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Ratios for Estimating Logging Residue in the Pacific Northwest

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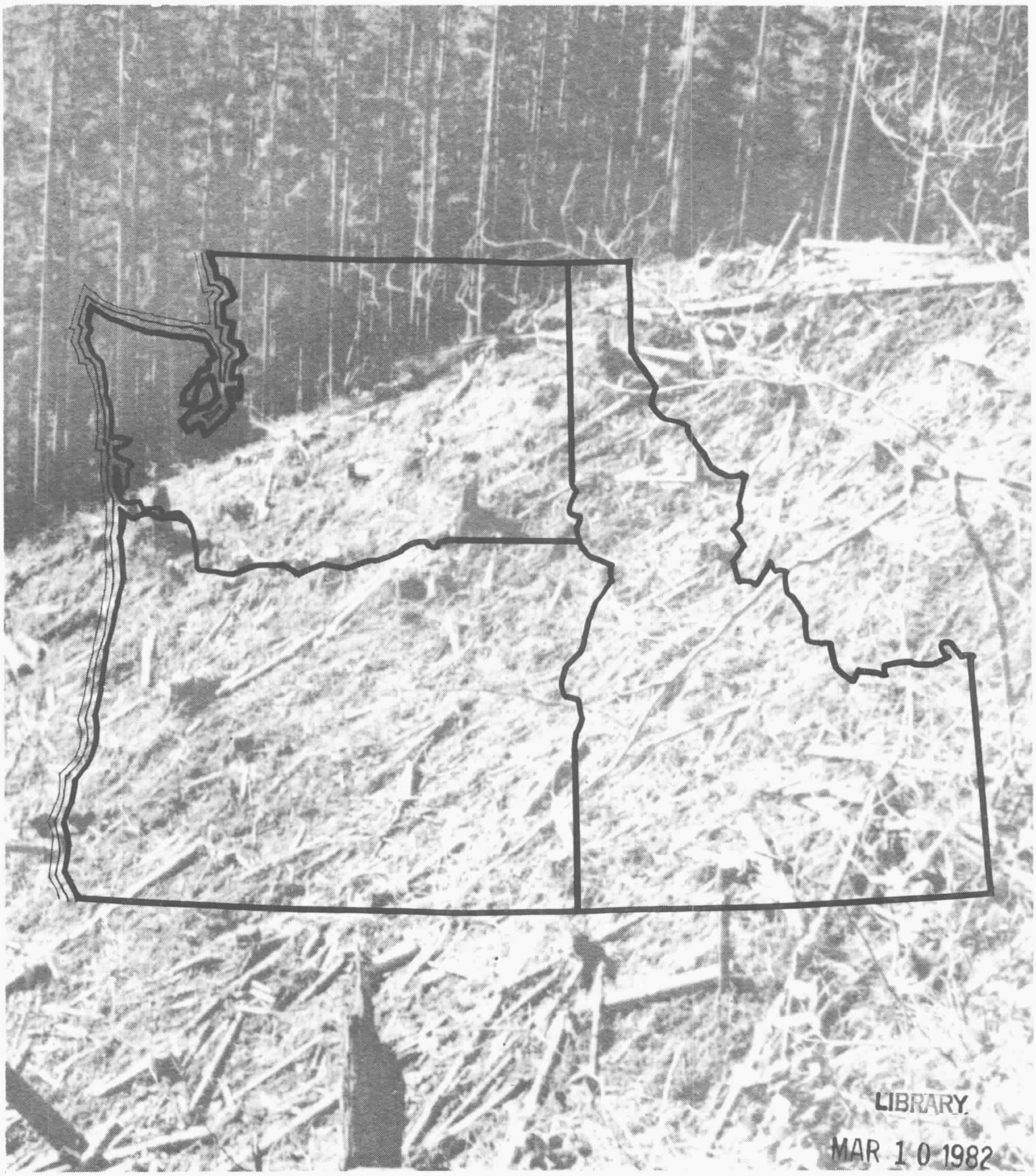

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Abstract

Howard, James O. Ratios for estimating logging residue in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-288, 26 p. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1981.

Ratios are presented for estimating the volume of logging residue for any location in Idaho, Washington, and Oregon. They show cubic-foot volume of logging residue per 1,000 board feet of timber harvested and per acre harvested. Tables show gross and net volumes, with and without bark. The volumes of live and dead and cull residue at the time of harvest are also given.

Keywords: Residue measurements, slash, Pacific Northwest.

Summary

The use of logging residue for energy has undergone significant change in the past few years. The focus is no longer on just the total quantity of residue and its possible impact on regional or national supplies. Instead, the number of studies to determine the feasibility of producing wood-fueled energy at specific sites—such as Kettle Falls, Washington; Sandpoint, Idaho; and Estacada, Oregon—is increasing.

These site-specific analyses have created a need for up-to-date and more flexible data. This study was conducted to develop estimators to determine the volume of logging residue for any specific site in Idaho, Washington, and Oregon. These estimators are in the form of ratios which relate the quantity of residue to volume of timber or number of acres harvested. Specifically, the ratios are cubic feet of residue per 1,000 board feet of timber harvested and cubic feet per acre harvested.

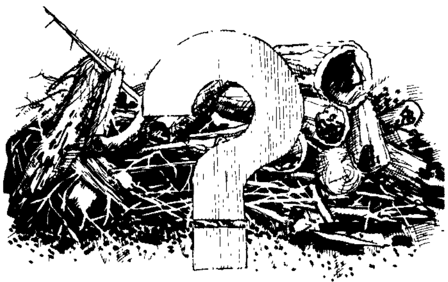
The information in this report is based on measurement of logging residue on 518 cutover areas in the three States. The sample areas were allocated among 19 strata (harvest method by geographic area and owner class).

Results are shown for each of the 19 strata. Tables show gross and net (chippable) volume, with and without bark, for both ratios. A breakdown of residue by live and dead or cull at the time of the harvest is also shown.

An example of how to apply the data is provided.

Contents

The Situation



Wood as a renewable resource is increasingly being examined to determine its potential impact on our future energy supplies. Most of this attention has been focused on what is considered underutilized portions of the resource. Although various components of the entire forest can be viewed as underutilized, logging residue is most often considered as having the greatest near-term potential. Since logging residue has long been a problem for forest managers, development of markets for this material has met with much enthusiasm.

During the past decade, numerous assessments have been made of the potential contribution of logging residue to the energy picture (Bergvall and Bullington 1978, Grantham and Estep 1974). These are but two of many reports that have examined the regional or national residue situation. These assessments provide information needed to compare the potential contribution of logging residue with other sources of fuel. The primary question has been whether enough residue existed to warrant special efforts to encourage its use for energy.

The situation has changed a great deal in the past few years. Cost of energy from conventional sources has increased rapidly. Electricity, especially important on the west coast, has been projected to be in short supply in the near future, and brownouts are a possibility. Industries based on wood fiber have begun to consider roundwood as a source of a larger share of the raw material needed for future expansion. National legislation has been enacted which encourages the use of wood residue for energy. These trends have caused a change from general questions of resource availability to those concerned with where conversion should occur (Kierulff and Adams 1980). Examination of potential locations for facilities and availability of wood for those sites have become key issues.

This new focus of investigation has created a need for better analytical tools. Existing data, however, are not well adapted to site-specific analysis of wood availability (Howard 1973). In addition, most of the existing information is outdated.

This report is based on a study designed to meet these newly defined needs. The objective was to generate a set of analytical tools that can be used to estimate quantities of logging residue for any uniquely defined supply zone[1] and to provide an up-to-date data base for logging residue in the Pacific Northwest region.[2]

[1] See "Glossary" for definitions of terms used in this report.

[2] For this report, the Pacific Northwest region includes the States of Idaho, Washington, and Oregon, and corresponds to Region X of the U.S. Department of Energy.

The tools are two sets of ratios. One set gives volume of logging residue (see "Glossary"), in cubic feet, which results from the harvest of 1,000 board feet (MBF) of timber. A second set gives residue in terms of cubic feet per acre (CF/AC). Because information on harvest volume is more readily available than acres harvested, the first set of ratios will be the most useful for site-specific analyses and is especially significant if near-term projections of residue are to be made. To aid in applying these ratios, conversion factors for dry weight and British thermal unit (Btu) values are included in the appendix. An example of how to use the ratios is provided later in this report.

The ratios are shown for the 19 strata (see "Glossary"), covering the three-State (Oregon, Washington, and Idaho) area. Three levels of stratification were used for sample allocation: Geographic area, owner class, and harvest method.

These stratifications were selected to reflect expected differences in residue volume, availability of data, and land management objectives.

Study Design

This section includes discussions of the number, allocation, and selection of harvested areas to be sampled, techniques for sampling logging residue, and procedures for computing volumes and ratios of residue.

Sample Size and Allocation

Stratification by ownership and harvest method was not appropriate for all geographic areas. In eastern Oregon and eastern Washington, for example, only a small percentage of the area is harvested by clearcutting. Thus, for these areas no stratification was made on the basis of harvest method. This was also true of the "Other public" and "Private" owner classes (see "Glossary") in Idaho.

Initial plans called for separate strata for partial cuts on National Forests in western Oregon and western Washington. During sample selection, it became apparent that an insufficient number of samples for partial cuts were available in western Washington, so all National Forest partial cuts for western Oregon and western Washington were combined and called the Douglas-fir region. The strata used in the study are:

Geographic area	Owner class	Harvest method
Idaho	National Forest	Clearcut, partial cut
	Other public	All harvest methods
	Private	All harvest methods
Western Oregon	National Forest	Clearcut
	Other public	Clearcut, partial cut
	Private	Clearcut, partial cut
Eastern Oregon	Public	All harvest methods
	Private	All harvest methods
Western Washington	National Forest	Clearcut
	Other public	Clearcut, partial cut
	Private	Clearcut, partial cut
Eastern Washington	Public	All harvest methods
	Private	All harvest methods
Douglas-fir region	National Forest	Partial cut

The next step was to determine sample size for each stratum. Where information was available, from which expected variation could be estimated, sample size was determined by the following formula:

$$N = \frac{CV^2t^2}{A^2};$$

where: N = stratum sample size,
CV = coefficient of variation,
t = Student's t-value, and
A = desired level of precision.

The values for t and A were fixed so that the computed sample size would result in an estimated average volume of residue per stratum that would be within ± 20 percent of the true average 9 times out of 10 (90-percent level). Coefficient of variation for logging residue volume (per acre) was used to compute sample size. This was done because residue volume (per acre) was assumed to be the major contributor to total variance. Values for CV were derived from previous studies that used similar sampling techniques (Howard 1973, 1978).

Where no previous data were available, as for partial cutting, a minimum of 25 samples were taken.

The number of samples for strata in which sampling occurred is shown below:

		Harvest method		
Area	Owner	Clearcut	Partial cut	All harvest methods
Idaho	National Forest	25	25	—
	Other public	—	—	25
	Private	—	—	25
Western Oregon	National Forest	20	[3]	—
	Other public	19	25	—
	Private	29	26	—
Eastern Oregon	Public	—	—	35
	Private	—	—	35
Western Washington	National Forest	20	[3]	—
	Other public	35	9	—
	Private	30	25	—
Eastern Washington	Public	—	—	35
	Private	—	—	35
Douglas-fir region	National Forest	—	40	—

Sample size for partial cuts on other public lands in western Washington was relatively small. Initially, sample size for this stratum was set at 25 cutover units. During sample selection it was determined, however, that little partial cutting was taking place in this owner class. Therefore, it was decided to sample all partial cuts that met study criteria, and only nine partial cuts were included in the study.

Sample size for the entire study was 518 cutover areas (see "Glossary").

Sample Selection

Specific cutover areas were selected after sample size for each stratum was determined. The basic approach was to identify all cutover areas by stratum (sample population), then randomly select the desired number of samples from this population.

Determining the available sample population generally followed one of two procedures. Where owners were able to provide lists of all areas cutover during the study period, areas to be sampled were randomly selected from the lists. Where owners could provide lists of all cutover areas that met study criteria, selection was randomly made from these lists. The latter procedure was used primarily for public lands.

Regardless of which selection procedure was used, all cutover areas selected had to meet five criteria:

1. Logging was completed after January 1, 1979, and before field examination.
2. The cutover area was 5 or more acres.
3. Harvesting was not done for fire salvage purposes.
4. None of the residue materials were burned before field examination.
5. None of the residue material was removed for firewood or subsequent recovery of wood before field examination.

These criteria were established to insure that residue estimates would represent normal harvesting situations.

A larger number of sample units was selected than was dictated by the process described. The extra units served as alternates to replace areas that failed to meet study criteria on field examination. Alternate sample units for each stratum were used in the order in which they were selected.

[3] Partial cut areas were combined into the Douglas-fir region because of an inadequate sample population in western Washington.

After selection of areas to be sampled, owners were asked to provide maps, location data, and information about characteristics of the area. This information was needed to locate sample areas in the field and to allow for analysis of residue data to meet study objectives.

Specific information collected for each cutover area was:

1. Age of timber harvested.
2. Acreage of area harvested.
3. Type of logging equipment used.
4. Percentage contribution of the three major species harvested.
5. Volume per acre of timber harvested and removed, in thousand board feet.

The harvest figure was net scaled volume of timber removed from the area, rather than cruised volume. No adjustments were made for differences in log scaling practices.

Sampling Techniques

Three techniques were used to estimate the average volume of logging residue on cutover areas. The line intersect method was used to estimate scattered materials and small piles (Howard and Ward 1972). An estimator obtained from a separate study[4] was used to determine the volume in large piles. The volume of bark was derived by using bark-to-wood factors, obtained from a companion study.[5] Following is a detailed discussion of each of these techniques.

[4] Little, Susan. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

[5] Snell, J. A. Kendall. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Estimating scattered residue.—The line intersect method was used to estimate the volume of the materials 3.01 inches and larger in diameter (d.i.b.) (see "Glossary") and 1.0 foot and longer in length. This method has been widely used for estimating residue and has been demonstrated to be efficient and unbiased (Pickford and Hazard 1978).

The sample design used in this study consisted of 200-foot line transects located at each of 30 points on a systematic grid (fig. 1).

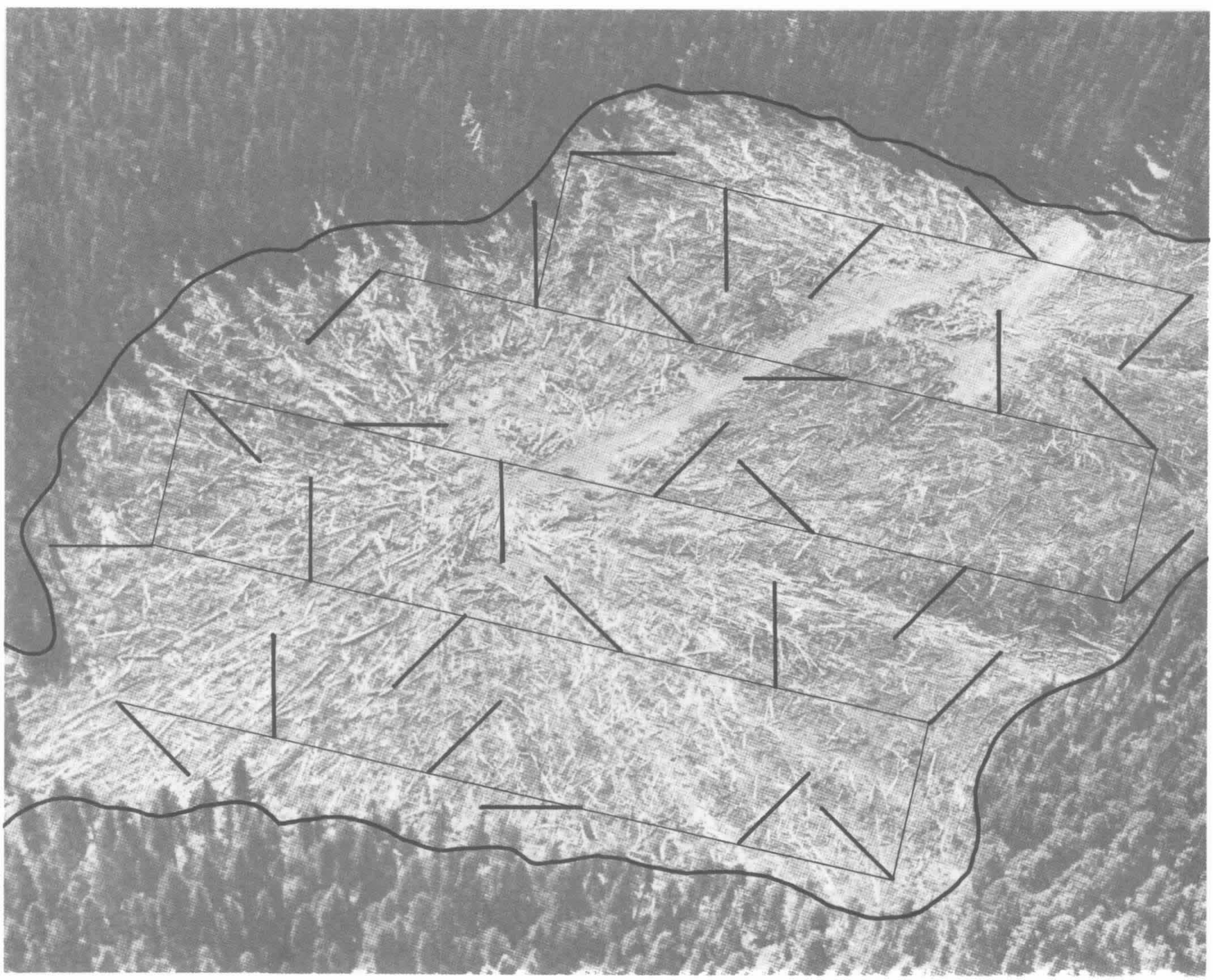


Figure 1.—Example of sampling grid for a cutover area.

The interval between grid points varied, depending on size of the cutover area. Except for very large partial cuts (most common in the ponderosa pine region—see "Glossary") the fluctuating grid interval resulted in a pattern that covered nearly all of each cutover area. The maximum interval was set to cover about 200 acres. For larger cutover areas, up to several thousand acres, yarding practices had created residue piles throughout the areas, rather than at central locations. Since scattered residue and residue piles tend to be distributed throughout the harvested area, the sample design used results in estimates of residue representative of the timber within the grid pattern.

To reduce bias, both the starting point and the base line for the grid system were randomly selected. To reduce piece orientation bias (Howard and Ward 1972), each of the 30 line transects was randomly oriented along 45° azimuths.

Measurements were taken for all qualifying residue intersected by the 200-foot line transects that was 3.01 inches and larger in diameter inside bark and 1.0 foot or longer in length. Older, dead pieces that were rotten to the point of losing their original form were excluded (fig. 2).

Specific measurements recorded for each piece of residue were: (a) diameter inside bark (d.i.b.) at the point of intersection with a transect line, (b) net chippable content at the point of intersection with a transect line, and (c) origin—whether a piece was live, dead or cull at the time of harvest, or if it was a limb.

Those are the only measurements required to provide an estimate of gross and net volumes (see "Glossary") of scattered logging residue and small piles for a specific cutover area.

Estimating residue piles.—Because many pieces in large piles are obscured, the line intersect method cannot be used to estimate volume in these piles. Large piles, commonly called PUM or YUM (see "Glossary"), occur most often in clearcuts in the Douglas-fir region (fig. 3). To a lesser degree, large piles made with tractors were encountered in the other geographic areas.

Figure 2.—Deteriorated logs such as this were not included in the study.

Figure 3.—Large piles of residue require separate procedures for estimating volume.

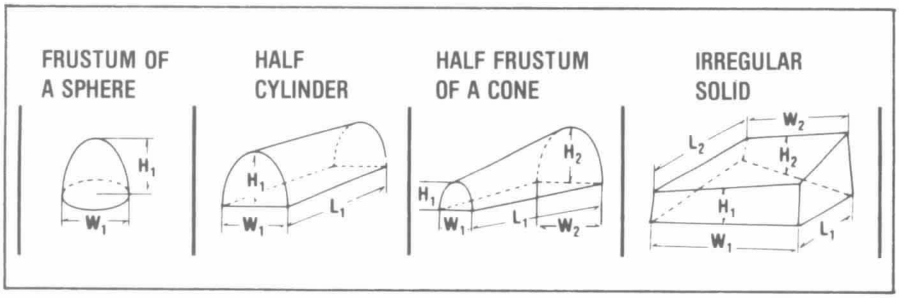


Figure 4.—Geometric solids and related dimensions for estimating volume of piles.

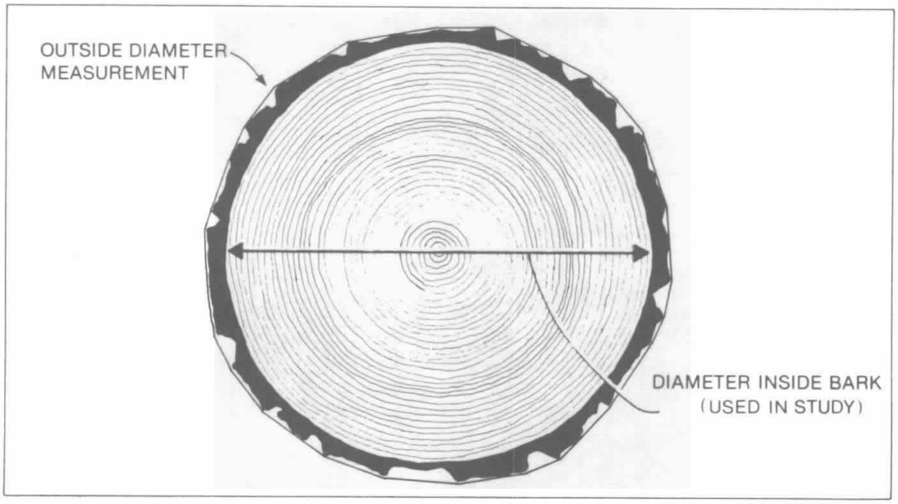


Figure 5.—Voids associated with irregularities in bark were avoided by recording inside bark measurements.

The procedure for estimating the volume of residue in these large piles involved two steps. First, each pile was visually classified as one of four geometric solids (fig. 4). Then the dimensions were recorded as indicated by the classification. Spatial volume of each pile was then computed from these measurements and converted to solid wood content using data from a separate study (see footnote 4, p. 3).

The net content and origin of residue in large piles were derived as follows: The proportion by origin (live or dead and cull material) in each pile was estimated by field personnel, and the net content of material in these piles was derived from data from Howard (1978). Residue measured in the 1978 study was mainly from the harvest of old-growth timber, and characteristics of residue pieces are generally similar to those found in piles from current harvesting. Therefore, the proportion of net volume to gross volume from the 1978 study was considered applicable to this study. This proportion, 0.54, was applied to the gross residue volume of each pile to obtain net chippable volume.

Estimating bark.—Diameters of residue pieces were measured inside the bark to avoid problems associated with voids when outside bark measurements are taken (fig. 5). Bark, however, is an important raw material, particularly for energy conversion. Thus, it was necessary to estimate bark volume by other means.

A review of literature did not provide adequate data about bark for the needs of this study. It was necessary, therefore, to conduct a companion study on bark factors (see footnote 5, p. 3). This involved collecting bark samples on 50 of the 518 cutover areas in this study. Data from the study on bark were processed to develop bark-to-wood ratios. These ratios were then applied to estimates of wood residue to generate bark volumes.

Findings

Computational Procedure

The volume of residue measured by the line intersect method was computed by the following formula:

$$V = \frac{\pi^2 D^2}{8L} \cdot \frac{43{,}560}{144};$$

where: V = volume of each piece of residue, in cubic feet per acre (CF/AC);
D = diameter inside bark, in inches, of each piece of residue; and
L = total length of transect lines (6,000 feet).

The summation of the computed volume for each piece from all 30 transects yields average gross volume (CF/AC) of residue for a specific cutover area. Pile volumes were computed separately. The total volume of all piles on each cutover area where piles were present was divided by the acreage of the respective cutover area to obtain an estimate of volume in piles on a per-acre basis. This figure was then added to the transect volume to obtain the overall gross wood residue volume for each cutover area. Estimates to include bark were derived by applying the bark-to-wood ratios described above. Net chippable volume of residue was computed by using information collected for each piece tallied by the transect, and from the pile-estimation process described earlier.

These computations provide estimates of residue in cubic feet per acre. The primary objective of this study, however, was to provide ratios of cubic feet of residue per 1,000 board feet of timber harvested (CF/MBF). To obtain this ratio for a cutover area, the average volume of residue (CF/AC) was divided by the average harvest volume (MBF/AC). This is shown by:

$$\text{Ratio}_i = \frac{(\text{Residue volume})_i}{(\text{Harvest volume})_i} = \frac{(\text{CF/AC})_i}{(\text{MBF/AC})_i} = (\text{CF/MBF})_i;$$

where: i = i^{th} cutover area (sample unit).

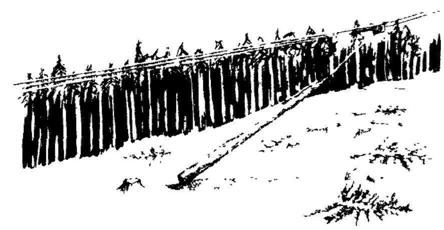
Determining residue ratios for a specific stratum required a further step. Since the grid interval varied, depending on size of the cutover area, observations for each cutover area in a stratum had to be weighted to derive stratum level ratios. Total volume of harvest and acreage for each cutover area were used as weighting mechanisms.

A ratio of the means approach was used to derive stratum level figures. The formula for a specific stratum level ratio is represented by:

$$\text{Ratio}_j = \frac{\dfrac{\sum_{i=1}^{n} x_{ij}a_{ij}}{\sum_{i=1}^{n} a_{ij}}}{\dfrac{\sum_{i=1}^{n} h_{ij}a_{ij}}{\sum_{i=1}^{n} a_{ij}}};$$

where: n = number of sample units in j^{th} stratum;
x_{ij} = per-acre residue volume for the i^{th} sample unit, in j^{th} stratum;
a_{ij} = acres of timber harvested for i^{th} sample in j^{th} stratum; and
h_{ij} = per-acre harvest volume for i^{th} sample unit, in j^{th} stratum.

Results of this study are shown in terms of CF/MBF and CF/AC, as each of these ratios addresses different needs.



Logging residues are presented in this report in two basic forms: cubic feet per 1,000 board feet of timber harvested and cubic feet per acre. Both ratios have value, depending on the user's needs and the availability of data. The first form meets the primary objective of this study and is the most useful in site specific analysis, since in most areas of the Pacific Northwest estimates of current or projected harvest are more readily available than estimates of acres harvested. Estimating residue volume is accomplished by applying the ratios appropriate to the study strata represented by the harvested areas, to the timber harvest of the respective stratum.

When acreage figures are available or when issues involving concentration of materials are being considered, the CF/AC ratio is used to estimate residue volume per acre.

A wide range of potential uses can be served by the tables, which show gross and net residue volumes, live versus dead and cull material, and residue with and without bark. Some of the tables are in the appendix. Also included in the appendix are conversion tables for metric values and wood density and Btu values for selected species.

Cubic Feet Per Thousand Board Feet Ratios

Table 1 gives the ratios for net volume of logging residues, including bark, for each of the study strata. These ratios represent the chippable portion of the residue, or that considered usable for fiber-based products. Because of a variety of defects, such as cracks, checks, or early stages of rot, a large share of this material would not be usable for solid wood products, such as lumber. Again, the net volume of logging residue is related most directly to value for potential products. It should be recognized that some unusable portions would be removed to recover the chippable portions.

Table 1—Average net volume (wood and bark) of logging residue by area, owner class, and harvest method

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per thousand board feet of timber harvest	
Idaho:		
National Forest	87	122
Other public	—	[1]142
Private	—	[1]109
Western Oregon:		
National Forest	47	[2]136
Other public	52	93
Private	40	296
Western Washington:		
National Forest	44	[2]136
Other public	51	118
Private	37	140
Eastern Oregon:		
Public	—	[1]76
Private	—	[1]80
Eastern Washington:		
Public	—	[1]96
Private	—	[1]72

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Use of these ratios to estimate residue for a given area requires only knowledge of timber harvest for that area. A separate ratio and corresponding timber harvest figure should be used for each stratum represented in the area being examined. These ratios are representative of current harvesting practices and markets and should remain useful as long as harvesting technology, stand conditions, and general market conditions do not change dramatically.

Some apparent differences in ratios between strata bear further discussion. Especially notable are the apparent differences between ratios for clearcut and partial cut areas. The differences may be partially explained by the nature of the harvest methods. Most partial cutting is oriented to products or tree classes. Thus, materials not sought are frequently not removed (previously down and dead material, for example). In clearcutting, however, nearly all trees are cut, exposing all timber to the possibility of removal, depending on the marginal product value of each piece. Also contributing to the difference is the fact that partial cutting is not usually evenly distributed over the total harvest area. The result is that material previously down may not be removed if the yarding equipment is not in the immediate vicinity. This is most significant in areas where stand disturbance is kept to a minimum to protect residual crop trees. An indication of this can be seen in table 2, which shows the percent of total residue that was dead or cull at the time of harvest.

As these data show, the proportion of dead or cull residue is higher for partial cuts than for clearcuts in all strata where comparison is possible. The data, of course, do not fully explain the differences between the two harvest methods. Various factors obviously contribute to the differences in ratios between the strata. It should be noted again that precommercial thinning operations were not included in this study.

As can be seen in table 1, clearcuts in Idaho produce substantially higher ratios than in the other two States. A possible explanation is the greater concentration of pulp and board mills in Oregon and Washington. These industries use raw materials (roundwood and mill residues) not extensively demanded by solid wood product industries. Therefore, in these areas a greater demand exists for logs that would be submarginal to a less diversified industry. The lack of a market for lower quality materials usually results in lower levels of utilization and more residue. The degree to which residue levels in Idaho have changed is not known because of the lack of studies with comparable data.

Generally, gross volume represents the bulk or mass of logging residue, based on external dimensions. This measurement includes space not occupied by woody material, such as in hollow logs (fig. 6) and pieces with splinters or with chunks missing. Gross volume also includes material too rotten to have product value. The extreme example is pieces with gross volume but no chippable material.

The importance of the gross volume measurement is that it represents material to be removed or otherwise treated to reduce its impact on the site. Gross volume of residue is directly related to reforestation concerns, esthetic and environmental qualities, wildlife habitat, mobility during stand management, and fire hazard. It is apparent that this measure of residue is important in the broad context of residue management. The cost of yarding and transporting residue is a key element in determining its use. Here again, consideration must be given the total volume of residue that must be handled to recover the usable portions.

Table 2—Dead and cull material (wood only) by area, owner class, and harvest method

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Percent of average gross residue volume	
Idaho:		
National Forest	55	71
Other public	—	74
Private	—	63
Western Oregon:		
National Forest	56	[1] 68
Other public	62	64
Private	58	69
Western Washington:		
National Forest	59	[1] 68
Other public	54	76
Private	54	70
Eastern Oregon:		
Public	—	78
Private	—	68
Eastern Washington:		
Public	—	67
Private	—	64

[1] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

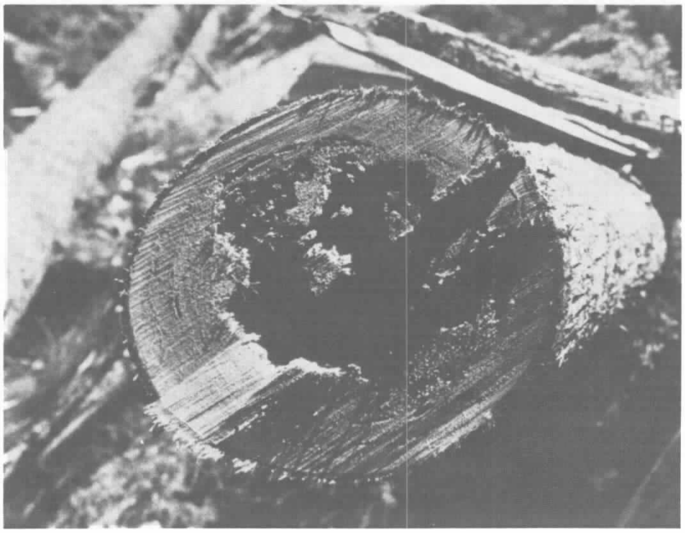


Figure 6.—Hollow logs, such as this, have a gross volume (represented by external dimensions) that includes space containing no usable wood fiber.

Table 3—Average net volume (wood and bark) of logging residue by area, owner class, and harvest method

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per acre	
Idaho:		
National Forest	2,182	1,701
Other public	—	[1]1,182
Private	—	[1] 824
Western Oregon:		
National Forest	2,471	[2]1,488
Other public	2,642	1,184
Private	2,070	1,537
Western Washington:		
National Forest	2,497	[2]1,488
Other public	2,110	895
Private	1,331	992
Eastern Oregon:		
Public	—	[1] 553
Private	—	[1] 534
Eastern Washington:		
Public	—	[1]670
Private	—	[1]394

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Tables showing ratios for the gross volume of logging residue are included in the appendix. Certain aspects of these data are discussed below.

Cubic Feet Per Acre Ratios

Cubic feet per acre is an important expression of the quantity of logging residue. Table 3 gives the average net volume per acre of residue by stratum. These data can be used to estimate residue volume when the number of acres harvested is known by simply multiplying acres harvested by the CF/AC ratio for the appropriate stratum.

A notable comparison in table 3 is that of CF/AC ratios for clearcuts on public versus private lands. The clearcut ratios for public lands is higher than that on private lands. This apparent difference also existed in earlier studies. Data from Howard's (1973) study show that the net per-acre volume of residue on public clearcuts is 1.5 to 2.4 times greater than on clearcuts on private lands. The current data indicate that the gap between the two owner classes has decreased considerably. Net residue volume on clearcuts on public land (table 12, appendix) is now only 1.1 to 2.0 times that on clearcuts on private land.

Information on cubic feet per acre can also be used to compare densities of residue between strata as input to set priorities for utilization options. Greater concentrations of residue, for example, are generally more feasible to recover. Thus, the data can help identify broad acreage groupings with the greatest potential for recovery.

Special Relationships

Tables 4 and 5 provide additional insight into the residue figures presented above by showing net residue volumes by stand age and harvest equipment used.

Examination of these data does not show the expected association between residue volume and stand age or equipment used in harvesting. Where consistent trends exist, care must be taken in assuming cause-and-effect relationships. It can only be said that a given factor is positively or negatively correlated with residue volume.

Table 4—Net volume (wood and bark) of logging residue, by area and owner class, harvest method, and stand age

Area and owner class	Clearcut—stand age (years)				Partial cut—stand age (years)			
	50	51-100	101-200	201 +	50	51-100	101-200	201 +
				Cubic feet per acre				
Idaho:								
Public	—	2,104	2,646	2,109	—	1,040	1,268	1,652
Private	NA	NA	NA	NA	—	648	1,242	1,523
Western Oregon:								
Public	—	2,800	2,300	2,899	345	1,132	1,849	1,643
Private	—	1,399	2,258	2,448	900	1,342	1,710	—
Western Washington:								
Public	—	1,870	1,834	2,452	—	977	2,112	1,606
Private	655	1,526	1,852	1,727	821	827	3,656	—
Eastern Oregon:								
Public	NA	NA	NA	NA	—	623	815	696
Private	NA	NA	NA	NA	—	405	551	472
Eastern Washington:								
Public	NA	NA	NA	NA	—	478	631	888
Private	NA	NA	NA	NA	—	365	587	—

NA = not available.

Table 5—Net volume (wood and bark) of logging residue, by area and owner class, harvest method, and harvest equipment

Area and owner class	Clearcut by				Partial cut by			
	Tractor	High-lead	Skyline	Other[1]	Tractor	High-lead	Skyline	Other[1]
				Cubic feet per acre				
Idaho:								
Public	2,358	2,380	—	—	1,124	1,147	1,320	4,628
Private	NA	NA	NA	NA	873	—	—	—
Western Oregon:								
Public	1,929	2,693	2,768	2,452	1,669	1,417	1,752	—
Private	1,679	2,283	1,601	—	1,303	1,366	1,238	—
Western Washington:								
Public	1,354	2,166	2,173	—	1,327	2,740	1,878	—
Private	1,126	1,578	1,501	—	863	2,736	—	—
Eastern Oregon:								
Public	NA	NA	NA	NA	752	—	581	—
Private	NA	NA	NA	NA	509	421	417	—
Eastern Washington:								
Public	NA	NA	NA	NA	626	625	923	—
Private	NA	NA	NA	NA	449	796	—	—

NA = not available.

[1] Primarily balloon or helicopter logging.

Table 6—Volume of residue in piles as a percent of average gross volume (wood only) by stratum

Stratum	Pile volume: Average percent	Pile volume: Highest percent
Idaho:		
National Forest—		
Clearcut	18.7	98.2
Partial cut	2.7	55.8
Other public (all methods)	.8	9.2
Private (all methods)	1.6	23.7
Western Oregon:		
National Forest—		
Clearcut	4.3	25.5
Partial cut[1/]	3.2	31.0
Other public—		
Clearcut	2.2	15.6
Partial cut	2.2	15.5
Private—		
Clearcut	1.1	8.6
Partial cut	.2	1.9
Western Washington:		
National Forest—		
Clearcut	5.8	48.1
Partial cut[1/]	3.2	31.0
Other public—		
Clearcut	1.5	31.2
Partial cut	[2/]	[2/]
Private—		
Clearcut	1.9	19.0
Partial cut	[3/]	28.0
Eastern Oregon:		
Public (all methods)	[3/]	2.4
Private (all methods)	[3/]	12.0
Eastern Washington:		
Public (all methods)	3.1	21.1
Private (all methods)	3.1	61.2

[1/] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

[2/] No piles observed in study sample.

[3/] Less than 0.05 percent.

Combining strata to increase precision of classifications presents certain problems. It is likely that variation is greater between strata than within strata. The impact of this difference has diminished somewhat with the decreasing differences in residue volume between owner classes. The following tabulation shows the effect of combining strata and the association between stand age and net residue volume (including bark) for all clearcut samples in western Oregon and western Washington.

Stand age	Net residue volume
(Years)	(CF/AC)
50	655
51-100	1,794
101-200	2,162
201 +	2,628

Given the problems discussed above, these data do show the expected associations between stand age and residue volume.

Residue piles are the most accessible material and are generally considered the least costly source of potentially usable material. The data in table 6 show the relative contribution of the volume of residue piles to overall averages.

As these figures show, the percentage of average residue volume in piles is low for all but one stratum. In individual cutover areas, however, the proportion of material in piles may be very high. These results suggest that if piles are considered the only cost-effective source of residue, it may be necessary to query landowners as to their plans for future piling operations.

The characteristics examined in tables 1 through 6 only partially explain variations in residue volume. Many other factors influence the accumulation of residue but are beyond the scope of this report. Ultimately, it is the responsibility of analysts to determine residue volumes, given the sensitivity of the required results.

It is especially important to understand that estimates based on data from this report indicate only the **existence** of residue material. Availability of materials for conversion to energy, pulp, or other products depends on a wide range of factors, such as competing uses, intent of the landowners, environmental concerns, and cost.

Use of the Data

The following hypothetical situation demonstrates how data in this report can be used to estimate the volume of logging residue available in a uniquely defined supply area. The site chosen for this example is Aberdeen, Washington, in the southern part of the Olympic Peninsula.

Figure 7 shows the supply area. Boundaries have been set to conform to criteria concerning a potential wood-using facility to be located at this site and to geography of the general area.

The assumptions that have been made are:

1. An estimate of annual volume of logging residue is needed as an input to the feasibility study of the proposed facility.
2. Wood and bark are considered as raw material for the proposed conversion process.
3. Cost-effective transportation of residue material is limited to 50 miles.
4. All three owner classes (National Forest, other public, and private), harvest timber in the supply zone.
5. Both clearcut and partial cut methods of harvesting are practiced in the area, but clearcutting predominates.

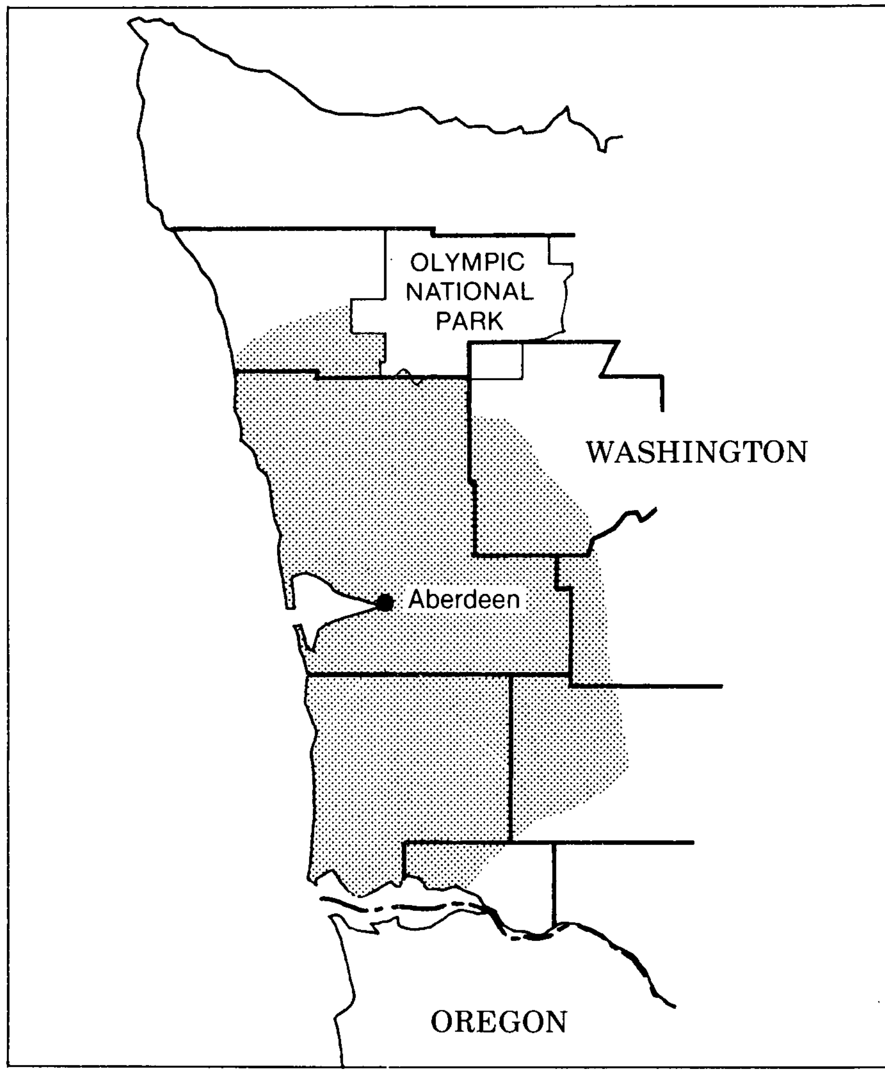


Figure 7.—Supply zone for hypothetical wood-using facility in Aberdeen, Washington.

Further investigation determines the estimated annual timber harvest from the supply area to be:

Owner class	Estimated timber harvest: Clearcut	Estimated timber harvest: Partial Cut
	(MBF)	
National Forest	116,100	3,000
Other public	303,900	7,800
Private	759,400	40,000

From this information, it is possible to estimate the net volume (wood and bark) of logging residue. Ratios from table 1 for the above owner classes are shown below:

Owner class	Logging residue ratios: Clearcut	Logging residue ratios: Partial cut
	(CF/MBF)	
National Forest	44	136
Other public	51	118
Private	37	140

Annual residue volume for the Aberdeen supply zone can be estimated by multiplying the harvest volume for each owner class and harvest method by the appropriate ratio as follows:

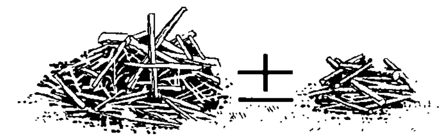
National Forest	(116,100 x 44) + (3,000 x 136)	= 5,516,400 cubic feet
Other public	(303,900 x 51) + (7,800 x 118)	= 16,419,300 cubic feet
Private	(759,400 x 37) + (40,000 x 140)	= 33,697,800 cubic feet
	Total	= 55,633,500 cubic feet

This example indicates that over 55 million cubic feet of residue material is associated with the current annual timber harvest. If weight of the residue is desired, conversion factors in the appendix can be used. Assuming an average bone-dry weight of 25 pounds per cubic foot, the total residue volume converts to 695,419 bone-dry tons.

The total residue volume derived above is only one step toward the final answer. If the total volume is assumed to be adequate for the proposed facility, it is then necessary for the analyst to address the issue of availability of the residue. In addition, projections of future levels of residue would have to be made. As a beginning, however, the above estimate provides a good base line for a feasibility study.

The ratios in this report provide a depth of analysis of logging residue not previously available, but as noted, there are limitations on their application. It is anticipated, however, that the sensitivity of site-specific analysis is such that adequate estimates of residue volume are attainable when coupled with general knowledge of the area being examined.

Precision of Study Results



The results of this study replace obsolete and less flexible data from previous studies. Nonetheless, it is important to be aware of the limitations of the data in this report. Although most users will apply the data as reported, it is especially important to consider the associated precision if the quantity of residue is marginal for the proposed use.

Indices of precision are based on estimates of total residue volume for each cutover area, represented by:

$Y_{ij} = (a_{ij})(x_{ij});$

where: y = observed variable for i^{th} cutover area in j^{th} stratum,
a = acreage of i^{th} cutover area in j^{th} stratum, and
x = gross per acre volume (wood only) of i^{th} cutover area in j^{th} stratum.

The gross volume of residue used for statistical analysis is that from the line transect measurements. Various conditions make this volume the only reasonable basis for statistical evaluation. These conditions are:

1. Gross volume per acre is the basic output of computations for the line transect; net volume involves subjective judgment by field personnel and makes statistical testing invalid.
2. Volume of piled residue is determined from information from a separate study (see footnote 4, p. 3); as can be seen from table 6, the average volume of piles is very low for most strata, so the overall precision of study results will not be greatly affected by variations in estimates of pile volume.
3. Bark volume is also derived by use of results from a separate study (see footnote 5, p. 3), which includes a discussion of the relative precision of the data.
4. Ratios for residue in terms of cubic feet per thousand board feet are not used to determine precision since they involve timber harvest information provided by owners of sample units.

Table 7 shows the relevant statistical elements for determining precision of study results.

Since the grid interval changed with size of the cutover area, the estimate of residue was weighted to reflect the contribution of each cutover compared with all areas in the population sample. Thus, the mean values of the strata were determined by weighting the appropriate residue estimate by the respective acreage for each cutover area in the stratum (see formula on p. 7).

The effect of using total residue volume for each sample unit in the statistical analysis is of special interest; the variation associated with stratum estimates was greatly increased by using weighted values. The amount of variation attributable to the size of the cutover area is estimated to be greater than that associated with residue volumes per acre.

Table 8 gives the range of study data for selected characteristics of the cutover areas. This information is included to provide additional insight into applicability of the results. This may be expecially useful if application is intended for conditions that may extend beyond those of the study.

This situation might occur, for example, if the supply zone for a selected site includes geographic areas outside the scope of this report. If the data in this report represent the only reasonable source, the information in table 8 may help determine the extent of its use. In this case, it is recommended that application be restricted to conditions indicated above. The level of accuracy associated with the results of this report do not apply to extensions beyond the scope of the study.

Table 7—Statistical information for determination of sampling precision, by stratum

Stratum	Sample size	Average volume per unit	Standard error of the mean
	Areas	*Cubic feet*	
Idaho:			
National Forest—			
Clearcut	25	77,706.2	21,281.6
Partial cut	25	108,385.8	44,964.9
Other public (all methods)	25	269,928.0	48,622.1
Private (all methods)	25	109,896.2	21,636.3
Western Oregon:			
National Forest—			
Clearcut	20	76,787.2	12,891.3
Other public—			
Clearcut	19	110,847.4	28,339.6
Partial cut	25	81,016.6	13,639.2
Private—			
Clearcut	29	158,310.7	15,076.0
Partial cut	26	161,054.0	33,595.3
Western Washington:			
National Forest—			
Clearcut	20	124,137.6	13,323.4
Other public—			
Clearcut	35	211,295.1	34,055.4
Partial cut	9	95,283.9	33,185.4
Private—			
Clearcut	30	145,432.6	30,124.5
Partial cut	25	96,580.2	37,140.4
Eastern Oregon:			
Public (all methods)	35	114,844.1	18,269.9
Private (all methods)	35	122,087.2	23,089.0
Eastern Washington:			
Public (all methods)	35	119,488.9	20,283.3
Private (all methods)	35	55,955.7	7,938.3
Douglas-fir region:[1]			
National Forest—			
Partial cut	40	118,711.4	16,997.0

[1] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

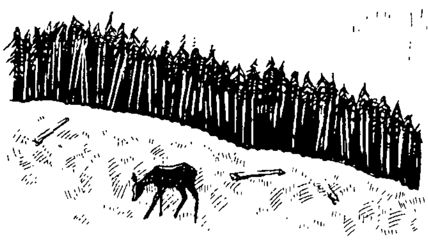
Table 8—Range of study data for stand age, harvest volume, harvest area, and residue volume

Stratum	Sample characteristics			
	Stand age	Harvest volume	Area harvested	Net wood residue volume
	Years	*Thousand board feet per acre*	*Acres*	*Cubic feet per acre*
Idaho:				
National Forest—				
Clearcut	70-300	5- 61	7-119	530-7,814
Partial cut	70-225	2- 23	7-200	336-3,679
Other public (all methods)	80-250	1- 22	[1]24-200	156-2,770
Private (all methods)	50-250	2- 39	[1]9-200	183-2,445
Western Oregon:				
National Forest—				
Clearcut	75-400	21- 95	8- 55	561-3,854
Partial cut[2]	60-350	1- 41	[1]6-200	336-3,139
Other public—				
Clearcut	80-250	9-105	6-107	1,085-3,097
Partial cut	35-300	5- 31	8-139	246-2,715
Private—				
Clearcut	50-400	12-148	9-196	347-2,662
Partial cut	32-160	1- 13	6-200	310-2,423
Western Washington:				
National Forest—				
Clearcut	150-350	34- 97	8- 86	841-3,515
Partial cut[2]	60-350	1- 41	[1]6-200	336-3,139
Other public—				
Clearcut	50-400	11-102	8-200	430-3,761
Partial cut	50- 65	3- 11	7-200	236-1,001
Private—				
Clearcut	40-275	8- 73	[1]8-200	363-2,134
Partial cut	35-110	1- 13	[1]6-200	143-2,717
Eastern Oregon:				
Public (all methods)	85-300	2- 32	[1]10-100	39-2,842
Private (all methods)	70-300	1- 22	[1]7-200	188- 891
Eastern Washington:				
Public (all methods)	50-300	3- 40	[1]5-200	153-1,343
Private (all methods)	55-200	1- 35	[1]10-200	85- 922

[1] Maximum acreage covered by sampling grid; actual sale area may encompass 200 to several thousand acres.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Literature Cited



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Appendix

Glossary[1]

Clearcut a harvest method in which all, or nearly all, of the trees in a stand of timber are cut in one operation.

Cutover area synonymous with sample unit or sample area; the area encompassing a single harvest operation (example: a clearcut).

Diameter diameter of residue pieces measured inside the bark (d.i.b.) at the point residue intersects a line transect.

Harvest volume net scaled volume of timber removed from a cutover area during harvesting, expressed in thousand board feet (log scale) per acre (MBF/AC).

Line transect a vertical sampling plane with no width, along which all intersecting residue pieces are measured.

Logging residue

General all down and dead woody material existing on an area after timber harvest is completed.

Specific all logging residue (as defined above) 3.01 inches and larger in diameter inside bark (d.i.b.) and 1.0 foot and longer in length, including limbs, slabs, splinters, and bark.

MBF 1,000 board feet of logs, a measurement of the quantity of timber harvested.

Owner class

Other public lands owned by the public or managed by a public agency, excluding National Forest lands.

Private lands owned by private individuals, forest industries, or other corporations.

Public lands owned by the public or managed by a public agency.

[1] Terms and abbreviations are defined as they are used in this report.

Partial cut a harvest method in which portions of a stand of timber are cut during a number of entries over time; precommercial thinning operations are not included.

Ponderosa pine region area of Oregon and Washington east of the Cascade Range.

Residue volume

Gross volume of a piece of residue measured only by its external dimensions; includes rot, cracks, and missing parts.

Net the usable portion of a piece of residue; for this report usability is based on physical chippability of the material.

Chippability condition of residue sound enough to be physically handled and capable of producing usable chips; includes residue exhibiting early stages of wet or dry rot.

Live residue from trees that were alive before they were cut or knocked down during harvest.

Dead residue from trees or portions of trees that were dead before harvest.

Cull residue from trees that were cull (less than 25 percent sound) at the time of harvest.

Stratum a category of timber harvest area defined for this study by geographic area, ownership class, and harvest method.

Supply zone a uniquely defined area containing timber determined to be potentially available for a processing facility.

YUM (or PUM) piles terms used by the USDA Forest Service for large piles of residue that have been yarded or bulldozed to a common location; if the residue has been piled with some degree of uniformity it is referred to as a PUM (piled unmerchantable material)—otherwise, the term YUM (yarded unmerchantable material) is used.

Conversion Factors

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters
1 mile = 1.609 kilometers
1 acre = 2.47 hectares
1 cubic foot = 0.283 cubic meter (stere)
1 pound = 0.454 kilogram
1 ton = 0.907 metric ton
1 British thermal unit (Btu) = 1 055.87 joules

Wood Density and Heating Values for Selected Species

Species	Density[2] (dry weight) (Pounds per cubic foot)	Higher heating values[3] (dry weight) (Btu per pound)
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)	28	9,050
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)	26	8,260
True firs (*Abies* spp.)	23	—
Western redcedar (*Thuja plicata* Donn.)	19	9,700
Ponderosa pine (*Pinus ponderosa* Laws.)	24	9,100
Lodgepole pine (*Pinus contorta* Dougl.)	24	8,730
Western larch (*Larix occidentalis* Nutt.)	30	—
Spruces (*Picea* spp.)	22	—
Red alder (*Alnus rubra* Bong.)	23	8,000
Bigleaf maple (*Acer macrophyllum* Pursh)	27	8,000
Black cottonwood (*Populus trichocarpa* Torr. & Gray)	19	8,510
Oregon white oak (*Quercus garryana* Dougl.)	37	8,170

[2] U.S. Forest Products Laboratory (1974).

[3] Arola (1976) and Bergvall et al. (1978).

Additional Study Results

Table 9—Average net volume (wood only) of logging residue, by area, owner class, and harvest method

Geographic area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per thousand board feet of timber harvest	
Idaho:		
National Forest	69	95
Other public	—	[1]113
Private	—	[1]87
Western Oregon:		
National Forest	36	[2]103
Other public	40	71
Private	31	221
Western Washington:		
National Forest	34	[2]103
Other public	40	87
Private	28	106
Eastern Oregon:		
Public	—	[1]53
Private	—	[1]59
Eastern Washington:		
Public	—	[1]71
Private	—	[1]54

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Table 10—Average gross volume (wood and bark) of logging residue by area, owner class, and harvest method

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per thousand board feet of timber harvest	
Idaho:		
National Forest	143	185
Other public	—	[1]221
Private	—	[1]167
Western Oregon:		
National Forest	77	[2]217
Other public	80	143
Private	65	477
Western Washington:		
National Forest	74	[2]217
Other public	80	202
Private	63	225
Eastern Oregon:		
Public	—	[1]138
Private	—	[1]128
Eastern Washington:		
Public	—	[1]148
Private	—	[1]112

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Table 11—Average gross volume (wood only) of logging residue by area, owner class, and harvest method

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per thousand board feet of timber harvest	
Idaho:		
National Forest	124	159
Other public	—	[1]191
Private	—	[1]146
Western Oregon:		
National Forest	65	[2]185
Other public	67	121
Private	55	403
Western Washington:		
National Forest	64	[2]185
Other public	69	171
Private	54	191
Eastern Oregon:		
Public	—	[1]115
Private	—	[1]108
Eastern Washington:		
Public	—	[1]122
Private	—	[1]94

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Table 12—Average net volume (wood only) of logging residue by area, owner class, and harvest method

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per acre	
Idaho:		
National Forest	1,716	1,331
Other public	—	[1]935
Private	—	[1]661
Western Oregon:		
National Forest	1,865	[2]1,133
Other public	2,008	905
Private	1,570	1,150
Western Washington:		
National Forest	1,923	[2]1,133
Other public	1,656	664
Private	1,002	751
Eastern Oregon:		
Public	—	[1]383
Private	—	[1]394
Eastern Washington:		
Public	—	[1]493
Private	—	[1]294

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Table 13—Average gross volume (wood and bark) of logging residue by area, owner class, and harvest method

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per acre	
Idaho:		
National Forest	3,564	2,585
Other public	—	[1]1,833
Private	—	[1]1,264
Western Oregon:		
National Forest	3,982	[2]2,375
Other public	4,037	1,820
Private	3,306	2,478
Western Washington:		
National Forest	4,173	[2]2,375
Other public	3,310	1,533
Private	2,273	1,596
Eastern Oregon:		
Public	—	[1]1,008
Private	—	[1]860
Eastern Washington:		
Public	—	[1]1,026
Private	—	[1]607

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Table 14—Average gross volume (wood only) of logging residue by area, owner class, and harvest method

Area and owner class	Harvest method	
	Clearcut	Partial cut
	Cubic feet per acre	
Idaho:		
National Forest	3,098	2,215
Other public	—	[1]1,586
Private	—	[1]1,101
Western Oregon:		
National Forest	3,375	[2]2,020
Other public	3,402	1,542
Private	2,806	2,092
Western Washington:		
National Forest	3,598	[2]2,020
Other public	2,856	1,301
Private	1,944	1,355
Eastern Oregon:		
Public	—	[1] 838
Private	—	[1] 720
Eastern Washington:		
Public	—	[1]850
Private	—	[1]508

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Table 15—Average net volume (wood only) of live and of dead and cull logging residue by area, owner class, and harvest method

Area and owner class	Harvest method			
	Clearcut		Partial cut	
	Live	Dead and cull	Live	Dead and cull
	Cubic feet per acre			
Idaho:				
National Forest	1,049	666	546	785
Other public	—	—	[1]351	[1]584
Private	—	—	[1]361	[1]299
Western Oregon:				
National Forest	1,104	761	[2]531	[2]602
Other public	1,159	849	492	413
Private	991	579	537	613
Western Washington:				
National Forest	1,145	778	[2]531	[2]602
Other public	1,097	560	285	378
Private	696	306	380	371
Eastern Oregon:				
Public	—	—	[1]150	[1]233
Private	—	—	[1]211	[1]182
Eastern Washington:				
Public	—	—	[1]238	[1]255
Private	—	—	[1]163	[1]131

[1] Samples selected randomly from all areas harvested since January 1, 1979; a large majority of samples were from partial cut areas, the predominant practice in this stratum.

[2] Average of partial cut areas in western Oregon and western Washington; these strata were combined because of an inadequate sample population in western Washington.

Howard, James O. Ratios for estimating logging residue in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-288, 26 p. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1981.

Ratios are presented for estimating the volume of logging residue for any location in Idaho, Washington, and Oregon. They show cubic-foot volume of logging residue per 1,000 board feet of timber harvested and per acre harvested. Tables show gross and net volumes, with and without bark. The volumes of live and dead and cull residue at the time of harvest are also given.

Keywords: Residue measurements, slash, Pacific Northwest.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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