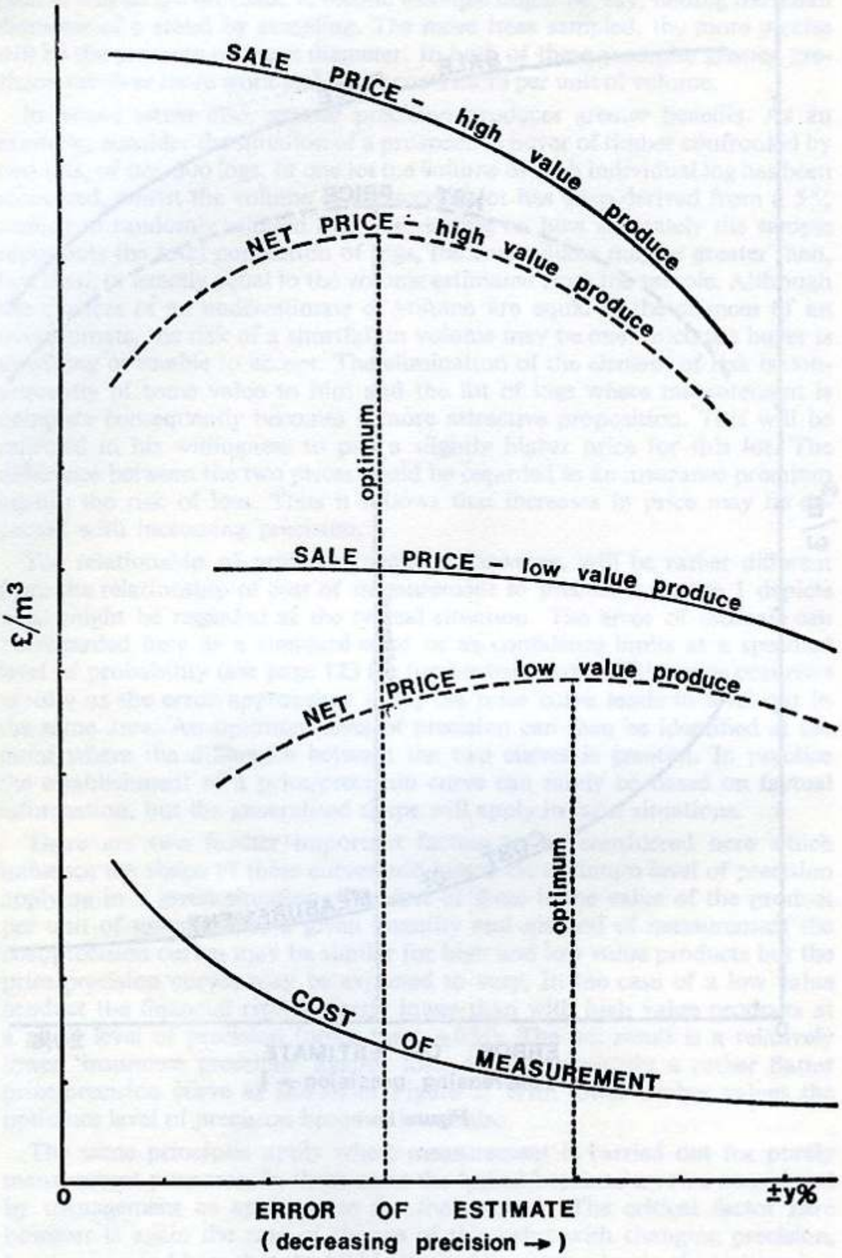

SALE PRICE
NET PRICE
optimum
COST OF MEASUREMENT
£/m³
0
± y%
ERROR OF ESTIMATE
(decreasing precision →)

Figure 1


SALE PRICE - high value produce
NET PRICE - high value produce
optimum
SALE PRICE - low value produce
NET PRICE - low value produce
optimum
COST OF MEASUREMENT
£/m3
0
±y%
ERROR OF ESTIMATE
(decreasing precision →)
Figure 2

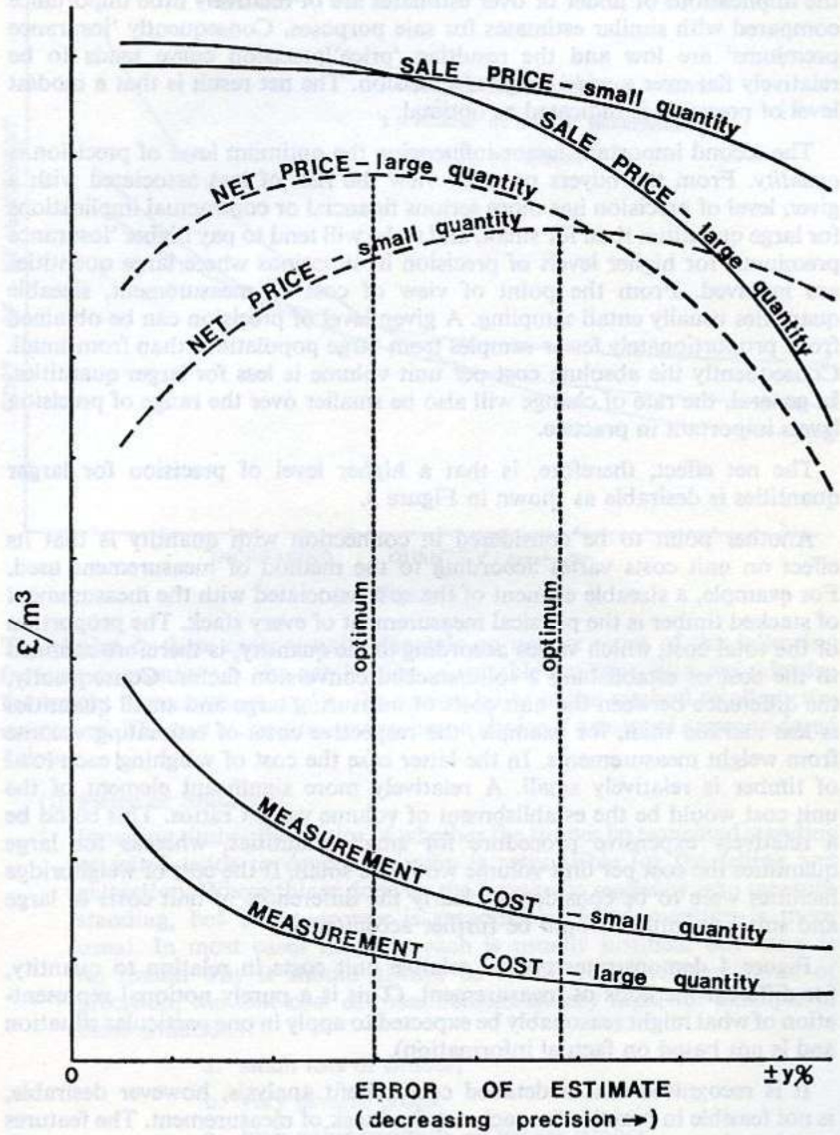

SALE PRICE – small quantity
SALE PRICE – large quantity
NET PRICE – large quantity
NET PRICE – small quantity
£/m3
optimum
optimum
MEASUREMENT COST – small quantity
MEASUREMENT COST – large quantity
0
±y%
ERROR OF ESTIMATE
(decreasing precision →)

Figure 3

the implications of under or over estimates are of relatively little importance compared with similar estimates for sale purposes. Consequently 'insurance premiums' are low and the resulting 'price'/precision curve tends to be relatively flat over a wide range of precision. The net result is that a modest level of precision is indicated as optimal.

The second important factor influencing the optimum level of precision is *quantity*. From the buyers point of view the risk of loss associated with a given level of precision has more serious financial or contractual implications for large quantities than for small, and so he will tend to pay higher 'insurance premiums' for higher levels of precision in situations where large quantities are involved. From the point of view of cost of measurement, sizeable quantities usually entail sampling. A given level of precision can be obtained from proportionately fewer samples from large populations than from small. Consequently the absolute cost per unit volume is less for larger quantities. In general, the rate of change will also be smaller over the range of precision levels important in practice.

The net effect, therefore, is that a higher level of precision for larger quantities is desirable as shown in Figure 3.

Another point to be considered in connection with quantity is that its effect on unit costs varies according to the method of measurement used. For example, a sizeable element of the cost associated with the measurement of stacked timber is the physical measurement of every stack. The proportion of the total cost, which varies according to the quantity, is therefore confined to the cost of establishing a solid/stacked conversion factor. Consequently, the difference between the unit costs of measuring large and small quantities is less marked than, for example, the respective costs of estimating volume from weight measurements. In the latter case the cost of weighing each load of timber is relatively small. A relatively more significant element of the unit cost would be the establishment of volume weight ratios. This could be a relatively expensive procedure for small quantities, whereas for large quantities the cost per unit volume would be small. If the cost of weighbridge facilities were to be considered, clearly the differences in unit costs of large and small quantities would be further accentuated.

Figure 4 demonstrates typical relative unit costs in relation to quantity, for different methods of measurement. (This is a purely notional representation of what might reasonably be expected to apply in one particular situation and is not based on factual information).

It is recognised that a detailed cost benefit analysis, however desirable, is not feasible in practice for each required task of measurement. The features mentioned above however, form the basis of the guidelines contained in this book for selecting an appropriate measurement procedure for a given purpose.

Choice of Method

The key to procedures (front inside cover) indicates an appropriate procedure for a given purpose. For some purposes a choice of method is presented.

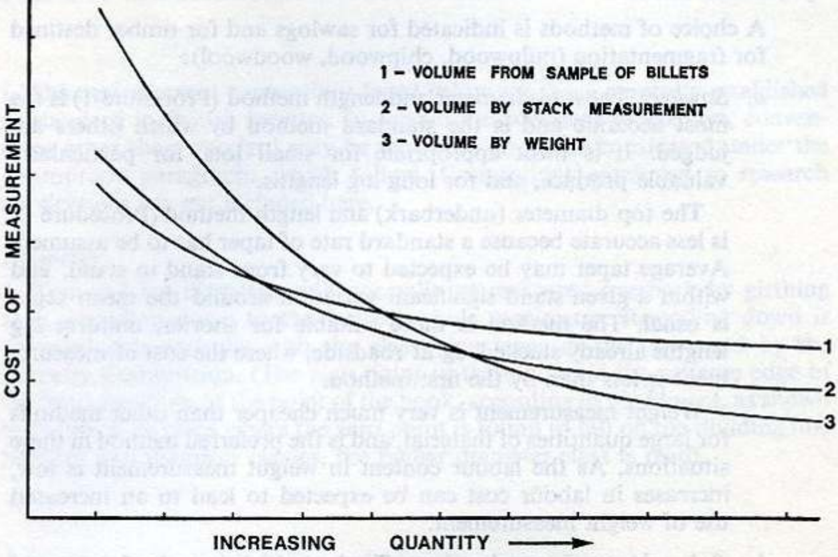


Figure 4

The choice in these cases usually depends on one or more of the following factors: a. quantity; b. the availability of suitable facilities, eg a weighbridge for weight measurement, and c. the acceptability of the method to all parties concerned. The particular situations where a choice is presented are considered below:

(i) **Felled or Standing?**

In selling timber the choice of whether the timber be measured standing or felled tends to depend on who is responsible for the felling and extraction. Where this is done by the buyer, the tendency is to measure standing, but if the grower is responsible, felled measure is more usual. In most cases this approach is usually justified, but there is no reason why it should always be so. If, for a required level of precision, the unit cost of measurement is very high, for example in these situations:

a. small lots of timber,

b. very diverse crops,

c. high value produce, eg veneer timber,

it may be better to provide a very rough and cheap estimate of standing volume (Procedure 9) in order to attract the interest of the prospective buyer, but to agree to sell on the basis of an appropriate felled measure.

(ii) **Standing Timber**

Apart from the situations outlined above the choice of method for measuring standing timber is clearly indicated in the key and requires no further explanations.

(iii) Felled Timber

A choice of methods is indicated for sawlogs and for timber destined for fragmentation (pulpwood, chipwood, woodwool):

a. Sawlogs. The mid-diameter and length method (Procedure 1) is the most accurate and is the standard method by which others are judged. It is most appropriate for small lots, for particularly valuable produce, and for long log lengths.

The top diameter (underbark) and length method (Procedure 2) is less accurate because a standard rate of taper has to be assumed. Average taper may be expected to vary from stand to stand, and within a given stand significant variation around the mean taper is usual. The method is more suitable for shorter, uniform log lengths already stacked, eg at roadside, where the cost of measurement is less than by the first method.

Weight measurement is very much cheaper than other methods for large quantities of material, and is the preferred method in these situations. As the labour content in weight measurement is low, increases in labour cost can be expected to lead to an increased use of weight measurement.

b. Pulp, chipwood, woodwool etc. Timber which is to be fragmented tends to be of small diameter, shorter length and often of less value than other products. These features imply cheaper measurement and the alternatives given are stack or weight measurement. Assuming in either case the objective is an estimate of the solid *volume* of the timber, weight measurement tends to be more efficient, in terms of precision achieved per unit cost, for large quantities, and has the further advantage of being the more objective method of the two. For more moderate quantities however, stack measure can produce greater precision per unit cost where billets are uniform, straight and properly stacked. Poor stacking, poor quality and very varied sizes lead to precision of a significantly lower level.

PART II MEASUREMENT CONVENTIONS

1. The measurement conventions listed below are those currently established as standard in British forestry. In certain measurement procedures, conventions other than standard may be required. These are considered under the appropriate paragraphs which follow. Conventions employed in research applications are not included here.

Diameter

2. Tree and log diameters will normally be measured overbark by girthing tape, rounding down to the nearest whole centimetre. Rounding down is achieved automatically with the classifying tapes of the type used by the Forestry Commission. (The zero point in these tapes is the extreme edge of the brass rectangle or the point of the hook, according to the fitment, as shown in Figure 5. In cases where the zero point is found to fall on the dividing line between two diameter classes, the higher diameter class is read).

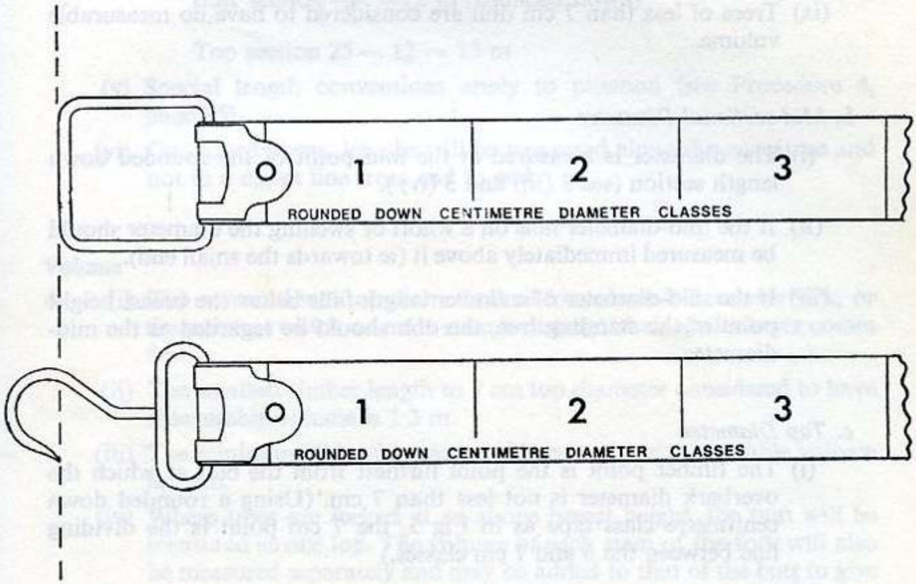


Figure 5

a. Diameter at Breast Height (dbh)

(i) Always ensure that trees are girthed at a point on the tree 1·3 m above ground level, which is the *breast height point.*

(ii) The diameter tape must be taut and at right-angles to the stem.

(iii) On *sloping ground* always measure the diameter at 1·3 m from ground level on the upper side of the tree.

(iv) On *leaning trees* (on level ground) always measure the diameter at 1·3 m from ground level on the under-side of the tree, parallel to the axis of the stem.

(v) Where trees are planted on *turfed or ploughed ground*, the diameter should be measured 1·3 m from the root collar or present ground level, whichever is the higher.

(vi) Where a *swelling* occurs at 1·3 m above ground level, measure the diameter below the swelling or deformity, at the point where the diameter is smallest.

(vii) Where the stem *forks* below 1·3 m treat each limb as a separate tree. Where a stem is forked at 1·3 m, treat the stem as one tree and measure the diameter below the fork at the point where it is smallest.

(viii) *Coppice* crops should be girthed at 1·3 m from ground level, not from stool level.

(ix) Trees of less than 7 cm dbh are considered to have no measurable volume.

b. Mid-sectional Diameter

(i) The diameter is measured at the mid point of the rounded down length section (see 3 (iii) and 3 (iv)).

(ii) If the mid-diameter falls on a whorl or swelling the diameter should be measured immediately above it (ie towards the small end).

(iii) If the mid-diameter of a timber length falls below the breast height point of the standing tree, the dbh should be regarded as the mid-diameter.

c. Top Diameter

(i) The timber point is the point furthest from the butt at which the overbark diameter is not less than 7 cm. (Using a rounded down centimetre class tape as in Fig 5, the 7 cm point is the dividing line between the 6 and 7 cm classes.)

(ii) Where top diameter (the diameter at the small end) is measured on pitwood or smallwood, a rule should be used in preference to a girthing tape. The diameter is rounded down to the nearest whole centimetre.

(iii) Where top diameter (underbark) is required for sawlog measurement (by Procedure 2) the diameter should be measured across the smallest diameter.

Length

3. (i) Length measurement will not normally include material beyond the timber point (7 cm diameter), or beyond the point at which no main stem is distinguishable.

   (ii) The minimum timber length to 7 cm top diameter which is considered to have measurable volume is 1·3 m.

   (iii) Lengths, measured from the butt-end, should be rounded down to the nearest 0·1 m for lengths up to 10 m and to the nearest whole metre for lengths greater than 10 m.

   (iv) Where the rounded down length exceeds 20 m it should be measured in two sections for volume assessment. Measured from the butt end, the butt section will be the rounded down length divided by two but rounded down to the nearest whole metre. The top section will be the remaining length.

   Example:

   Timber length 25 m (rounded down)

   Butt section $\frac{25}{2} = 12$ m (rounded down)

   Top section $25 - 12 = 13$ m

   (v) Special length conventions apply to pitwood (see Procedure 4, page 25).

   (vi) On curved stems, lengths will be measured along the curvature and not in a direct line from end to end.

Volume

4. (i) The conventional top diameter limit for volume is 7 cm overbark, or the point at which no main stem is distinguishable, whichever comes first.

   (ii) The smallest timber length to 7 cm top diameter considered to have measurable volume is 1·3 m.

   (iii) The minimum dbh of a tree considered to have measurable volume is 7 cm.

   (iv) Where trees are forked at or above breast height, the butt will be measured as one log. The volume of each stem of the fork will also be measured separately and may be added to that of the butt to give the volume of the tree.

   (v) Where trees are forked below breast height each limb is treated as a separate tree and will be girthed as such. The volume of the tree is therefore the volume of the appropriate limb. The volume of the butt piece will be ignored, its length being excluded in determining the volume of the tree.

PART III MEASUREMENT OF FELLED TIMBER

PROCEDURE 1

THE ASSESSMENT OF VOLUME FROM LENGTH AND MID-DIAMETER

GENERAL

1. This is the traditional method of assessing the volume of timber lengths, sawlogs, selected poles, billets etc.

2. The volume is derived from the product of the length of the log or section and its mean cross-sectional area. The latter is assumed to be approximately equal to the cross-sectional area at the mid point of the section. (There are alternative ways of finding an estimate of mean cross-sectional area, but this principle is the only one considered here.) In practice it is the *diameter* at the mid point which is actually measured.

3. The volume is derived from the following formula which is known as Huber's formula:

$$V = \frac{\pi \, d_m^2}{40\,000} \times L$$

where V = volume in cubic metres
L = length in metres
d_m = mid diameter in centimetres
π = 3·1415927

PRACTICE

4. The length of the section is measured observing the rounding conventions specified on page 19.

5. The diameter (overbark) at the mid point of the rounded down length is measured according to the normal conventions (page 18).

6. Table 64 (pages 202–241) is used to estimate the volume from these measurements. The lengths are tabulated from 1·0 to 10 m. For lengths greater than 10 m the decimal place in the lengths and volumes is moved one place to the right.

7. **Examples**

(i) *Actual length:* = 7·36 m
Rounded down length = 7·3 m
Rounded down diameter at
$\left(\frac{7\cdot 3}{2}\right)$ m = 3·65 m from butt end = 18 cm

Volume from Table 64 (page 205) = 0·186 m^3

(ii) *Actual length*: = 12·85

Rounded down length = 12 m

Rounded down diameter at 6 m from butt end = 25 cm

Volume from Table 64 (page 206)

(enter 1·2 m length, move decimal point) = 0·59 m^3

(iii) *Actual length*: = 25·7 m

Rounded down length = 25 m

1st (butt) section length = $\frac{25}{2}$

" " " " (rounded down) = 12 m

2nd section length (25 − 12) = 13 m

1st section mid diameter (at 6 m from butt) = 29 cm

1st section volume from Table 64 (page 206)

(enter 1·2 m, move decimal point) = 0·79 m^3

2nd section mid diameter (at 6·5 m from large end of section or 18·5 m from extreme butt end) = 16 cm

2nd section volume from Table 64 (page 204)

(enter 1·3 m, move decimal point) = 0·26 m^3

Total volume of timber length = 0·79 + 0·26 m^3

= 1·05 m^3

THE ASSESSMENT OF UNDERBARK VOLUME OF SAWLOGS FROM LENGTH AND TOP DIAMETER

GENERAL

1. The use of this method is confined to softwood sawlogs. It is a method which is less time consuming and consequently cheaper than Procedure 1 and is best suited to batches of uniform length logs. The description of logs in terms of top diameter and length provides a more useful basis for size classification and can often be more meaningful to the potential buyer.

2. Because of the need to assume a standard rate of taper, volume estimates derived by this method are subject to greater errors than by the mid-diameter and length method.

3. A standard taper of 1: 120, ie 1 cm diameter in 1·2 m length has been used in constructing the tables (Table 65, pages 242–249). This rate, which refers to the taper between the top and mid point of a log, is considered to be reasonably appropriate for softwood sawlogs in Britain. The taper of individual logs may be expected to differ significantly from the standard rate, and for this reason the tables will tend to be less reliable for small numbers of logs or when butt or top logs predominate.

4. The formula used in calculating the tables is:

$$V = L \times \left(\frac{\pi}{40\,000} \times \left(d_t + \frac{(L \times 0{\cdot}5)}{1{\cdot}2}\right)^2\right)$$

where V = volume in cubic metres

L = length in metres

d_t = top diameter in centimetres

π = 3·1415927

5. Lengths will normally be rounded down to the nearest 0·1 m. The international sawn softwood standard length specifications range from 1·8 m to 6·3 m in steps of 0·3 m (see page 186). In order to provide for those cases where logs are cross-cut to conform to these specifications, the length intervals in the tables have been grouped in threes so that the standard 0·3 m multiples appear as the first entry in each group. In such cases a small extra allowance of 0·05 m will be made on the sawlog length to permit subsequent cross-cutting and should be agreed with the buyer beforehand.

6. The top diameter entries in the tables are tabulated in 2 cm intervals from 10 cm to 72 cm. The diameter values at the head of each column refer to the lower limit of each diameter class, eg the 14–16 class is headed 14.

7. The specified volumes are based on the mean diameter of each class. For example the 14–16 cm class is headed 14, but volumes are calculated using 15 cm top diameter. This is based on the assumption that the top diameters of individual logs will be distributed evenly over the range of each 2 cm class. It follows therefore that if logs are cut to specified top diameters the volumes in the tables will be more appropriate if the specified diameters accord with the *mean* top diameter of the 2 cm class.

8. It is intended that the tables be used with underbark top diameter to give underbark volumes, but estimates of overbark volume can be obtained from the tables by using overbark rather than underbark top diameter.

9. It is advisable to confine the use of this method to log lengths under 8·4 m.

PRACTICE

10. Measure the length, following the convention of rounding down to the nearest 0·1 m.

11. The top diameter underbark should be measured across the smallest diameter. (Plastic rules incorporating an abbreviated version of the tables are available and are graduated in terms of the 2 cm classes).

12. Table 65 is entered by the appropriate top diameter class and length in order to find the volume.

Example:

Actual length = 6·67 m

Rounded down length = 6·6 m

Actual u.b. diameter 23·5 cm = diameter class 22 cm.

Volume (from Table 65, page 243) = 0·34 m^3

PROCEDURE 3

THE ASSESSMENT OF SMALLWOOD VOLUMES FROM TOP DIAMETER AND LENGTH

GENERAL

1. This method is applicable for small lots of small diameter material, eg stakes, garden poles, etc where other methods, eg weight, are not practicable.

2. A standard taper of 1: 84, ie one centimetre diameter in 84 cm length, has been assumed in constructing the tables on pages 250-253 (Table 66). This rate of taper is also used in the pitwood volume tables (Procedure 4) and is regarded as suitable for small material which is taken from the uppermost part of trees where the taper rate is generally above average. The taper is that between the top and mid-point of the billet.

3. Top diameters are given in centimetre classes and lengths in intervals of 0·1 m. The formula used in calculating the tables is:

$$V = L \times \left(\frac{\pi}{40\,000} \times \left(d_t + \frac{(L \times 0{\cdot}5)}{0{\cdot}84}\right)^2\right)$$

where V = volume in cubic metres

L = length in metres

d_t = top diameter in centimetres

π = 3·1415927

4. Volumes shown are for 100 pieces of the specified dimensions.

5. For top diameters of less than 7 cm the specified volumes *include* the material beyond the conventional top diameter limit for measurable volume of 7 cm overbark.

6. Where top diameters are measured overbark the volumes indicated will be overbark. Likewise underbark volumes are implied from the use of underbark measurements of top diameter.

PRACTICE

7. Top diameters should be measured with a rule and rounded down to the nearest whole centimetre. One measurement taken in a random direction across the diameter is sufficient.

8. Lengths should be rounded down to the nearest 0·1 m.

9. Volumes are obtained from Table 66 (pages 250–253).

Example:

Actual top diameter – 7·6 cm, rounded down top diameter – 7 cm.

Actual length – 2·67 m, rounded down length 2·6 m.

Volume – 1·49 m^3 per 100 pieces (page 250).

or 0·0149 m^3 per piece.