AN ABSTRACT OF THE THESIS OF

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Title: STREAM PROTECTION AND THREE TIMBER FALLING TECHNIQUES

A COMPARISON OF COSTS AND BENEFITS

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Henry A. Froehlich

The objective of this study was to quantify the amounts of logging residues that are added to mountain stream channels as a result of timber falling - logging procedures, and to evaluate these procedures with respect to both ecologic and economic considerations. Three falling - logging treatments were observed: Conventional falling, Cable-assist falling, and Conventional falling with streamside buffer strips. Streamside environmental impact was evaluated in terms of the potential for damage due to the addition of organic logging residues to stream channels. Economic considerations included stream debris removal, timber volume left unharvested in buffer strips, timber falling labor and equipment, and timber breakage.

Stream debris was quantified for ten headwater streams in western Oregon prior to logging, after falling, and after yarding. To determine timber falling breakage and direct falling costs for both conventional and cable-assist methods, over 1.6 million board feet of timber was observed during falling
operations.

Results show that buffer strips were most effective in preventing logging debris from reaching stream channels. A 160 foot wide buffer strip allowed no debris penetration. During falling operations, 1.8 and 2.0 tons of debris per 100 feet of stream penetrated buffers with widths of 36 and 15 feet respectively. Conventional falling added an average of 47 tons of debris per 100 feet of stream. Cable-assist falling added only 14 tons per station, thus demonstrating its applicability as a stream protection technique.

Stream debris removal costs were found to be quite low for the observed buffer strip units. Estimated clean-up costs for the conventional falling treatment averaged $400 per station compared to only $154 per station for cable-assist falling.

Timber falling production rates averaged 9.3 MBF per hour for conventional falling, and 6.3 MBF per hour for cable-assist falling. Due to lower production rates, larger falling crews, and additional machinery costs, direct falling costs for cable-assist falling averaged $8.02 per MBF (gross scale) compared to $3.33 per MBF for conventional falling. Timber breakage averaged 7.35 percent of gross scale for conventional falling compared to 5.92 percent for cable-assist falling, a difference of 1.43 percent. For both methods, breakage increased as trees became larger and more defective.
The total cost of the economic factors evaluated was applied to a hypothetical 40 acre setting of 2,800 MBF. The analysis showed that of all treatments, the narrow 15 foot wide buffer strip treatment was most economical, total cost being only $6.12 per MBF. Due to the high cost of leaving 285 MBF of timber the 160 foot wide buffer strip treatment was most expensive at $13.18 per MBF. For the conventional falling - logging treatment, the total cost per MBF was $7.93. This compares with $10.96 per MBF for cable-assist falling; savings of breakage and stream debris removal costs were offset by much higher direct falling costs.

Although not included as a cost consideration in this analysis, cable-assist falling produced a greater average log length than did conventional falling. Consideration of log length relationships, and use of higher stumpage values would have altered the outcome of this analysis. The cable-assist treatment would have become more economically desirable compared to the conventional and buffer strip treatments.
Stream Protection and Three Timber Falling Techniques
A Comparison of Costs and Benefits

by
Dale Jay McCreer

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INTRODUCTION

The Problem

Increasingly intensive use of our forest lands and resources in the Pacific Northwest has been the inevitable result of population growth, increasing per capita resource consumption, and in the case of harvesting operations, a decreasing land base. With the continued conversion of old-growth stands to a managed condition, timber harvesting and road construction activities steadily move into steeper and more fragile areas. The result is greater interaction between potentially conflicting land uses, and an increased probability of environmental damage.

Of particular concern to the public, to land managers, and to the forest products industry, is the protection and conservation of forest streams. Of all areas within our forests, the greatest potential for environmental degradation and for conflicts between land uses often occurs in or near streams. Another subject of concern is the large amount of unused wood residue that remains in harvested areas after the completion of logging activities. These residues represent a loss of a potentially valuable wood resource, an expensive
and hazardous disposal problem, a source of site degradation, and when accumulations occur in or adjacent to streams, a cause of stream damage.

These wood residues can be classified into four general categories:

1. Dead and decaying material which was also present prior to logging
2. Brush, tops, branches, small conifers, and undesirable species
3. Log bolts containing extensive defect
4. Broken log bolts which would otherwise be merchantable

While current economic and technical conditions do not normally permit profitable utilization of much of this material, breakage of sound wood represents a direct loss of revenue, loss of an important resource, and often unnecessarily contributes to stream channel logging residues. (Dell, 1971)

When added to the stream channel, large concentrations of logging residue may harm both resident and anadromous fish populations (Narver, 1970, Hall, 1969, Meehan, 1969, Cordone, 1961), and may increase the danger and severity of "stream sluceouts", which in addition to the changes produced in the stream itself, cause costly damage to roads, bridges, reservoirs, and other engineering works that exist downstream. (Fredriksen, 1963, Froehlich, 1970, Rothacher, 1968)
In response to such problems, public land management agencies are developing general forest land regulations and are enforcing practices that are designed to minimize the occurrence and severity of stream degradation attributable to timber harvesting operations. (USDI, 1970, Ore. Forest Protective Assn., 1972)

The following is quoted from the Oregon Forest Practices Act of 1972:

"Felling shall be done in a manner to minimize break-age. Trees should be felled, bucked, and limbed so that the tree or any part thereof will not fall into or across any Class I stream. Remove all material that gets into such a stream as an ongoing process during harvesting operations. Place removed material above high water level. As a minimum, fell all trees away from Class I streams whenever possible. Remove slash that gets into the stream following harvesting."

Froehlich (1970) adds that the "necessity" of affecting a stream (in this case, the difficulty of falling timber that is adjacent to the stream) is a dominant factor in judging whether the regulations have been met.

With these economic and ecologic considerations in mind, it becomes clear that methods of reducing logging residue stream damage must be implemented.

Commonly employed methods include:

1. Preventing logging residues from entering the stream channel by leaving a buffer strip of standing timber,

2. Preventing logging residues from entering the stream channel by using directional cable-
assisted timber falling techniques, and

3. The removing of logging residues which enter the channel.

Each of these methods has its comparative advantages and disadvantages, and two important questions arise: What degree of protection is provided by each method? What are the costs of providing this protection? Until these questions are answered, rational management decisions on the logging residue stream protection problem cannot be made.

Study Objectives

The main objective of this study was to compare the costs and streamside environmental impact of conventional timber falling to two stream-protection variations: uphill cable-assist timber falling, and conventional falling with buffer strip. The cost due to loss of timber through breakage, stream debris removal, the timber value left in buffer strips, and timber falling labor and equipment was evaluated. Streamside environmental impact was evaluated in terms of the quantity of logging debris entering stream channels during falling and yarding and remaining in the stream channels after logging was completed.
The Project

This study is an outgrowth of a much more encompassing project entitled, "The Relationship of Timber Harvesting Systems to Logging Residue", that is being carried out by the Oregon State University Department of Forest Engineering under the direction of Professor H. A. Froehlich. Much of the field and analytical work involved in quantifying and characterizing stream debris was conducted prior to my introduction to this study by Dr. Froehlich, with the assistance of Dick Lammel, a former graduate student. Much of this work has been published by Froehlich, and also appears in Lammel's thesis.1 Stream debris clean-up costs are being investigated by Dennis P. Dykstra, a member of the forest engineering staff at Oregon State University.

Numerous researchers have studied the effects of timber harvesting operations on the stream environment. These studies most often concern themselves with the turbidity, temperature, and dissolved oxygen levels of stream waters.

Papers by Megahan (1972), and by Copeland (1963) provide excellent reviews of forest stream sedimentation studies. Brown (1971), and Fredrikson (1970) give specific results of studies conducted in the Oregon Coast Range and Cascades respectively.

Dyrness (1963) reviews the effects of burning on forest soils, and reports that physically and chemically injurious effects are wrought by intense fires. Intense heat is more likely to occur when fuel concentrations are great.

Brown (1972) provides a good review of stream temperature as affected by timber harvesting. According to Brown, stream temperature increases are dependent only upon the exposure of stream waters to direct solar radiation. He also discusses the role of streamside vegetative strips, or "buffer strips", in preventing such exposure.

Organic stream debris and its relationships with stream ecology have been studied to some extent. Hall (1969), Narver (1970), and Cordone (1961) discuss the relationships between biochemical oxygen demand and organic stream debris, and their effects upon resident and migratory fish populations. Aerobic
decomposition of organic debris places an "oxygen demand" upon the dissolved oxygen of stream waters. Oxygen levels can be lowered to levels injurious to aquatic organisms by excess organic decomposition. Hall (1969) reports that following clearcut logging of a small watershed in the Oregon Coast Range, dissolved oxygen decreased significantly in both surface and intragravel waters. He attributed this drop to the presence of excess organic debris and sediments that entered the stream as a result of logging. Hall also reports that while surface oxygen levels recovered rapidly, intragravel levels remained depressed for over two years. Narver (1970) adds that organic debris buried by sediment may create conditions favorable to anaerobic decomposition, with toxic benthol deposits resulting.

These facts are of great significance to anadromous fish, whose eggs and alevins must survive within intragravel waters. Meehan (1969) also reviews literature which shows that adult fish migration may be delayed or prevented by large debris jams that present a physical barrier to their passage.

Natural stream debris has been found to be an important factor in the stream environment. Heede (1972) found that natural log and rock debris jams exert a stabilizing influence upon streambeds. By creating a series of sharp drops, pools, and gravel bars, energy is dissipated in turbulence as water falls over the log jams into pools below. Gravel bars develop in quiet water which lies downstream from the pools. The net
effect is to reduce the energy available for sediment transport.

Man-caused debris, however, such as logging residues, may indeed be a source of streambed instability when added in large quantities, and during a short period of time. Helmers (1966) found that the introduction of two artificially constructed debris jams increased streambed scouring and deposition. He concluded that artificially introduced stream debris produces increased streambed instability.

Several authors report that stream debris is often directly or indirectly damaging to forest engineering works. Natural stream debris builds up over a period of years. Periodically a stream's unconsolidated debris may be violently avalanched down the stream channel, scouring it down to bedrock. Damage to downstream roads, bridges, reservoirs and other works is often severe. (Fredriksen, 1963, Froehlich, 1970, Rothacher, 1968, Rothacher, 1959) These authors also agree that the likelihood and severity of damage produced by such an event is increased by the addition of large amounts of logging debris. Even in the absence of catastrophic events, high streamflow during storm events can cause unstable organic debris to be floated downstream. Rothacher (1968) found that during the historic December flood of 1964, culvert failure and subsequent road failure was most often due to the plugging of culverts with debris.

Despite these important influences, few studies have sought to quantify either natural or artificially introduced stream
debris. In a study in Southeast Alaska, Meehan (1969) approached the problem by counting the number of pieces of debris that he judged to be large enough to create debris jams. He found that the number of pieces increased from 1120 to 1630 following extensive clearcutting. Meehan's study and Froehlich's work (1973) (of which this paper is a part), constitute the entire body of literature in this area.

The logging debris problem in general has been studied to some extent. Dell (1971) measured residue volumes in 30 clearcuts in Douglas-fir forests of western Washington and Oregon. He found an average volume of 7,430 cubic feet per acre, 45% of which was judged to be suitable for chipping. In a similar study, Howard (1971) found volumes of from 325 to 3,156 cubic feet per acre. Wilson (1970) reported the relative importance of felling and skidding as formative agents of residues. He concludes that timber falling creates by far the largest share of logging residues.
METHODS

Treatments

Three timber falling - logging treatments were analyzed in this study:

1. Conventional falling and high-lead yarding, followed by channel clean-up as required.

2. Conventional falling and hi-lead yarding, but with a buffer strip of uncut standing trees remaining between the setting and the stream channel, followed by stream clean-up if necessary. This method will hereafter be referred to as "Conventional falling with buffer strip".

3. Cable-assisted uphill falling ("tree-pulling"), again followed by stream clean-up if necessary. In this treatment a climber attaches a cable to the bole of the tree so that when tension is placed on the cable by a small yarding engine positioned above the setting, the tree is felled uphill with directional control.²

²See Barwell (1971) for a more detailed description of the pulling machine and cable-assist falling techniques.
Selection of Study Areas

Study areas for stream debris measurement were selected in the old-growth Douglas-fir forests of western Oregon on Bureau of Land Management, Forest Service, and private lands. Stream debris data were gathered from undisturbed headwater streams that were located in or directly below settings that were subsequently clearcut logged by cable yarding methods. We were therefore able to measure the debris under natural conditions, and following each stage of logging. Nine study areas were on the west side of the Cascades, while one was on the east side of the Coast Range in similar timber and terrain. Three settings were conventionally felled, three were buffer strip felled, and four were felled by the tree pulling method.

Timber falling data were collected from six different clearcut units in the Cascades. Three of the settings were conventionally felled, and three were "tree-pulled". In collecting the data, four different conventional falling crews, and two cable-assist falling crews were observed.

Evaluation of Stream Protection: Procedures for Quantifying Stream Channel Debris

Data previously collected by Froehlich and Lammel plus additional data on logging residues observed at later stages of logging and for additional streams were included for this phase.
of the study. Basically, the residue values were obtained from measurement in a 30 foot strip (15 feet on each side of the stream centerline) that was laid out along the stream for a distance of 400 feet.  

Economic Considerations: Collection of Cost Data

Stream Clean-up Costs

Surveys conducted by Dennis Dykstra* show that most logging contractors estimate a cost of from 100 to 500 dollars per station for hand cleaning of relatively small-sized logging debris, with an average being about 300 dollars per station. An additional 100 dollars per station is added to cover machine cleaning costs of larger debris that are incurred as an ongoing part of the yarding process. Although operators base these estimates largely upon the quantity of debris to be removed, their judgment of this quantity is only relative and based upon past experience. To convert these average costs from a "per station basis" to cost "per unit of stream debris" requires some sort of unifying assumption. I have assumed that in timber stands of similar characteris-

*For detailed procedures, see Lamme's thesis.

*Unpublished data on file at Oregon State University.
tics the amount of logging debris that would not normally be profitable to remove from a stream (yarded and sent to the mill) is directly proportional to the total amount of material that is added during falling. I therefore assumed that the average machine clean-up cost of $100 per station was based upon the average amount of large or "coarse" debris that was added during falling to the stream channels of those conventionally felled units that we had observed. It should be noted that in the results, Table 1 shows for the conventional treatment that some of the coarse debris added during falling was not removed during yarding. It would then be necessary to remove this material by hand. The actual volume which must be machine cleaned is then computed by subtracting this volume, as shown in Table 1, from the volume of coarse debris that was added during falling. For the cable-assist and conventional with buffer strip treatments there was, on the average, no excess debris remaining in the channels following yarding. The volume of coarse debris added during falling can then be directly taken as the volume that was machine cleaned. Following these assumptions, I calculated an average stream clean-up cost of $2.78 per ton of coarse debris which is applied to all falling treatments. Total machine clean-up costs for the cable-assist and conventional with buffer strip
treatments vary proportionately with the quantity of coarse debris added during falling. Fine debris clean-up costs (hand clean-up costs) per ton of stream debris were similarly computed, based upon the total amount of coarse and fine debris that remained in the stream channels of conventionally felled units following yarding. The clean-up cost per ton of fine debris was found to be $25.86 per ton. The calculations showing these stream clean-up costs are shown in the results.

Falling and Breakage Costs

Falling costs may increase when it is necessary to fall timber adjacent to buffer strips. From information gathered from logging operators by Dennis Dykstra, and from my own informal conversations with falling crews, it appears that these cost increases are minimal. This falling cost increase when distributed through the large volume of an entire setting should become insignificant. Therefore, data for falling costs and costs of breakage were collected separately for the tree-pulling and conventional methods only. Accordingly, falling and breakage costs based on data collected for the conventional treatment were also applied to the conventional with buffer strip treatment.

Falling and Breakage cost data were collected by working in close cooperation with the fallers. When the fallers started in the morning I recorded the time and worked with them throughout the day. After each tree was felled, I scaled each log bolt
Bolt being defined as any log or broken section) and also roughly graded each broken log bolt while they were being bucked. Although somewhat hazardous, this was the only reliable way of clearly identifying individual trees, and pieces of trees. By recording data in this manner I was subsequently able to compute the gross volume, volume of breakage by grade, and other statistics for each day. Time was recorded while the crews were working. Time spent traveling to and from work was not included. I then computed production rates per hour, the percentage of total volume broken, and frequency distributions of logs and broken log bolts. Grading also allowed classification of breakage figures into merchantable and non-merchantable classes.

An important part of the buckers job is to continually make judgments on whether a given piece of wood is worth taking to the mill. By observation I also developed this capability to the extent that it was possible for me to make a decision on whether a given broken log bolt would have been merchantable, and thus represented a loss of potential value, or was non-merchantable. It is recognized that the standards that I used may change with time and place.

6More detailed scaling procedures are given in Appendix A.
Defect Index = \frac{\text{Sound Volume of Breakage}}{\text{Total Volume of Breakage}}

Topographic roughness was often difficult to estimate. If there were no apparent topographic obstacles in the immediate section of ground where a tree was meant to be felled, I classified this as "good ground". If one or more obstacles were present the topography was classified as "poor ground". Such obstacles included breaks in slope gradient, large rocks or rock outcroppings, and small drainages.

Timber falling labor costs. In order to develop a uniform basis for comparison, hourly labor costs for fallers and buckers were developed from figures supplied by BLM Production Schedule 18. In the tree pulling treatment, labor costs for the puller-
operator and treeclimber were developed from information that was supplied by cooperating logging operators. Faller and bucket labor cost per man was found to be $13.97 per hour from BLM Schedule 18. This figure is applied to fallers and buckers for all treatments. Two man conventional falling crews were observed 21.5 percent of the time. Therefore, the average cost per crew hour for conventional falling is computed as:

\[ 13.97 \times 2 \times 0.785 + 13.97 \times 3 \times 0.215 = 30.94 \]

Due to lower labor cost of the tree climber ($8.10 per hour), and puller operator ($6.49 per hour), the average labor cost per man hour is less than $13.97 for the cable-assist treatment. The average cost per man hour was found to be $10.23. The average cost per crew hour was $49.01. Additional equipment necessary for cable-assist falling incurs additional costs. These costs include the owning and operating costs of the tree-pulling machine and radio system. The total machinery cost was computed to be $1.57 per hour. Total labor and equipment cost per hour for cable-assist falling is therefore $50.58. These computations are given in detail in Appendix B.

Evaluation of timber breakage costs. Some material observed was so highly defective that, in my judgment, it was not economically feasible to market. It is possible, however, that broken material that I observed and judged to be unmerchantable ("cull") may on the average have had some positive value had it not been broken. I should point out that the material that I labeled in
the woods as "cull: should not be confused with logs that are
graded as culls by formal grading standards. Many of these logs
indeed have substantial value as lumber, veneer and chips. (Woodfin,
1973) However, many of the cull logs that Woodfin observed in
his study were "created" at the mill by further bucking a cull
section (a section less than one-third sound) out of a longer
log. In other words, Woodfin's mill culls were of higher average
quality than the "woods culls" that I observed. Also, the
cost of bringing Woodfin's culls to the mill had already been
paid. Had they been bucked in the woods, they may not have been
merchantable.

Since all stumpage values vary with time and place, assigning
a general value becomes somewhat arbitrary. (Beuter, 1971)
However, from examination of recent timber sale bid prices within
the study area, and for similar timber types, I found that
the average stumpage bid value was $90 per MBF "net" scale
(net scale meaning that a defect and breakage allowance was
taken out). My data show that since most breakage occurs within
the crowns of the trees, the average grade of merchantable
breakage is below that of the average grade of the stand. I
have therefore assigned a stumpage value of $70 per MBF for
merchantable breakage.

Buffer Strip Opportunity Cost Determination

In this analysis the income forgone by not harvesting buffer
strips was considered. It is reasonable to assume that the timber volume and value of these buffers will never be recovered. The timber volume present within the buffer strip is essentially "tied up" at least until the time that the unit above the buffer is again harvested, which in these areas will be a period of at least 50 years, under current projections. There is evidence that a substantial amount of this volume may be lost to blowdown, death and decay. Also, of course, the original stream protection considerations and additional harvesting difficulties may cause the buffer strip to again be left unharvested. This value is then included in the total cost-of-treatment computation.

The buffer strip areas lying immediately adjacent to stream debris study plots were 100% cruised. All commercial conifers were measured for DBH to the nearest two inches and for height to an eight inch top. Trees of less than ten inch DBH or 16 foot height to an eight inch top were not included. Gross volumes were then found from standard volume tables. It should be noted

7I have made measurements on a buffer strip that was left near one of the study plots. The data show that over 25 percent of the original buffer strip volume had been lost to blowdown within a period of less than two years following harvesting of the adjacent unit.
that most timber appraisal procedures adjust from gross scale to net scale by measuring defect, and by estimating breakage. These factors are inevitably reported as only one figure, and I was unable to identify standard breakage allowances in timber stands of this type. Defect-breakage allowances for these sale areas, as shown in timber sale appraisals, range from 30 to 36 percent. By subtracting the amount of sound breakage, which from my results for conventional falling is about four percent, I have estimated that an average gross-scale adjustment factor for defect would amount to about a 30 percent reduction in scale. Accordingly, I have adjusted buffer strip gross volumes downward by this factor. I then assigned a stumpage value of $90 per MBF net, as discussed earlier.

**Analysis of Cost Data**

In order to most effectively demonstrate how each cost component varies with the falling treatment, and with width of buffer strip, the results of the stream debris and clean-up cost study and the breakage and buffer strip cost values were applied to a hypothetical setting. In doing so, the setting acreage, setting volume and length of stream below the setting were taken to be 40 acres, 1.8 MBF, and 1340 feet respectively, It was then possible to demonstrate what each individual cost component would have been.
Accordingly, five cases were analyzed:

1. Conventionally felled with buffer strip for three cases:
   Case F: 15 foot wide buffer strip
   Case L: 36 foot wide buffer strip
   Case N: 160 foot wide buffer strip
   Costs to include:
   a) cost of buffer:
      actual volume measured multiplied by the value per MBF
   b) stream debris clean-up cost:
      machine and hand clean-up costs per ton of stream debris multiplied by the number of tons actually measured
   c) direct falling costs:
      labor costs per MBF
   d) timber breakage costs:
      percent merchantable breakage multiplied by the value per MBF of breakage. (Breakage for conventional with buffer strip treatment equals breakage for conventional treatment.)

2. Cable-assist felled, costs to include:
   a) buffer strip cost is zero
   b) stream debris clean-up cost:
      machine and hand clean-up costs per ton of
stream debris multiplied by the average number of tons measured in the three cable-assist streams observed.

c) direct falling costs:
    labor and equipment costs per MBF

d) timber breakage costs:

3. Conventionally felled, costs to include:
   a) buffer strip cost is zero
   b) stream debris clean-up cost:
       machine and hand clean-up costs per ton of stream debris multiplied by the average number of tons measured in the three conventional treatment streams observed.
   c) direct falling costs:
       labor costs per MBF
   d) timber breakage costs

The respective component and total costs of each treatment as outlined above were then compared and are shown in the results.

In order to make the comparisons it was necessary to make a detailed study of timber falling breakage and costs of both conventional timber falling and cable-assist falling. The value of the cable-assist falling method as a stream protection measure had been demonstrated by previous work. However, it was not known at the beginning of this study whether the potential for stream protection of cable-assist falling would be offset by increased falling costs.
RESULTS
Streamside Environmental Impact and Clean-up Costs

Logging Residues

The amount of logging debris that is added during falling, and the amount which remains following yarding is shown in Table 1 for each treatment. The table shows that there is high variability in the amount of debris added for different channels both within a given treatment, and between treatments. Despite the variability, certain relationships are apparent. At 44.5 tons per 100 feet of stream channel, conventional falling added over three times the amount of coarse debris that was added in felling by cable-assist falling, and over 40 times that added where buffer strips were employed. Conventional falling also added over four times the amount of fine debris as did cable-assist falling and over 16 times as much as did the conventional falling with buffer strip treatment.

During yarding, which includes some stream clean-up operations, an average of 36 tons of coarse stream debris was removed from the conventional treatment channels, with 8.55 tons remaining. For both the cable-assist and conventional with buffer strip treatments more coarse debris was removed than was actually added during falling. This is due to two possible causes: 1) excess cleaning of streams in order to be sure of meeting contract or Forest Practice Rule requirements; 2) removal of sound merchant-
Table 1. Changes in debris volume with logging and with timber falling method. Tons per hundred feet of channel.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Debris added in tree falling</th>
<th>Excess debris after yarding</th>
<th>Debris which must be hand cleaned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse</td>
<td>Fine</td>
<td>Coarse</td>
</tr>
<tr>
<td>I</td>
<td>78.7</td>
<td>3.32</td>
<td>16.73</td>
</tr>
<tr>
<td>K</td>
<td>38.6</td>
<td>3.39</td>
<td>7.47</td>
</tr>
<tr>
<td>M</td>
<td>16.3</td>
<td>0.69</td>
<td>1.46</td>
</tr>
<tr>
<td>Average</td>
<td>44.5</td>
<td>2.47</td>
<td>8.55</td>
</tr>
<tr>
<td>C</td>
<td>9.3</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>19.1</td>
<td>0.94</td>
<td>6.53</td>
</tr>
<tr>
<td>G</td>
<td>10.0</td>
<td>0.99</td>
<td>-9.24</td>
</tr>
<tr>
<td>J</td>
<td>15.7</td>
<td>0.28</td>
<td>-1.90</td>
</tr>
<tr>
<td>Average</td>
<td>13.4</td>
<td>0.61</td>
<td>-1.54</td>
</tr>
</tbody>
</table>

Conventional Falling with Buffer Strip

<table>
<thead>
<tr>
<th>Channel</th>
<th>Debris added in tree falling</th>
<th>Excess debris after yarding</th>
<th>Debris which must be hand cleaned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse</td>
<td>Fine</td>
<td>Coarse</td>
</tr>
<tr>
<td>F</td>
<td>1.7</td>
<td>0.36</td>
<td>-3.52</td>
</tr>
<tr>
<td>L</td>
<td>1.7</td>
<td>0.09</td>
<td>1.03</td>
</tr>
<tr>
<td>N</td>
<td>0.0</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Average</td>
<td>1.1</td>
<td>0.15</td>
<td>-0.82</td>
</tr>
</tbody>
</table>
able timber that was present in the stream channels prior to falling. The volume of fine debris in the channels actually increased during yarning for all treatments. This increase is due to the addition of branches and small pieces of debris that roll down into the channels during yarning.

The quantity of debris that must be removed from the observed stream channels in order to meet stream clean-up requirements is also shown in Table 1 for each treatment. For conventional falling, 44.5 tons of coarse debris could potentially have been removed during yarning. However, only 36 tons were actually removed. This remaining quantity of 8.55 tons, plus 3.08 tons of fine debris, would have to be removed in order to meet stream cleaning requirements, if strictly enforced. For the cable-assist and conventional with buffer strip treatments, more coarse debris was removed than was necessary. However, it would be necessary to also remove the fine debris that was added. Therefore, the quantity of debris which must be hand cleaned in order to meet standards is the sum of coarse and fine debris excesses, with negative values being ignored. Using this procedure, Table 1 shows that the quantity of debris which must be hand cleaned is 11.6 tons per hundred feet of stream channel for conventional falling. This quantity is 2.57, and 20.35 times that quantity which must be removed from the cable-assist and conventional with buffer strip channels, respectively.
Characteristics of the three conventionally felled with buffer strip units are compared in Table 2. Note the average width and corresponding areas of the three buffer strips. Buffer strip widths for the three units varied from a low of 15 feet for Channel F, to a high of 160 feet for Channel N. The commercial timber volumes contained within the buffer strips increased as the buffer strips became wider. As shown, Channel F contained almost no commercial volume. This unit, which was on the east side of the Coast Range, had streamside vegetative characteristics not common to the other two buffer strip units, which were located in the Cascades. The dominant vegetation along Channel F was composed almost entirely of hardwoods, a condition not uncommon to coastal streams. In contrast, the streamside vegetation of Channel L and N consisted mainly of large coniferous species, with individual tree volumes as great as 15,000 board feet Scribner.

By comparison of Tables 1 and 2 it can be seen that as the width of buffer strip increases, the amount of debris penetrating the buffer strip and entering the stream channel decreases. Buffer strip N, with a width of 160 feet, allowed almost no debris penetration to the stream channel. Debris volumes in Channels F and L, with buffer strip widths of 15 and 36 feet respectively, increased during tree falling by 1.7 tons of coarse debris per 100 feet of channel each. Fine debris added during falling also increased, the addition being 4 times as great for the narrower
<table>
<thead>
<tr>
<th>Item</th>
<th>Channel F</th>
<th>Channel L</th>
<th>Channel N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual length of stream below unit</td>
<td>1,766</td>
<td>1,785</td>
<td>716</td>
</tr>
<tr>
<td>-- feet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit size -- acres</td>
<td>39.2</td>
<td>30.5</td>
<td>45.1</td>
</tr>
<tr>
<td>Average width of buffer strip adjacent to survey plot -- feet</td>
<td>15</td>
<td>35</td>
<td>160</td>
</tr>
<tr>
<td>Area of buffer strip adjacent to stream debris survey plot -- acres</td>
<td>0.14</td>
<td>0.33</td>
<td>1.46</td>
</tr>
<tr>
<td>Commercial volume of buffer strip adjacent to survey plot -- MBF</td>
<td>6.1</td>
<td>16.21</td>
<td>86.30</td>
</tr>
<tr>
<td>Commercial volume of buffer strip per station of stream -- MBF</td>
<td>0.025</td>
<td>4.05</td>
<td>21.58</td>
</tr>
</tbody>
</table>
buffer strip. Fine debris also penetrated these two buffer strips and entered the stream channels during yarding operations. Again, the wider buffer strip was more effective in preventing fine residues from reaching the stream channel area.

Stream Clean-up Costs

The machine clean-up cost per unit stream debris was computed by dividing the average machine clean-up cost per station of $100 by the average excess quantity of coarse debris that remained in conventional treatment channels following yarding. The hand clean-up cost per unit of stream debris was computed by dividing the average hand clean-up cost per station of $300 by the average excess quantity of stream debris that remained in conventional treatment channels following yarding.

The basic computation for coarse debris clean-up is shown below:

Conventional Falling

Average conventional treatment machine clean-up cost = $100/station
(from data gathered by Dykstra)

The cost per unit stream debris is calculated as:

\[
\frac{\$100/\text{station}}{35.95 \text{ tons/station}} = \$2.78/\text{ton of stream debris}
\]

Cost for standard 13.2 station setting =
$100/\text{station} \times 13.2 \text{ stations} = $1320

This unit cost of $2.78 per ton of stream debris is then applied to each treatment. To demonstrate the application of this base cost per ton to the cable-assist falling units and the buffer strip units, the following example is given:

Cable-Assist Falling

Machine clean-up cost/station = cost/ton \times \text{tons of coarse debris}/station = $2.78/\text{ton} \times 13.4 \text{ tons/station} = $37.25/\text{station}

Cost for standard 13.2 station setting =

$37.25/\text{station} \times 13.2 \text{ stations} = $492

Calculations of approximate costs for clean-up of fine debris were made in a similar manner. The results are shown in Table 3. For each case studied, both machine and hand cleaning costs are given in Appendix B.

The costs shown in Table 3 for total clean-up costs per MBF were calculated by dividing the total cost by the standard setting volume of 2,800 MBF. For the buffer strip units, the standard setting volume has been reduced by the volume contained within the buffer strips. The table shows that with a direct cost of $1.89 per MBF, stream clean-up costs for conventional falling are 2.62 times those of cable-assist falling, and many times those of the buffer strip treatments.
Table 3. Stream clean-up costs for standard setting (13.2 stations, 2,800 MBF).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Machine Clean-Up Dollars</th>
<th>Hand Clean-Up Dollars</th>
<th>Total Dollars</th>
<th>Dollars/MBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>1,320</td>
<td>3,960</td>
<td>5,280</td>
<td>1.89</td>
</tr>
<tr>
<td>Cable-Assist</td>
<td>492</td>
<td>1,536</td>
<td>2,028</td>
<td>0.72</td>
</tr>
<tr>
<td>Conventional with Buffer Strip</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel F</td>
<td>62</td>
<td>174</td>
<td>236</td>
<td>0.08</td>
</tr>
<tr>
<td>Channel L</td>
<td>62</td>
<td>410</td>
<td>472</td>
<td>0.17</td>
</tr>
<tr>
<td>Channel N</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Buffer Strips and Costs

Table 2 summarized some of the characteristics of the three buffer strips and buffer strip units studied. The opportunity costs of leaving these buffer strips are calculated and shown in Table 4. The total commercial volume that is present within each buffer strip is found by multiplying the volume per station, from Table 2, by the standard stream length of 13.2 stations. This volume varies from a high of 284.9 MBF for the 160 foot wide buffer of Channel N to 0.3 MBF for the 15 foot wide buffer of Channel F. To adjust the total volumes for defect, the total volumes are multiplied by a factor of 0.70 to arrive at the net volumes shown. This net volume is then assigned a value of 90 dollars per MBF, as was discussed in the methods. Multiplying the net volumes by $90 yields a buffer strip opportunity cost of 18 dollars for Channel F, 3,366 dollars for Channel L, and 17,945 dollars for Channel N.

Timber Falling Labor and Machine Costs

Timber stand and falling site conditions vary greatly even within what appear to be relatively homogenous sale areas. Because of this high variability, timber falling production rates, and the volume of breakage incurred, also vary greatly. In order to gather a representative sample under these conditions, I
<table>
<thead>
<tr>
<th>Item</th>
<th>Channel F</th>
<th>Channel L</th>
<th>Channel N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total commercial buffer strip volume -- MBF</td>
<td>0.3</td>
<td>53.3</td>
<td>284.9</td>
</tr>
<tr>
<td><em>(vol. /sta. x 13.2 sta.</em>)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total buffer strip volume minus 30% for defect -- MBF</td>
<td>0.2</td>
<td>37.3</td>
<td>199.4</td>
</tr>
<tr>
<td>Value per MBF net -- dollars</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Value of buffer strip volume -- dollars</td>
<td>18</td>
<td>3,357</td>
<td>17,946</td>
</tr>
<tr>
<td>Volume of standard 2,800 MBF setting minus buffer volume</td>
<td>2,800</td>
<td>2,747</td>
<td>2,515</td>
</tr>
<tr>
<td>-- MBF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost per MBF of standard setting -- dollars</td>
<td>0</td>
<td>1.22</td>
<td>7.14</td>
</tr>
</tbody>
</table>

Table 4. Calculation of buffer strip opportunity cost.
observed falling operations for a total of 215 hours: 91 hours for conventional falling, and 124 hours for cable-assist falling. In doing so, I scaled over 1.6 million board feet of timber. These totals are summarized in Table 5.

Some variability in slope, tree diameter and tree height was found to exist between the samples taken for the two falling methods. However, Defect Index, the major variable that was found to influence breakage, was observed to be nearly identical. The timber and site characteristics that I observed for the conventional and cable-assist falling areas are given in Table 6. The parameters shown are also shown separately for good and poor ground conditions. Table 6 shows that the averages of the characteristics observed for conventional falling are comparable to those observed for cable-assist falling. In general, I believe that the conditions under which I made my observations were similar enough to allow valid comparisons of both timber falling production and of timber falling breakage.

Timber Falling Production Rates

The production rates, or volumes of timber felled and bucked per unit time, are shown in Table 7. An average of nearly 9,300 board feet of timber per hour was cut by conventional falling, as compared to 6,300 board feet per hour by the cable-assist method. The conventional method therefore, cut timber at a rate
<table>
<thead>
<tr>
<th>Falling Method</th>
<th>Volume Felled</th>
<th>Volume Minus Breakage</th>
<th>Total Breakage</th>
<th>Sound Breakage</th>
<th>Number of Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Board Feet</td>
<td>Board Feet</td>
<td>Board Feet</td>
<td>Board Feet</td>
<td>Hours</td>
</tr>
<tr>
<td>Conventional Falling</td>
<td>845,219</td>
<td>781,727</td>
<td>63,492</td>
<td>35,748</td>
<td>90.9</td>
</tr>
<tr>
<td>Cable-Assist Falling</td>
<td>782,520</td>
<td>736,942</td>
<td>45,578</td>
<td>24,029</td>
<td>124.0</td>
</tr>
<tr>
<td>Total</td>
<td>1,627,739</td>
<td>1,518,569</td>
<td>109,070</td>
<td>59,777</td>
<td>214.9</td>
</tr>
<tr>
<td>Topography</td>
<td>Falling Method</td>
<td>Slope Percent</td>
<td>Stump Diameter Inches</td>
<td>Tree Height Feet</td>
<td>Tree Volume Feet</td>
</tr>
<tr>
<td>------------</td>
<td>----------------</td>
<td>---------------</td>
<td>----------------------</td>
<td>------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Good</td>
<td>Conventional</td>
<td>47</td>
<td>35</td>
<td>120</td>
<td>3066</td>
</tr>
<tr>
<td></td>
<td>Cable-assist</td>
<td>52</td>
<td>32</td>
<td>138</td>
<td>2609</td>
</tr>
<tr>
<td>Poor</td>
<td>Conventional</td>
<td>47</td>
<td>36</td>
<td>146</td>
<td>3139</td>
</tr>
<tr>
<td></td>
<td>Cable-assist</td>
<td>51</td>
<td>35</td>
<td>149</td>
<td>3537</td>
</tr>
</tbody>
</table>
Table 7. Timber falling production rates.

<table>
<thead>
<tr>
<th>Measure of Productivity</th>
<th>Falling Method</th>
<th>Conventional MBF</th>
<th>Cable-assist MBF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume cut per hour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total gross scale</td>
<td>9,298</td>
<td>6,308</td>
<td></td>
</tr>
<tr>
<td>Total minus breakage</td>
<td>8,600</td>
<td>5,940</td>
<td></td>
</tr>
<tr>
<td>Volume cut per man hour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total gross scale</td>
<td>4,190</td>
<td>1,289</td>
<td></td>
</tr>
<tr>
<td>Total minus breakage</td>
<td>3,895</td>
<td>1,214</td>
<td></td>
</tr>
<tr>
<td>Man hours per MBF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total gross scale</td>
<td>0.239</td>
<td>0.776</td>
<td></td>
</tr>
<tr>
<td>Total minus breakage</td>
<td>0.258</td>
<td>0.824</td>
<td></td>
</tr>
</tbody>
</table>
of 1.47 times that of the cable-assist method. The differential between net production rates, or the total volume felled minus breakage, was reduced slightly to a ratio of 1.4 : 1 due to a greater amount of breakage observed for conventional falling. In terms of the total timber volume per man hour, conventional falling produced 4,190 board feet compared to 1,289 for cable-assist falling, for a ratio of conventional falling production to cable-assist production of 3.25:1. This measure of production is also shown in Table 7 as "man hours per unit volume cut". This parameter is only the inverse of "volume cut per man hour".

The falling and bucking cost per MBF is calculated by dividing the values of "total cost per hour" by the "total volume cut per hour" for labor and machinery, as shown in Table 8. As shown in the table, the total cost of equipment and labor is $3.31 per MBF, gross (total) scale, for conventional falling. This compares with $8.02 per MBF for cable-assist falling. In terms of the net volume felled (total volume minus the volume of breakage) the cost was $3.60 per MBF for conventional falling, and $4.52 per MBF for cable-assist falling. Thus we find that cable-assist falling incurs costs of 2.37 times those of conventional falling per unit net volume.

Timber Falling Breakage

The loss of potential value through the breakage of sound
<table>
<thead>
<tr>
<th>Falling Method</th>
<th>Volume cut per hour</th>
<th>Average cost of labor per crew hour</th>
<th>Equipment cost per hour</th>
<th>Total cost per MBF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Gross scale</td>
<td>Total minus breakage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional Falling</td>
<td>9,298</td>
<td>8,600</td>
<td>30.94</td>
<td>30.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.60</td>
</tr>
<tr>
<td>Cable-Assist Falling</td>
<td>6,308</td>
<td>5,940</td>
<td>49.01</td>
<td>50.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.52</td>
</tr>
</tbody>
</table>
timber volume is an important economic consideration. By affecting the amount of timber actually harvested from a given unit area, it not only affects the harvesting costs, but also has significant land management implications. In order to adequately compare and evaluate the stream protection measures, I found it necessary to devote a major part of my research efforts to the investigation of timber falling breakage. The timber industry, land management agencies, and even conservation organizations have been concerned with timber falling breakage. Although some organizations may have records of breakage volumes, there is yet no existing public information on breakage volumes expressed as percentages of volume felled for cable-assist falling. It was my goal to quantify the amounts of breakage that occur for both conventional and cable-assist falling. In addition, I have sought to identify some of the factors that are important in causing breakage to occur.

The volume of timber breakage incurred during both falling methods, and expressed as percentages of the respective total volumes felled, are shown in Table 9. The table compares both total and sound breakage. Sound breakage being the total volume of breakage minus the volume of "cull" breakage. The figures are also given for "good" ground and for "poor" ground conditions. From examination of the table it can be seen that in all cases more breakage was observed for conventional falling than for cable-assist falling. Total breakage varied from a low of 5.05
Table 9. Percentage of total volume broken during falling.

<table>
<thead>
<tr>
<th>Topographic Class</th>
<th>Falling Method</th>
<th>Conventional</th>
<th>Cable-Assist</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Sound</td>
<td>Total</td>
</tr>
<tr>
<td>Good Ground</td>
<td>6.75</td>
<td>2.55</td>
<td>5.05</td>
</tr>
<tr>
<td>Poor Ground</td>
<td>7.96</td>
<td>5.22</td>
<td>6.79</td>
</tr>
</tbody>
</table>
percent for cable-assist falling on good ground, to a high of 7.96 percent for conventional falling on poor ground.

Following the same pattern, sound breakage varied from a low of 2.29 percent for cable-assist falling on good ground to 5.22 percent for conventional falling on poor ground. As would be expected, breakage increased as ground conditions became more adverse.

By subtracting the appropriate categories of breakage shown in Table 9 for cable-assist falling from those of conventional falling, the percentages of volume saved by cable-assist falling are found. These values are given in Table 10. This table shows that on good ground there was an average of 1.7 percent less total breakage, (breakage saved), for cable-assist falling. For sound breakage, however, this difference was only 0.26 percent.

On poor ground, cable-assist falling reduced total breakage by 1.17 percent, and reduced sound breakage by 1.16 percent. Expressed as a percentage of the actual breakage observed itself, cable-assist falling reduces total breakage by 25 percent on good ground, and 15 percent on poor ground. Sound breakage was reduced by 10 percent on good ground and by 22 percent on poor ground.

The value forgone, or cost of timber breakage for each falling method is shown in Table 11. Only sound breakage is considered. Also note that the entries are identical for conventional falling and for conventional falling with buffer.
Table 10. Volume saved by cable-assist falling.

<table>
<thead>
<tr>
<th>Topographic Class</th>
<th>Percentage of Total Volume Saved</th>
<th>Percentage of Breakage Saved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Sound</td>
</tr>
<tr>
<td>Good Ground</td>
<td>1.70</td>
<td>0.26</td>
</tr>
<tr>
<td>Poor Ground</td>
<td>1.17</td>
<td>1.16</td>
</tr>
</tbody>
</table>
Table 11. Breakage cost comparison.

<table>
<thead>
<tr>
<th>Item</th>
<th>Conventional</th>
<th>Buffer Strip</th>
<th>Cable-Assist</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Sound Breakage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good Ground</td>
<td>2.55%</td>
<td>2.55%</td>
<td>2.29%</td>
</tr>
<tr>
<td>Poor Ground</td>
<td>5.22%</td>
<td>5.22%</td>
<td>4.06%</td>
</tr>
<tr>
<td>Average</td>
<td>3.89%</td>
<td>3.89%</td>
<td>3.18%</td>
</tr>
<tr>
<td>Breakage Value per MBF</td>
<td>$70.00</td>
<td>$70.00</td>
<td>$70.00</td>
</tr>
<tr>
<td>Cost of Breakage per MBF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good Ground</td>
<td>$1.78</td>
<td>$1.78</td>
<td>$1.60</td>
</tr>
<tr>
<td>Poor Ground</td>
<td>$3.65</td>
<td>$3.65</td>
<td>$2.84</td>
</tr>
<tr>
<td>Average</td>
<td>$2.71</td>
<td>$2.71</td>
<td>$2.22</td>
</tr>
</tbody>
</table>
strip. The average stumpage value for breakage of $70 per MBF is assumed for this calculation. Average percentages of breakage, assuming equal amounts of good and poor ground conditions have also been added to this table. These values, as shown, are 3.89 percent for conventional falling, and 3.18 percent for cable-assist falling. By multiplying the quantities of breakage shown by the stumpage value of $70 per MBF, the cost of timber breakage incurred during falling is computed. These values for average ground conditions are $2.71 and $2.22 per MBF for conventional and cable-assist falling methods, respectively.

Timber and Site Factors Affecting Breakage

Stepwise linear regression techniques were used to help identify those factors that were consistently most significant as contributory agents causing timber falling breakage. Characteristics of the individual trees felled, and characteristics of the falling sites were both considered. Tree characteristics investigated included volume, height, diameter, form factor, and defect, as expressed by the defect index. Falling site char-

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8Computer programs which are publicly on file in the OS3 computer system at Oregon State University were used for this analysis.
acteristics included slope percent, and a qualitative rating of the ground conditions. Although a quantitative rating of ground conditions would have been desirable, my log scaling responsibilities and other activities left little time for such investigations. As a result, all variables were evaluated separately for good and poor ground conditions. Regression equations with total breakage as the dependent variable were therefore developed for both conventional and cable-assist falling, and for both good and poor ground conditions.

Small (<500 bd. ft.) trees were found to have great variation in the percentage of total tree volume broken, and breakage was very unpredictable for these trees. While most small trees sustained no breakage whatsoever, occasional trees sustained breakage as high as 50 percent of their total volume. These high values were usually due to breakage within the lower bole area of the tree when large trees fell on them. For this reason I used only trees whose volume was greater than 500 bd. ft. in the regression analysis.

Another complication encountered was that breakage values and characteristics varied between timber species; breakage being higher for Libocedrus decurrens (incense cedar), Thuja plicata (western redcedar), and Abies nobilis (noble fir) than for Tsuga heterophylla (western hemlock) and Pseudotsuga menziesii (Douglas-fir). No differences in breakage character-istics were observed for western hemlock and Douglas-fir and
these were the only species I included in the regression analyses. 
The analysis showed that of those variables investigated, defect 
and volume were consistently the most significant predictive 
variables. Slope, stump diameter and height were also found to be 
important in most cases. The four regression equations with 
brakeage as the dependent variable are shown below.

Conventional Falling, Good Ground $R^2 = 0.48$
Breakage (%) $= -2.49 + 1.57S + 0.424SD - 0.007H - 1.12V - 5.09DI$

Cable-Assist Falling, Good Ground $R^2 = 0.43$
Breakage (%) $= 17.14 - 6.78S - 0.118SD - 0.009H + 0.756V - 7.58DI$

Conventional Falling, Poor Ground $R^2 = 0.37$
Breakage (%) $= 15.16 + 1.25S + 0.070SD - 0.0007H + 0.669V - 14.39DI$

Cable-Assist Falling, Poor Ground $R^2 = 0.29$
Breakage (%) $= 11.67 - 11.62S + 0.280SD - 0.024H - 0.280V - 6.25DI$

$S$ = Slope in percent
$SD$ = Stump diameter in inches, inside bark
$H$ = Tree height in feet to six inch top, or total 
   height if top is larger than six inches
$V$ = Total tree volume, in MBF, Scribner
$DI$ = Defect index. $DI =$ Sound breakage vol. divided 
   by total breakage volume
Examination of the above equations reveals some interesting relationships. For conventional falling, on both good and poor ground, breakage tended to increase as slopes became steeper. This is logical, as when slope steepness increases, trees tend to lean downslope to a greater degree. This forces the fallers to adopt a falling pattern which is not directly on the contour, but is angled down the slope to some extent. This in turn causes the trees to fall through a longer arc, therefore attaining higher velocities by the time they strike the ground. The higher stresses that result cause increased breakage. For cable-assist falling, the effects of slope are reversed. Breakage decreases as slope steepness increases. Of course, with uphill falling the arc that falling trees travel becomes shorter as slope steepness increases. These effects are illustrated in Figure 1. If for example, a tree on a very steep 100 percent slope is felled up the hill, a point on the tree that is 150 feet above the ground falls a distance of 117.8 feet through an arc to the ground.\(^9\) If the same tree were felled directly across the slope

\[ \text{Distance} = \frac{90}{360} \times 2\pi r \]

\[ \theta = \text{the angle between the tree and the ground where it is felled} \]

\[ r = \text{the distance to the height considered} \]
FIGURE 1: -- ARC FOLLOWED BY A TREE UPHILL.
UPHILL FRIED VS. SIDEMILL FRIED

A: UPHILL FRIED
B: SIDEMILL FRIED
it would fall through exactly twice the distance, or 235.6 feet. If felled downslope at an angle of 10° from directly across slope it would fall a distance of 261.8 feet. On a 50% slope, the same point 150 feet above the ground would fall 166 feet when uphill felled.

As was expected, total breakage increased as trees became more defective. This was true for both falling methods and for all ground conditions. This relationship is shown in Figure 2. The linear relationship of breakage to defect index shown in Figure 2 was plotted from values obtained by regressing breakage on defect only.

These regression equations for total defect are:

**Conventional Falling, Poor Ground**

$R^2 = .34$

Percent Breakage = 19.01 - 14.61 x Defect Index*  

**Cable-Assist Falling, Poor Ground**

$R^2 = .18$

Percent Breakage = 16.50 - 12.39 x Defect Index  

**Conventional Falling, Good Ground**

$R^2 = .30$

Percent Breakage = 10.59 - 7.62 x Defect Index  

**Cable-Assist Falling, Good Ground**

$R^2 = .38$

Percent Breakage = 10.53 - 8.84 x Defect Index
FIGURE 2.—PERCENT TOTAL BREAKAGE vs. TREE DEPACT

Conventional, Poor Ground
Cable-Assist, Poor Ground
Conventional, Good Ground
Cable-Assist, Good Ground

DI = Sound Breakage Volume
Total Volume of Breakage

DEPACT INDEX (increasing defect→)
A Defect Index of 1.0 indicates that no call breakage was observed.

As shown in Figure 2, the effects of defect were most pronounced for conventionally felled trees on poor ground. Volume, stump diameter and height variables were interdependent, and the relationship of breakage to these tree size variables is confusing if the percent total breakage equations are examined by themselves. Univariate regression of breakage on volume shows that in all cases, as tree volume increases, so does the total percentage of the tree volume that is broken. The equations are:

Conventional Falling, Poor Ground  $R^2 = .05$
Percent Breakage = 4.77 + 0.577 x Gross Volume (NBF)

Cable-Assist Falling, Poor Ground  $R^2 = .09$
Percent Breakage = 3.43 + 0.688 x Gross Volume (NBF)

Conventional Falling, Good Ground  $R^2 = .11$
Percent Breakage = 3.30 + 0.532 x Gross Volume (F)

Cable-Assist Falling, Good Ground  $R^2 = .12$
Percent Breakage = 1.11 + 0.767 x Gross Volume (NBF)
These relationships of breakage vs. tree volume are illustrated in Figure 3. Figures 2 and 3 should only be used as indications of the general relationships between defect, volume, and breakage. They should not be considered accurate predictive tools of specific breakage values.

**Log Length and Volume Relationships**

Some log lengths are more advantageous to log milling operations than others. The falling crews that I observed were instructed to cut these lengths and to avoid odd lengths whenever possible. While mill requirements varied from one operation to another, logs of long length, such as 40 feet, and 36 feet, or peeler lengths such as 17, 26, and 34 feet were usually requested. However, broken sections of the tree stem, or "breaks", often makes it impossible to cut as many logs of desirable length as would otherwise be produced. For example, if a tree broke at 79 feet above the stump, two forty foot logs could not be produced from this lower section of the tree, which of course would have been more advantageous. If additional breakage has occurred higher in the tree, additional shorter-than-desired logs may result. Although not included as a cost consideration in this analysis, my work has led me into some observations of log length relationships and differences in these relationships for cable-assist and conventional falling.
FIGURE 3. TOTAL PERCENT BREAKAGE
vs. TREE SIZE

<table>
<thead>
<tr>
<th></th>
<th>Poor Ground</th>
<th>Good Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable-Assist</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conventional, Poor Ground
Cable-Assist, Poor Ground
Conventional, Good Ground
Cable-Assist, Good Ground

Individual Tree Volume (Board Feet) vs. Percentage of Total Tree Volume Broken.
Table 12 expresses the averagedistance to the first breakage occurrence (distance between stump and first break) as a percentage of total tree height. These values were based on Douglas-fir and hemlock trees containing at least 500 board feet volume. The table shows that on the average the first break occurs higher in the trees for cable-assist falling than for conventional falling. Also, for both treatments, this distance is greater on good ground than on poor ground. For Cable-assist falling, the distance to the first break was found to be greater by 3.8 percent of the total tree length than for conventional falling, and 2.9 percent greater on poor ground. For a 200 foot tall tree, this represents a distance of 7.6 feet on good ground and 7.8 feet on poor ground. This relationship indicates that there may be significant differences in the frequency distributions of the log lengths that were cut from the trees felled by each falling method.

Table 13 shows the distribution of bolts (logs and broken log sections) that were cut from the trees that I observed for each falling method. The figures shown in this table are standardized. Although the volume sampled for conventional falling was greater by 7.4 percent (845.1 MBF vs. 782.5 MBF), the total linear lengths of the trees felled were 38,197 feet for conventional falling and 38,557 feet for cable-assist falling. This difference is only one percent. (The trees observed for cable-assist falling tended to be somewhat taller, but of lower volume.) Therefore, in order to standardize Table 13, the actual values observed for
Table 12. Average distance from stump to first breakage occurrence divided by average tree height.

<table>
<thead>
<tr>
<th>Topographic Condition</th>
<th>Conventional Falling</th>
<th>Cable-Assist Falling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>0.756</td>
<td>0.794</td>
</tr>
<tr>
<td>Poor</td>
<td>0.672</td>
<td>0.701</td>
</tr>
</tbody>
</table>
Table 13. Distribution of bolts cut from trees of greater than 500 board foot volume.

<table>
<thead>
<tr>
<th>Falling Method</th>
<th>Logs cut from lower 60% of tree</th>
<th>Logs cut from upper 40% of tree</th>
<th>Broken bolts cut from lower 60% of tree</th>
<th>Broken bolts cut from upper 40% of tree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total # of bolts</td>
<td>Average length Feet</td>
<td>Total # of bolts</td>
<td>Average length Feet</td>
</tr>
<tr>
<td>Conventional Falling</td>
<td>629</td>
<td>33.2</td>
<td>461</td>
<td>21.5</td>
</tr>
<tr>
<td>Cable-assist Falling</td>
<td>610</td>
<td>34.9</td>
<td>431</td>
<td>26.3</td>
</tr>
</tbody>
</table>
"number of bolts" were increased for conventional falling by a factor of 1.01 to give the values shown. Also note that in Table 13 the number of logs and the average length of these logs that were cut for each method are divided into categories by position in the tree. I separated the bolts cut from the lower 60% and upper 40% of each individual tree stem so as to identify the bolts that were cut from the lower grade crown area, represented by the upper 40% of the tree.

Examination of Table 13 shows that 629 logs with an average length of 33.2 feet were cut from the lower 60% of the trees for conventional falling. Only 610 logs were cut in cable-assist falling, but their average length was longer by 1.7 feet. As a result, cable-assist falling produced 21,289 linear feet of logs from the lower 60% of the tree stems, while conventional falling produced only 20,883 feet. Cable-assist falling therefore produced 406 more feet of logs. The difference is even greater in the top 40 percent of the trees, where most breakage was observed to occur. Again, conventional falling produced more logs, but they were 4.8 feet shorter on the average. As a result, cable-assist falling produced 1424 more linear feet of logs than did conventional falling.

Examination of broken log bolts shows that conventional falling produced a greater linear length of breakage than did cable-assist falling. Not only were more broken log bolts produced by conventional falling, they also were of longer average
length. The result was that conventional falling produced 327 linear feet more breakage in the lower 60% of the trees than did cable-assist falling. The same relationship was found in the upper 40% of the tree. Conventional falling resulted in 1.26 times as many breaks as did cable-assist falling, and their average length was longer. As a result, cable-assist falling produced 1308 linear feet less breakage in the upper 40% of these trees.

Figures 4 through 7 show the frequency distributions of log and broken log lengths cut from the lower 60% and upper 40% of the trees felled for each falling method. Figure 4 compares logs cut from the lower 60% of the trees stems. From the histograms, it can be observed that log lengths of 17, 26, 32, 34, 40, and 42 feet were most often bucked in the cable-assist method. For conventional falling, lengths of 18, 20, 26, 34, 40, and 42 feet were most often cut. For each treatment these lengths were those which were most desired by the different mills involved. Comparison of the histograms shows that cable-assist falling was able to produce more logs of desirable length, and fewer logs of less desirable length than was conventional falling.

From Figure 5 differences for each method in the frequency distributions of logs cut from the upper 40% of the trees can be compared. Far more short logs resulted from conventional falling. These less desirable short logs generally occurred as a result of
FIGURE 4. - FREQUENCY DISTRIBUTION OF LOGS BY LENGTH, LOWER 60 PERCENT OF TREE
CONVENTIONAL FALLING

CABLE-ASSIST FALLING

BOLT LENGTH (FEET)
FIGURE 5. — FREQUENCY DISTRIBUTION OF LOGS BY LENGTH, UPPER 40 PERCENT OF TREE
CONVENTIONAL FALLING

CABLE-ASSIST FALLING
FIGURE 6. - FREQUENCY DISTRIBUTION OF BROKEN LOG BOLTS BY LENGTH, LOWER 60 PERCENT OF TREE

CONVENTIONAL FALLING

CABLE-ASSIST FALLING

BOLT LENGTH (FEET)
FIGURE 7. - FREQUENCY DISTRIBUTION OF BROKEN LOG BOLTS BY LENGTH, UPPER 40 PERCENT OF TREE
CONVENTIONAL FALLING

BOLT LENGTH (FEET)

CABLE-ASSIST FALLING
being sandwiched in between two breaks, or because they were the remaining length of a longer piece from which a long log of desirable length was cut. The figure also shows that cable-assist falling produced more long logs. These patterns graphically help explain the large difference in average log length of 4.8 feet that is obtained from Table 13.

Figures 6 and 7 show the frequency distributions of broken log bolts. Most of the broken log bolts occurred within the upper 40% of the stems. Figure 6 compares broken log bolts which occurred in the lower 60% of the trees stems. The figures show that conventional falling resulted in more breakage occurrences throughout the distributions. Figure 7 show the distributions of broken log bolts cut from the upper 40% of the trees stems. Again, throughout the distributions, fewer broken log bolts are shown for cable-assist falling than for conventional falling.

Most logs that were shorter than a scaling length of 16 feet were cut only because it was necessary to do so due to the presence of a nearby break. The frequency distributions of the log volumes represented by logs of these less desirable short lengths are shown for conventional and cable-assist falling in Figure 8. The figure shows that in general, a greater volume of short logs was produced by conventional falling. These volumes are shown in Table 14. Also shown are the percentages of the total volume felled that was produced in short logs. Table 14
FIGURE 8. - FREQUENCY DISTRIBUTION OF SHORT LOGS BY VOLUME
(MAXIMUM LENGTH = 15 FEET)

LOG VOLUME (BD. FT.)
<table>
<thead>
<tr>
<th>Item</th>
<th>Cable-Assist Falling</th>
<th>Conventional Falling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total volume in logs of &lt; 16 ft. length</strong></td>
<td>8,070</td>
<td>10,700</td>
</tr>
<tr>
<td><strong>Percentage of total volume felled represented in logs of &lt; 16 ft. length</strong></td>
<td>1.03</td>
<td>1.27</td>
</tr>
<tr>
<td><strong>Total volume in logs of &lt; 12 ft. length</strong></td>
<td>2,906</td>
<td>4,736</td>
</tr>
<tr>
<td><strong>Percentage of total volume felled represented in logs of &lt; 12 ft. length</strong></td>
<td>0.37</td>
<td>0.56</td>
</tr>
</tbody>
</table>
is further broken down to show the volumes for logs of less than 12 feet long. Where marketing standards are not as rigid as those that I used, these values could be used to adjust the scale volumes and percentages that I have reported.

**Total Estimated Costs**

The costs that I have estimated for each of the economic considerations evaluated in this analysis are summarized in Table 15 for each falling treatment, and for the three buffer strip widths examined for the conventional with buffer strip treatment. Of all cases examined, the conventionally felled with 15 foot wide buffer strip treatment was found to have the lowest total cost: $6.12 per MBF. The cost per MBF for the 36 foot wide buffer strip treatment is higher, followed by the costs for the conventional, cable-assist, and 160 foot buffer strip treatments. The cost per MBF for the 15 foot wide buffer strip treatment was less than half that of the 160 foot wide buffer strip treatment. From comparison of the cable-assist and conventional treatments, cable-assist falling is shown to be more expensive by $3.03 per MBF, or 138 percent as expensive as conventional falling.
Table 15. Estimated costs for a hypothetical setting for each falling technique dollars per MBF harvested.

<table>
<thead>
<tr>
<th>Cost Consideration</th>
<th>Conventional Falling</th>
<th>Cable-Assist Falling</th>
<th>Conventional Falling with Buffer Strip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>F -- 15' wide</td>
</tr>
<tr>
<td>Falling Labor and Equipment</td>
<td>$3.33</td>
<td>$8.02</td>
<td>$3.33</td>
</tr>
<tr>
<td>Timber Breakage</td>
<td>$2.71</td>
<td>$2.22</td>
<td>$2.71</td>
</tr>
<tr>
<td>Buffer Strip</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stream Clean-Up</td>
<td>$1.89</td>
<td>$0.72</td>
<td>$0.08</td>
</tr>
<tr>
<td>Total</td>
<td>$7.93</td>
<td>$10.96</td>
<td>$6.12</td>
</tr>
</tbody>
</table>
DISCUSSION AND CONCLUSIONS

Logging residues and the Stream Environment

Logging residues have been shown to have significant chemical, physical, and biological impacts upon the stream environment. The magnitude of the impacts caused by the introduction of logging residues to stream channels is in part dependent upon the quantity of residues introduced. The results of this study demonstrate that streamside vegetative strips effectively provide protection against logging debris introduction to stream channels. The degree of protection was found to increase as width of buffer strip increased. The results indicate that good stream protection can be achieved with buffer strips of widths of less than the 160 foot wide buffer that we observed. In fact, the much narrower 15 and 36 foot wide buffers observed may indeed have provided an adequate degree of protection from logging residues.

Cable-assist directional falling techniques compared to conventional falling have also been shown to significantly reduce the amount of residues that are added to stream channels during falling operations. The observed quantity of debris added to stream channels during cable-assist falling averaged only 30 percent of the average quantity added during conventional falling. This demonstrates that in addition to buffer strips, cable-assist falling can also be an effective stream protection technique.
In addition to those of logging residues, other streamside environmental factors are influenced by timber falling - harvesting methods. Buffer strips are often employed so as to maintain stream shading, and to prevent stream temperature increases. Cable-assist falling by itself cannot provide this protection. Where buffer strips are used, however, the danger of extensive blowdown, with resultant stream environmental impacts, should be considered.

Economic Considerations

Both the environmental and economic implications of any procedure must be considered in order to properly evaluate its utility. The results of this study show for the environmental and economic factors considered, that cable-assist falling has both environmental advantages, and economic disadvantages when compared to conventional falling. The conventional falling with buffer strip treatment has been shown to have environmental advantages, and also may be economically advantageous, depending upon the width and volume of the buffer strip employed. Buffer strips of excessive width may not provide a significantly greater degree of stream protection from logging residues than do more narrow buffers, and are decidedly less advantageous economically.

Throughout this analysis, comparisons were made on the basis of observations that were made in different areas, and under varying circumstances. While efforts were made to take samples under conditions that were as similar as possible, conditions
have varied. As a result, discussion of the economic considerations also warrants discussion of some of the factors that have affected the various cost considerations, and the total economic comparison.

Referring again to Table 15, examination reveals that cable-assist falling incurred much greater falling labor and equipment costs than did conventional falling. This increase of $4.69 per MBF represents an increase of 241 percent. This factor alone more than nullifies the economic savings of reduced timber breakage and stream clean-up costs realized by cable-assist falling.

Production rates, for which falling labor and equipment costs are based, did not vary excessively for the conventional falling crews that I observed. However, the production rate for one of the two cable-assist falling crews that I observed was less than half that of the other observed cable-assist crew. I was able to observe the more productive of these two crews as they were conventionally falling. Their conventional falling production rate was near the mean of production rates of all conventional crews observed. The less productive cable-assist crew simply did not work as hard as the other crews observed. This leads me to believe that the labor and equipment costs that I have reported for cable-assist falling are higher than should normally be observed. I should note, however, that even if production costs for cable-assist falling were based solely upon the more productive
crew, cable-assist production costs would remain higher by over two dollars per MBF, or by at least 60 percent.

In all cases, the falling crews that I observed constantly tried to keep timber breakage to a minimum as they worked. In conventional falling, all trees of any size were wedged over for directional control. For a small portion of my conventional sample, some trees were felled with the aid of a manually operated hydraulic jack. In some instances, stumps were recut at gound level to prevent breakage. The average values of breakage observed for each conventional falling crew did not vary appreciably.

However, my breakage data for the two cable-assist falling crews show that a significant difference in the amount of breakage observed did occur; the crew that had higher production rates also sustained greater breakage. These greater values of breakage are partially attributable to less favorable topographic conditions, and to generally larger and more defective trees. I do believe, however, that some of the increased breakage was incurred as a result of this crew's greater attention to production rates. However, even if breakage costs were based upon the lower values observed for cable-assist falling, the adjustment of breakage costs would not appreciably alter the relative comparison of total costs; the much higher production costs for cable-assist falling overshadows the savings in costs of timber breakage.
Stream channel residues found after falling appeared in the field to be unnecessarily high for the conventional treatment Channel I. More careful falling in this unit could have reduced this volume. The stream clean-up costs shown for conventional falling may therefore be somewhat high relative to those reported for the other techniques.

In the foregoing discussion of the cost components, I have emphasized possible areas of weakness in the data, and that different specific results might be found given more favorable sampling conditions. In self defense, however, I will add that the values that I have reported for production rates, breakage volumes, buffer strip volumes, and quantities of stream residues are based upon actual in-the-field observations. The economic comparison that I have formulated is of course subject to adjustment if the assumptions that I have made are modified.

Conditions Favoring Cable-Assist Falling

From my observations, I have identified what I believe to be the circumstances in which cable-assist falling would be most effective in reducing timber breakage. Cable-assist falling provides additional alternatives to the timber fellers. Even highly defective trees with extensive side or downhill lean can be cable-assist felled uphill, or in any other direction, if enough care and planning is exercised. The more adverse the falling conditions, the more these alternatives become of value. According-
ly, cable-assist falling would be most advantageous under the following circumstances:

1. steep slopes
2. rough, rocky ground
3. where streams or young timber must be avoided
4. in large timber
5. in defective timber

**Additional Work**

There are many factors, both economic and ecologic, that I have not included in this analysis. I should at this point in the discussion bring them to attention. Cable-assist falling may have additional benefits to those that I have discussed. Reduction of timber breakage through use of cable-assist falling may preclude the necessity for slash burning, with resultant economic and environmental benefits. Yarding costs could be lowered for cable-assist felled units for two reasons: For the same amount of volume, fewer but longer logs would be present. (Loading and trucking costs would also be lowered); Due to uphill felling, most logs would lie closer to the landing, in effect producing shorter average yarding distances.

Scaling and grading of all volume felled would be of great advantage. I only included the volume that was actually isolated in bucking as breakage. An experienced scaler would be able to take into consideration the reduction of scale volume, and of
grade that often occurs in logs that lie adjacent to what I have defined as "breaks". I suspect that this inclusion could as much as double the values of breakage that I have reported, with a proportionately greater increase in breakage for conventional falling. This, would of course make the savings in costs of breakage for cable-assist falling more significant. Grading could also allow the percentages of breakage calculations to be based upon the total "net" volume felled ("net" being defined for these purposes as sound or merchantable material).

Consideration of additional factors for units where buffer strips are employed would probably increase the comparative cost of this technique. Additional costs incurred in buffer strip units could include increased yarding costs due to less favorable landing placement and increased roads and landing construction costs. Line moving time increases and resultant increased costs could also be a problem, especially if skyline yarding systems are considered.
In summary, based upon the economic and environmental factors that I have considered, buffer strip widths and volumes do not need to be excessively great to realize environmental benefits, and should not be excessively great if economic benefits are to be realized. Cable-assist falling also has ecologic advantages over conventional falling, but does not provide the degree of stream protection afforded by buffer strips. However, if buffer strips are impractical due to blowdown problems, or if the timber resource base itself is of critical importance, cable-assist falling could be of better advantage. Again, however, the total cost of the cable-assist falling method is significantly higher than that for conventional and conventional with buffer strip treatments, due to increased falling labor and equipment costs. Additional study with inclusion of additional cost considerations could substantially alter the comparative total costs of these three timber falling - harvesting techniques.


APPENDIX A

LOG SCALING PROCEDURES

After each tree is felled, the bucker measures the tree and then cuts it up or "bucks" it into sections for later transfer to the mill. In doing so he also isolates and cuts broken sections and ragged broken ends free of the logs.

Accordingly, for each tree I recorded the length and scaling diameter of each "log" and "break". A log is herein defined as any section of the tree bole with a scaling length of at least 8 feet and that has not been broken to the extent that it cannot be utilized. Breaks, or "broken log bolts", are defined as sections that are so badly broken that they cannot be utilized. Occasional sound sawtimber logs that were reduced to sections suitable only for use as low value chip logs due to defects incurred during falling were also scaled as breaks. I measured the scaling length of logs and breaks with a 50 foot steel loggers tape as the distance between buck cuts (runs) as placed by the bucker. In the case of logs, standard trim allowances for log length were deducted. Scaling diameters (small-end, inside bark) were taken at the runs with a steel tape. Occasionally the bucker would leave a rough broken log end unbucked. In these cases I estimated the point at which the run would have normally been made, and scaled the adjoining log and break accordingly.

Figure A, which follows, clarifies this procedure.
FIGURE A. -- LOG SCALING PROCEDURES

Log a. Scaling length = 40', Scaling diameter = 27''
Log b. Scaling length = 32', Scaling diameter = 23''
Log c. Scaling length = 5', Scaling diameter = 22''
Log d. Scaling length = 26', Scaling diameter = 19''
Break e. Scaling length = 12', Scaling diameter = 17''
Log f. Scaling length = 8', Scaling diameter = 15''
Break g. Scaling length = 9', Scaling diameter = 12''
Log h. Scaling length = 10', Scaling diameter = 12''

1. This section lies beyond the six inch top scaling diameter, and is ignored.
APPENDIX B

CALCULATION OF CABLE-ASSIST LABOR AND MACHINE COSTS

Average cost/man hour for 5 man cable-assist falling crew:
(observed 80% of the time)

1 Faller @ $13.97/hr.
1 Bucker @ $13.97/hr.
2 Tree Climbers @ $8.10/hr.
(Tree climber + assistant who was learning and who also helped mark and buck)
1 Tree-puller Operator @ $6.49/hr.

Average total cost per crew hour = $50.63
Average total cost per man hour = $10.13

Average cost/man hour for 4 man cable-assist falling crew:
(observed 20% of the time)

Computation is the same, except that only 1 tree climber is included.

Average total cost per crew hour = $42.53
Average cost per man hour = $10.63
Average weighted cost per man hour for the cable-assist method
= $10.13 x .80 + $10.63 x .20 = $10.23

Average weighted cost per crew hour
= $50.63 x .80 + $42.53 x .20 = $49.04
Additional equipment necessary for cable-assist falling incurs additional costs for this method. These costs include the actual cost of the tree-pulling machine and the radio system. From information given to me by cooperating logging operators, I have estimated these machine owning and operating costs. They are developed as follows:

Machine Rate for Tree-Puller

Initial Cost: $5000
Life: 10 years (180 days/yr. @ 6 hrs./day)
Residual Value: None
Total Fixed Cost = $5000
= (180 days/yr.) (6 hrs./day) (10 yrs.)
= $0.463/hr.
Operating Costs:
Gas and Oil: $2.20/day
Repairs and Maintenance: $200/yr. = $1.11/day
Total Tree-Puller Operating Cost = $3.31/day = $0.522/hr.

Machine Rate for Radio Control System

Initial Cost: $3000
Life: 5 years (180 days/yr. @ 6 hrs./day)
Residual Value: None
Operating Cost: None
Total Radio System Cost = $3000
= (180 days/yr.) (6 hrs./day) (5 yrs.)
= $0.556/hr.
Total Equipment Cost of Tree Pulling System = $1.571 per hour
Total Labor and Equipment Cost per hour = $50.58
APPENDIX C
STREAM DEBRIS CLEAN-UP COST COMPUTATIONS

Machine Clean-up
Conventional falling with buffer strip

Channel F
Machine clean-up cost = cost/ton x tons of coarse debris/station
= $2.78/ton x 1.7 tons/station = $4.72/station
Cost for standard 13.2 station setting
= $4.72/station x 13.2 stations = $62

Channel L
(same as Channel F)

Channel N
Machine clean-up cost = cost/ton x tons of coarse debris/station
= $2.78/ton x 0.025 tons/station = $0.07/station
$0.07/station x 13.2 stations = $0.90
This cost is so low that I will use a cost of $0.00 in the analysis.

Hand Clean-up
Conventional falling
Average conventional treatment hand cleaning cost = $300/station
The cost per unit stream debris is calculated as:

\[
\text{\$300/station \over 11.6 \text{ tons/station}} = \text{\$25.86/ton of stream debris}
\]

Cost for standard 13.2 station setting =
\[
\text{\$300/station} \times 13.2 \text{ stations} = \text{\$3,960}
\]
This unit cost of \$25.86 per ton of stream debris is then applied to all treatments.

Cable-assist falling

Hand clean-up cost = cost per ton x tons of debris per station
\[
= \text{\$25.86/ton} \times 4.50 \text{ tons/station} = \text{\$116.37/station}
\]
Cost per standard 13.2 station setting =
\[
\text{\$116.37/station} \times 13.2 \text{ stations} = \text{\$1,536}
\]

Conventional falling with buffer strip

Channel F

Hand clean-up cost = cost per ton x tons of debris per station
\[
= \text{\$25.86/ton} \times 0.51 \text{ tons/station} = \text{\$13.19/station}
\]
Cost per standard 13.2 station setting =
\[
\text{\$13.19/station} \times 13.2 \text{ stations} = \text{\$174}
\]

Channel L

Hand clean-up cost = cost per ton x tons of debris per station
\[
= \text{\$25.86/ton} \times 1.20 \text{ tons/station} = \text{\$31.03/station}
\]
Cost per standard 13.2 station setting =
\[
\text{\$31.03/station} \times 13.2 \text{ stations} = \text{\$410}
\]
Channel N

Hand clean-up cost = cost per ton x tons of debris per station
= $25.86/ton x 0.01 tons/station = $0.26/station

Cost per standard 13.2 station setting =
$0.26/station x 13.2 stations = $3.41

This cost is so minimal that I have considered it to be zero.
APPENDIX D: PHOTOGRAPHS
FIGURE B. - LARGE ACCUMULATION OF DEBRIS IN STREAM CHANNEL FOLLOWING CONVENTIONAL FALLING.
FIGURE C. - HEAVY CONCENTRATION OF DEBRIS REMAINING IN STREAM CHANNEL FOLLOWING YARDING.
FIGURE D. - LOGGING RESIDUES REMAINING IN CONVENTIONALLY FELLED UNIT FOLLOWING HIGH LEAD YARDING. NOTE LARGE LOG BROKEN OVER STUMP IN FOREGROUND.
FIGURE E. - POTENTIALLY HAZARDOUS STREAM DEBRIS CONCENTRATION CAUSED BY WINDTHROW FROM AN ADJACENT 50 FOOT WIDE BUFFER STRIP.
FIGURE F. - TREE CLIMBER PREPARING TO CLimb TREE AND ATTACH LINE FOR CABLE-ASSIST FALLING. NOTE TIMBER IN BACKGROUND FELLED UPSLOPE.
FIGURE G. - FALLER CUTTING A STUMP OFF FLUSH TO GROUND. THIS TECHNIQUE WAS OBSERVED TO BE OF SOME SUCCESS IN PREVENTING BREAKAGE.