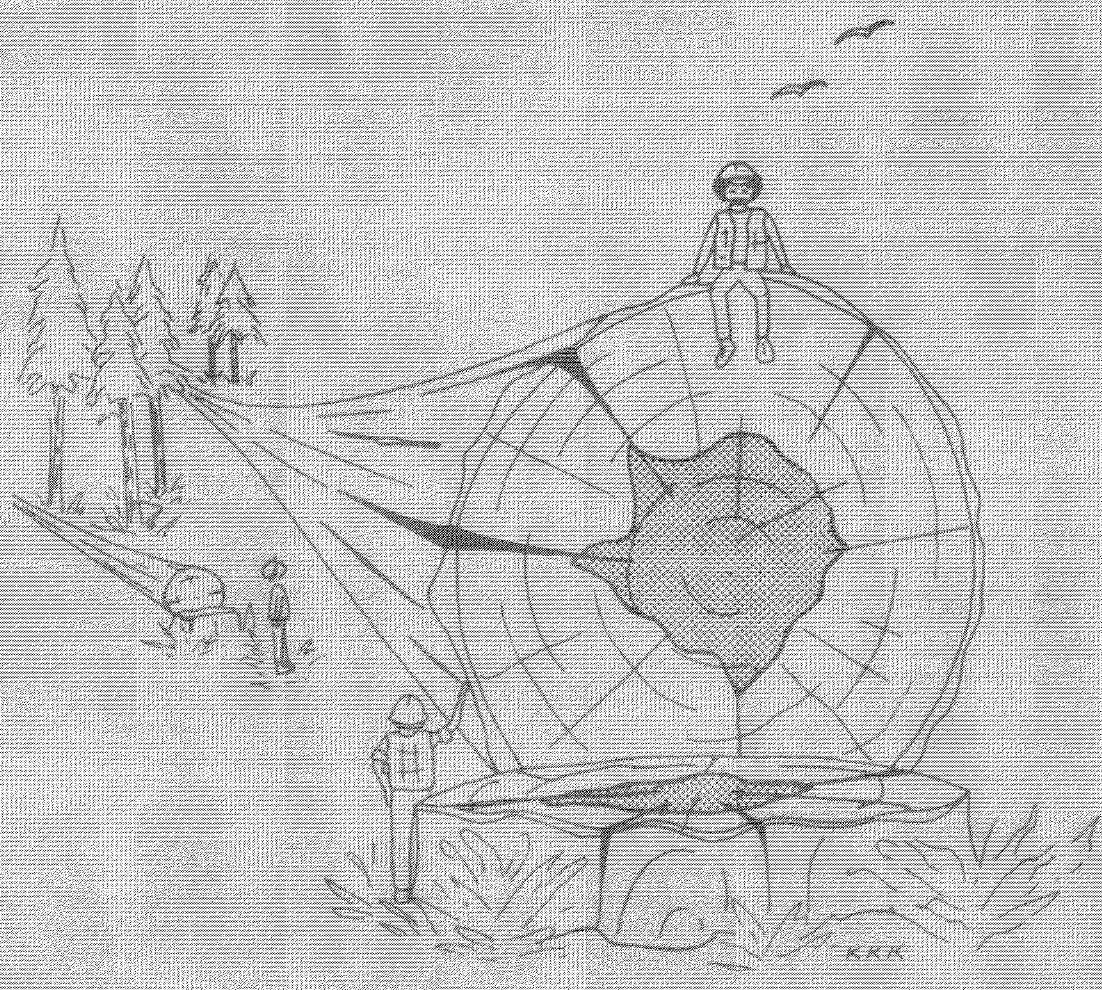
FERIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

DIRECTIONAL FELLING OF LARGE OLD-GROWTH CEDAR TREES

D.Y. GUIMIER

TECHNICAL REPORT NO. TR-43
JULY 1980



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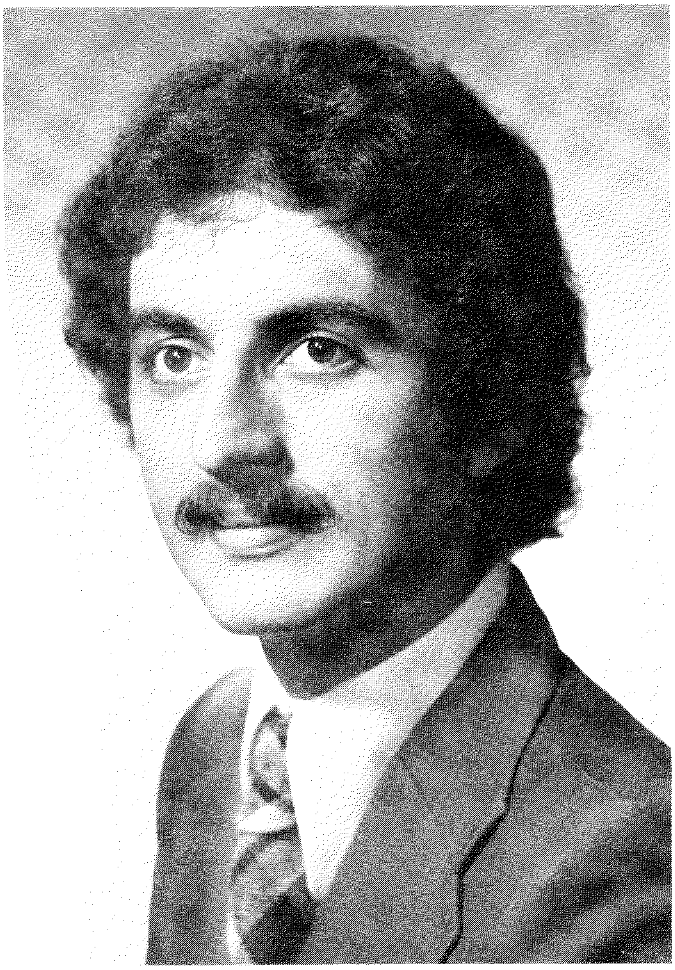
FOREWORD

This report presents the research done by FERIC on the problem of felling breakage of large old-growth Western red cedar during the period of 1977 to 1979. The research work was divided into four phases and an interim report was published at the completion of each phase. The interim reports present the data summarized in this report in greater detail and are available to anyone wishing them.

The author acknowledges the work of Mr. D. Moulson, project leader for the study during Phase I and Mr. B. Sauder, project leader for Phase II. Mr. K. Hallberg and Mr. J. Ulinder participated actively in the field work and provided invaluable practical expertise. The author is grateful to them for their help.

Three divisions of MacMillan Bloedel--Kennedy Lake, Sarita and Menzies Bay--were directly involved in the study. The author thanks the many individuals from those divisions who cooperated in this study. The patience and cooperation of Mr. W. Horsman, faller at Sarita Division, is specially acknowledged.

The author is also grateful to all FERIC personnel involved in this study.



Daniel Y. Guimier graduated as a mechanical engineer in 1975 from the École Nationale Supérieure des Arts et Métiers in France. He then enrolled in a graduate program at the Faculty of Forestry of the University of British Columbia and obtained a M.A.Sc. degree in 1977. In September 1977 he joined FERIC to work on logging equipment design and development.

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ABSTRACT

In 1977 FERIC began to investigate the problem of cedar breakage from conventional felling. Prices had become higher for Western red cedar logs than for Douglas-fir peeler grade, and logging companies were renewing efforts to reduce waste from conventional felling in stands of old-growth Western red cedar. In one case studied, FERIC estimated potential savings of \$36.80/cunit (\$13.00/m^3) if felling breakage could be eliminated. Although FERIC's research was aimed at minimizing cedar breakage losses, some of the results also apply to species other than cedar, and to felling large trees close to fish streams or areas of forest regeneration.

FERIC's solution to the problem of cedar breakage is a combination of directional felling and banding. Jacking and pulling are two methods for directionally felling large trees uphill. Pulling cedar is performed by a three-man crew using a tree-pulling machine with a 10-ton (9-tonne) pulling capacity at bare drum. Cedar trees can be easily rigged using a line-throwing gun. Jacking can also be used to fell small cedars and trees of other species uphill if the lean is not excessive and the stump is sound. Banding should be used only for trees with large potential savings and obvious signs of internal decay.

A comparison study showed that the cost of directional felling was two or three times greater than the cost of conventional felling, but a 7.5% increase in the volume recovered--combined with improved log quality--gave directional felling a slight economic advantage. There were other advantages in addition to the increase in volume recovery and wood quality. Tree pulling is safer than conventional felling, and directional felling increases the number of logs bucked at preferred lengths, reduces the amount of debris left on the setting, and permits logging trees along fish streams without environmental disturbance.

Even if directional felling of a whole setting is not warranted, loggers should still consider the potential savings of directionally felling individual valuable trees which would otherwise be destroyed, especially if these trees are close to the road.

RÉSUMÉ

En 1977, FERIC entreprit l'étude du problème de la cassure des cèdres, problème courant lorsqu'on emploie les méthodes traditionelles d'abattage. Les prix de vente de billes de cèdre de l'ouest étaient devenus plus élevés que ceux des billes de déroulage de sapin de Douglas, et les compagnies forestières redoublaient leurs efforts en vue de réduire les pertes encourues lors de l'abattage dans des peuplements surannés de cèdre de l'ouest. Dans un des cas étudiés, FERIC évalua à \$36.80/cunit (\$13.00/m^3) les économies possibles, si on réussissait à éliminer complètement les cassures dues à l'abattage. Bien que les recherches de FERIC aient visé à trouver des méthodes d'abattage plus économiques pour des cèdres surannés, certains des résultats peuvent s'appliquer aux problèmes communs à l'abattage de gros arbres sur des pentes ou à l'écart des cours d'eau poissoneux et des aires de régénération.

La solution de FERIC au problème de la cassure du cèdre combine l'abattage directionnel et le ceinturage. On peut diriger la chute de gros arbres vers le haut d'une pente, au moment de l'abattage, en les soulevant ou en les tirant. Le tirage se fait à l'aide d'une équipe de 3 hommes et d'un treuil ayant une traction à tambour nu de 10 tonnes (9 tonnes métriques). Les cèdres peuvent être facilement amarrés au moyen d'un fusil lance-câble. Dans le cas de cèdres de petit diamètre ou autres essences, on peut les soulever avec un vérin hydraulique si leur inclinaison n'est pas trop forte et si la souche est saine. Le ceinturage ne devrait être utilisé que pour des arbres offrant la possibilité d'économies importantes et montrant des signes évidents de carie interne.

Une étude comparative a démontré que le coût de l'abattage directionnel était de deux à trois fois plus élevé que celui de l'abattage traditionnel; par contre l'augmentation de 7.5% du volume récupéré (jointe à une meilleure qualité des billes) offre un avantage économique léger dans le cas de l'abattage directionnel. En plus ce dernier favorisait le tronçonnage d'un plus grand nombre de billes aux longueurs désignées, réduisait les quantités de déchets laissés sur coupe et permettait l'exploitation des arbres le long de cours d'eau poissoneux sans entraîner de détérioration de l'environnement. Mentionnons également que le tirage des arbres présente beaucoup plus de sécurité que l'abattage traditionnel.

Même si l'abattage directionnel d'un chantier complet n'est pas toujours économiquement possible les forestiers devraient considérer la possibilité de gains importants pouvant résulter de l'abattage directionnel de certains gros arbres sains et proches de la route qui autrement seraient détruis.

INTRODUCTION

Felling large trees on steep and rugged terrain is a daily challenge to the hand-fallers of coastal British Columbia. No matter how expert, conventional tree-falling methods still result in a high percentage of breakage and log value losses in some coastal settings.

Felling breakage has always been considered inevitable, and measures to reduce it too costly. The price for Western red cedar logs is higher now than for Douglas-fir peeler grade, however, and the logger has a new incentive to reduce waste in stands of old-growth Western red cedar. In 1977, FERIC was asked to study the problem.

FERIC Study Objectives

FERIC's objectives were to assess the economic significance of breakage from conventional felling, to review previous techniques used in other places, to evaluate current techniques for reducing felling losses in large cedars, and to propose a practical solution to the problem of felling breakage.

Breakage Reduction Could Yield $15,000,000 Annually

Hedin (1978) indicated that trees over 41-in. dbh (104-cm dbh) on slopes greater than 20% make up a net volume of over 39 million cunits (110 million m^3)--and this applies only to B.C. coastal cedar types. This is equivalent to a cut of 1 million cunits (2.8 million m^3) each year over 39 years--or a total log value of $150,000,000 at current log prices ($150/cunit, $53/$m^3$). A 10% reduction in felling breakage would yield $15,000,000 annually.

Typical Tree Studied

The Western red cedar shown in Figure A is typical of the trees we studied. It is overmature with evidence of extensive rot. It has a heavy cathedral top of large dry branches. It has a dbh of 88 in. (224 cm), a height of 155 ft (47 m), a volume of 15 cunits (42 m^3), and it weighs

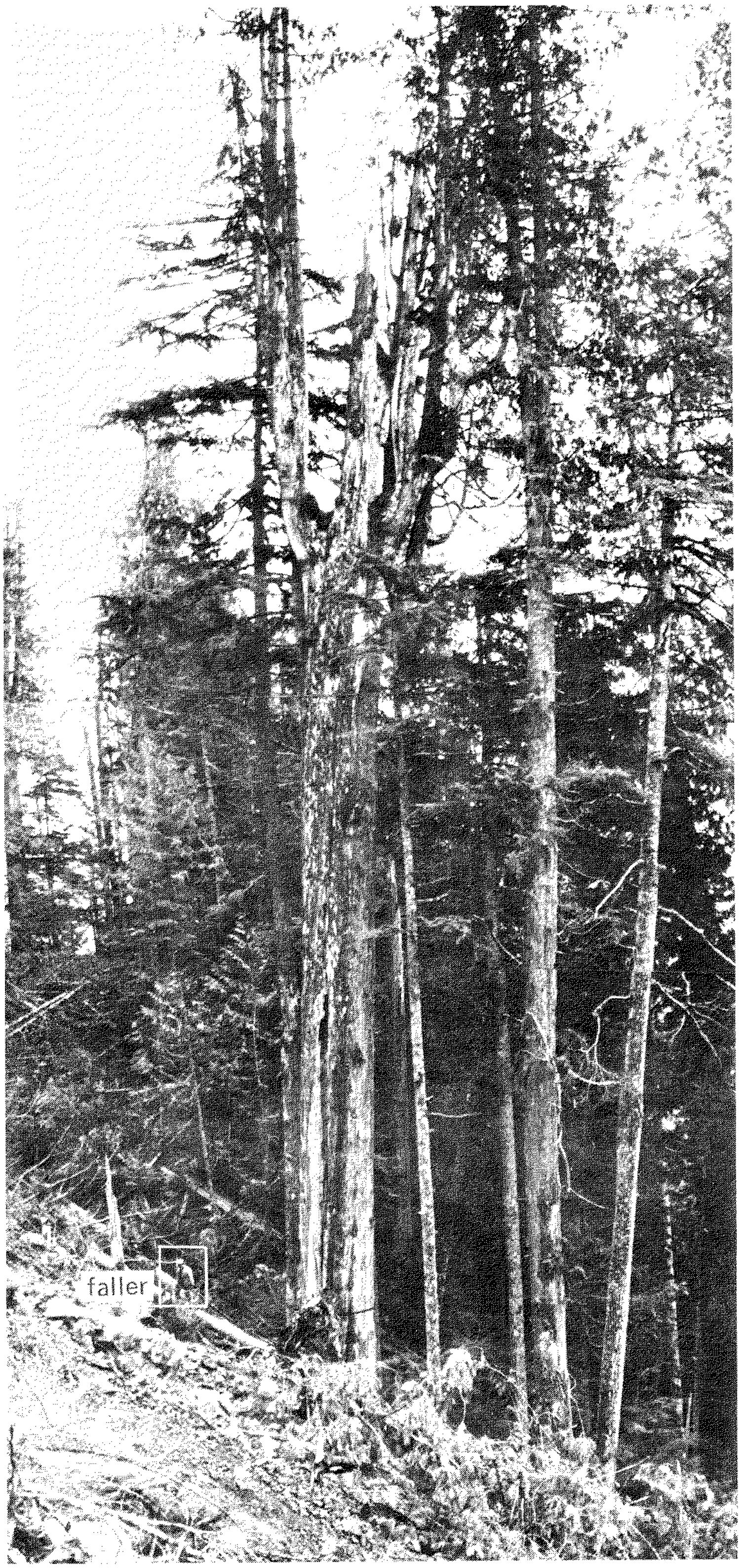

FIGURE A. Large Western red cedar

about 60,000 lb (30 t). Most trees growing on slopes lean downhill toward the light. The cedar shown in Figure A leans 7° down the slope and its top is offset 19 ft (6 m) horizontally from the base. Western red cedar wood is soft and breaks easily, especially in overmature trees.

Conventional hand-falling with a chainsaw requires that such trees be felled in the direction of the lean (generally downhill) because of the brashness of the holding wood and the lack of stump support. The combination of rot, large size and broken terrain below would lead to heavy breakage if this tree were conventionally felled downhill.

Literature Reviewed

Only one report dealt with the particular problem of old-growth cedar-felling breakage (Rocke 1974). Rocke describes a trial made at the Kennedy Lake Division of MacMillan Bloedel to minimize the splitting and slabbing of cedar logs by banding the butts of the trees before felling. The test showed that banding the butts reduced the percentage of slabbed logs but it made no definite recommendations on the economic feasibility of a banding operation.

Other reports describe methods for reducing felling breakage in Douglas-fir or California redwood. Potter (1979) describes a timber-jacking experiment done in a Douglas-fir stand on Vancouver Island. In his analysis he shows that the net value recovered from the stand by jacking the trees was increased by only 1.8 percent. In a similar study Groben (1976) finds a much higher increase (5.8%).

Burwell (1971, 1972) describes work done in tree pulling. His reports give the methodology, advantages and disadvantages of uphill pulling at Rosboro Lumber Company in Oregon. Hirt (1978) describes a similar operation in California. Both authors agree that the advantages of tree pulling outweigh its drawbacks and that using a tree puller for nearly every tree on a high-value setting is economical in their particular areas.

PRELIMINARY EVALUATION OF FELLING BREAKAGE LOSSES

In May 1977, FERIC undertook its first evaluation of the problem of cedar breakage at the Kennedy Lake Division of MacMillan Bloedel on the West coast of Vancouver Island (Moulson 1977). The objective of this first study was to evaluate the breakage losses caused by felling on a sample of large cedar trees and estimate the potential saving that could be made if felling breakage could be eliminated. The results were used to determine if any effort should be made to reduce breakage and if so, how much. This first study also showed the technical problems involved in felling large cedar trees on rugged terrain; this awareness of the problem led toward solutions that were practical and easy to apply in the woods.

A typical high value stand of cedar was selected at Kennedy Lake and 20 typical large cedars were chosen in that stand for the test (minimum 55 in. dbh (140 cm) with no unusual defects). Table 1 shows the characteristics of this sample. After all data were recorded for the standing trees, the trees were free-felled and bucked. The logs were then scaled and graded and the breakage recorded. The averages per tree are shown in Table 2 with June 1977 dollar values calculated for net volume after deductions for decay alone, deductions for breakage, and deductions for losses from degrade. The volume of breakage averages 24% of the total potential volume. In addition to the straight breakage loss in wood volume, another loss comes from the degrade of the logs because of splits and other damage. The combined loss from breakage amounts to $460 for the average tree or 22% of the tree's potential value. The potential saving per net cunit is $36.80 ($13.00 per m^3). A special felling technique that would reduce breakage to one-third its present average would be economical if it did not cost more than $307 per tree to implement. This sum represents a faller's wage for about 2 days.

These figures refer to the average tree and do not give a complete picture of the results for individual trees. In fact, the potential saving on the 20 trees actually studied ranged from $1 per cunit to $64 per cunit ($0.35 to $22.60 per m^3). The benefit from using a special technique to fell these trees and reduce breakage will therefore vary greatly from tree to tree. A careful evaluation of the potential

TABLE 1. Characteristics of the 20 Trees in the Kennedy Lake Sample

	Smallest Tree	Average Tree	Largest Tree
dbh (inch) (cm)	55 140	85 216	159 404
Height (feet) (m)	159 48	175 53	198 60
Gross Volume (cunits) (m^3)	7.6 21.5	19.5 55.2	47.7 135.1

TABLE 2. Average Volumes and Values per Tree Kennedy Lake Sample

	A V E R A G E			
	Volume		Dollar Value	
	Cunit	m^3		
Gross	19.5	55.2	-	
Decay	3	8.5	-	
Potential Volume	16.5	46.7	$2,110	
Breakage	4	11.3	$390	
Degrade	-	-	$70	
Net Volume	12.5	35.4	$1,650	
Potential Saving:				
Total	-	-	$460	
Per Net Cunit (per m^3)	-	-	$36.80	($13.00)

savings should be done for each tree before any special felling technique is selected.

After the Kennedy Lake test, several possible solutions to the problem of breakage were proposed. Tree lowering and directional felling were the two techniques that presented the greatest practical and economic potential. Before they were tried in the woods these two techniques were simulated, as described in the next section.

THEORETICAL INVESTIGATION

To better understand the mechanics of the falling tree we calculated its falling speed and its ground impact energy and tested how speed and energy were affected when the tree was lowered or pulled.

The simulation of tree falling used is a basic application of the general principles of mechanics to a tree defined by its physical characteristics. This simulation is described in more detail in FERIC TR-42 (Guimier 1980). In this section all results are given for the tree shown in Figure A.

The simulation shows that an enormous amount of energy is released as a large tree falls. During the fall the potential energy available in a standing tree is transformed into about 80% kinetic energy and 20% air friction losses. (The amount of friction depends on the crown size and shape.) In theory the tree shown in Figure A will hit level ground with an angular velocity of 43^{o} per second. This corresponds to a linear speed of 26 mph (42 km/h) for a point 50 ft (15 m) up the tree and a speed of 80 mph (129 km/h) at the tree top. The kinetic energy accumulated just before the tree hits the ground was calculated as 4 450 kilojoules; this kinetic energy is a measure of the impact force and consequently of the amount of felling breakage. The key to reducing breakage is to reduce the kinetic energy (or the falling speed) on impact.

One technique used to reduce felling breakage is to direct trees uphill with a line and winch or with a hydraulic jack. Uphill falling reduces the impact of the tree on the ground by reducing the arc through which the tree accumulates speed and kinetic energy. The simulation was used to evaluate the effects of uphill falling. Figure B shows how much the impact energy varies for the same tree felled on level ground, downhill or uphill. The graph shows that a tree felled straight downhill on a 60% slope hits the ground more than twice as hard as if it were felled uphill on the same slope.

Another way of reducing the falling speed would be to lower the tree to the ground with a powerful winch. The simulation was used to determine the size of winch required to ease down the tree shown in Figure A. We assumed that the energy of impact had to be reduced by half to create a noticeable reduction in the amount of breakage and to be roughly equivalent to tree pulling. This meant that the falling speed had to be reduced by about 30 percent. The winch had then to absorb 2 250 kilojoules in a very short time (20 sec) and therefore had to have a braking power of over 300 hp (225 kW). This describes a very large machine. The technique is also further complicated by the need to rig a heavy line on the tree to lower it. Because the uphill-felling technique appeared to be easier to implement than tree-lowering, it was decided to experiment with it in the field.

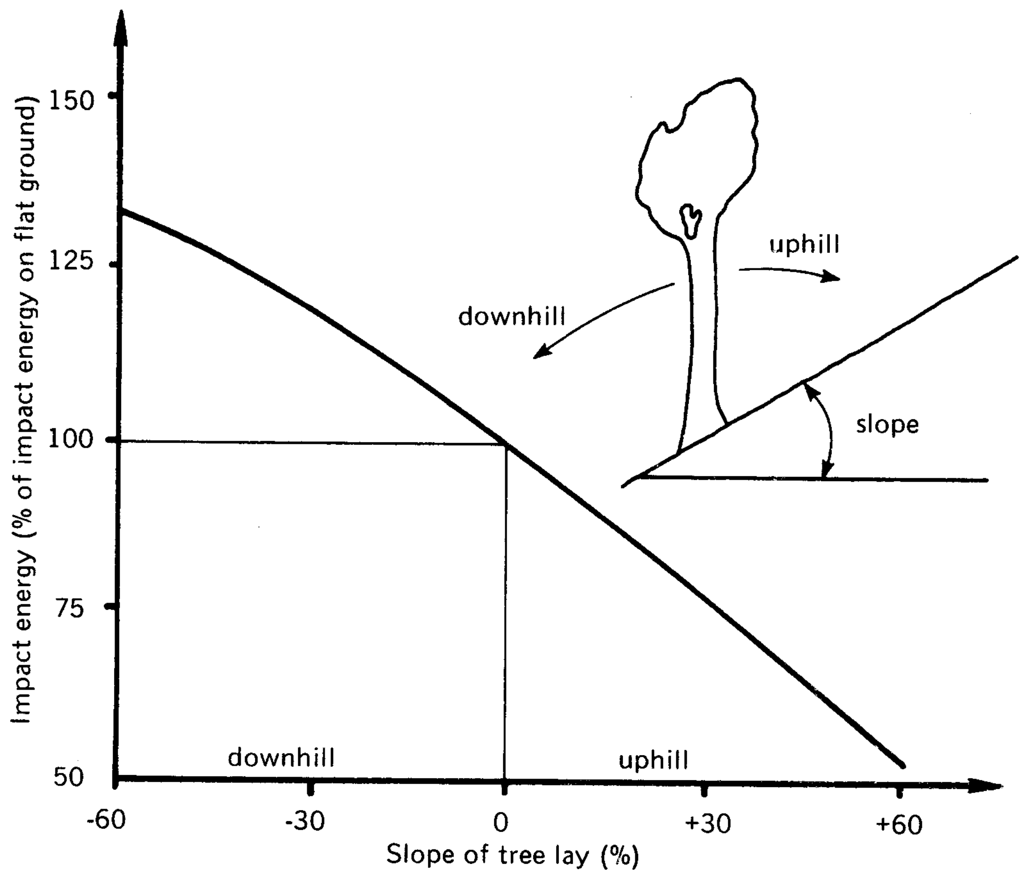

FIGURE B. Falling impact variation with slope of tree lay

FIELD TRIALS

The first trials took place at the Sarita Division of MacMillan Bloedel in September 1977 (Sauder 1977). During that test six trees were pulled over with a cable and a line horse (Figure C) and one tree was jacked with a hydraulic ram. The butts of two of the trees were also banded with strong steel strapping before the trees were pulled. This additional measure to reduce breakage will be referred to as "banding" in this report.

FIGURE C. Line horse used as tree puller

Two of the trees felled grew beside a deep canyon and leaned heavily into it. Uncontrolled felling of those trees would have resulted in severe losses in wood value. All seven trees were located on the lower edge of the road right-of-way and were directionally felled toward the road. All the logs were close to the road and could be easily and inexpensively "cherry-picked." The estimated profits from the improved quality and increased volume--combined with the low yarding cost--were substantial.

The test showed the feasibility of banding and tree-pulling, and also of jacking--provided the cedar tree butt was free of rot and the lean moderate.

The next step after the initial trials was to improve the banding and tree-pulling experimental procedures and apply the techniques in an actual logging operation. We also needed to make a study of the economic viability of directional felling and banding as part of the log production system. This part of the study took place again at the Sarita Division of MacMillan Bloedel (Guimier 1978). It consisted of a comparison test between conventional free-felling and directional felling in two similar and adjacent settings.

TREE-PULLING TECHNIQUE (BASED ON THE SARITA EXPERIMENTS)

SETTING LAYOUT

The timber type, volume and quality, the general topography of the area, and the layout of the setting are important factors to consider before pulling a setting. A ground slope of 30% to 90% is ideal. Little reduction in the speed of the tree at ground impact (and therefore of the felling breakage) is achieved by felling the tree uphill on slopes less than 30 percent. It may still be desirable to direct trees away from local rock outcrops, streams and gullies, however, even when the overall slope is moderate. Directionally-felled trees have a tendency to slide downhill on slopes over 90%, creating secondary breakage and jeopardizing the faller's safety.

The tree-pulling setting should be below rather than above a road. The tree puller can then be anchored on that road and the cable easily rigged for a direct pull uphill on the tree. If trees above the road must be pulled, the cable can be led uphill through one or more blocks, and then downhill to the tree, but this is time-consuming and costly.

The distance from the tree puller to the trees is generally limited to a maximum of 1,500 ft (450 m). The shorter this distance, the easier the rigging process.

The felling pattern differs from that used for conventional felling. Figure D is a sketch of a typical setting being pulled. The area is steep and broken by a gully between two ridges, as indicated by the contour lines. The tree puller is on the road above the setting. The proper felling procedure is to start felling the trees at the bottom of the gully along the roadside and open a corridor down to the lower boundary of the setting, then come back to the road and start to work down again, pulling trees along the felling face until all trees are felled up to the ridge top, then come back to the bottom of the gully, and, using the same felling pattern, start pulling the other side.

This procedure reduces the risk of accident from rolling logs. Falling trees will not break the limbs of standing timber and create widow-makers or brush up the bases of the trees still to be felled. While the tree is being pulled

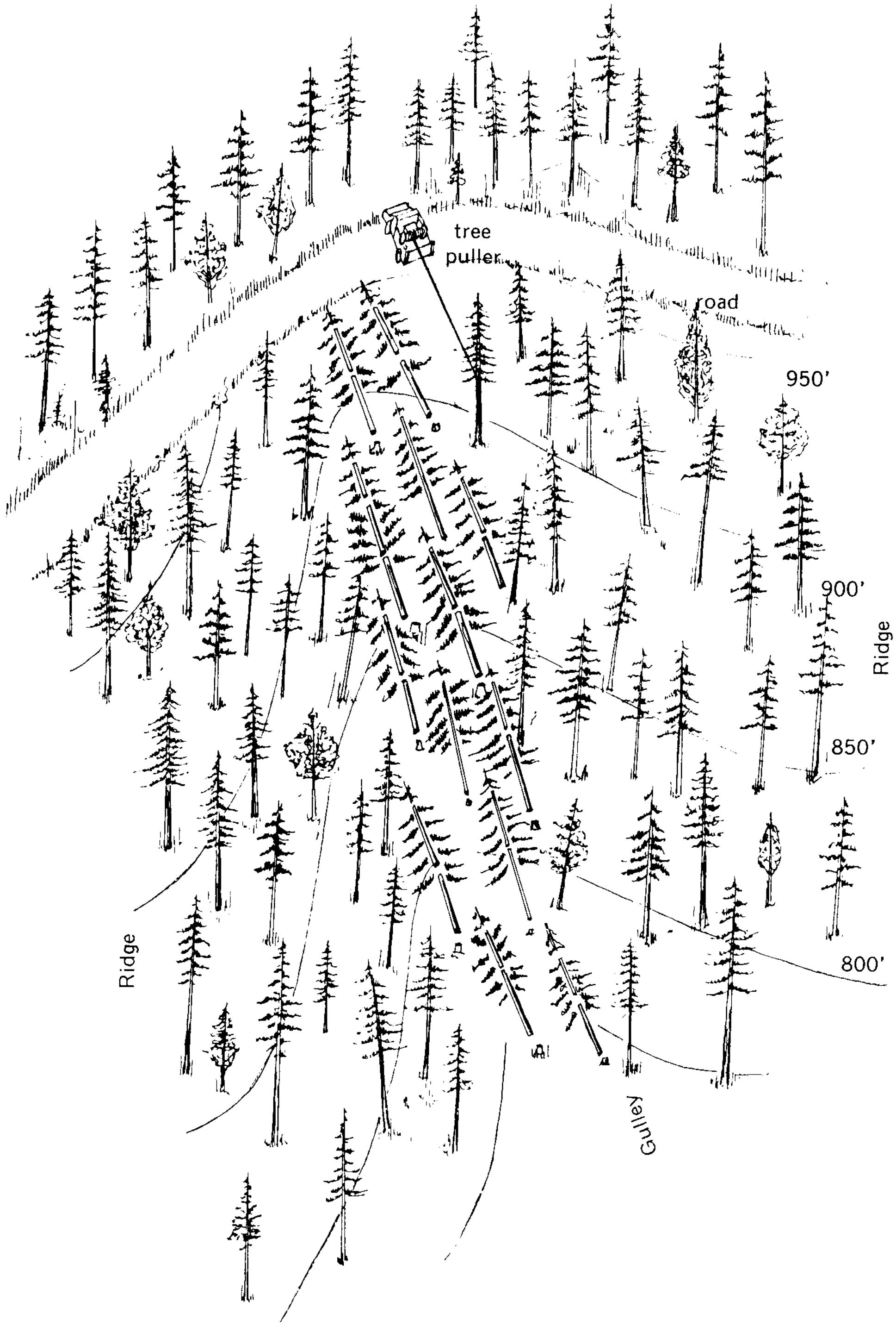

FIGURE D. Sketch of setting being pulled the crew is safe in the standing timber. If the felling direction is slightly off the straight uphill direction very few trees will run away downhill (Figure E).

FIGURE E. Trees pulled remain at the stump after felling

Tree-Pulling Crew

A 3-man crew is required in a tree-pulling operation: a faller, a rigger and a winch operator. The faller does the falling and bucking. He also directs the whole operation. He decides which trees should be pulled, in what order and in which direction. For his own safety and the safety of the other members of the crew, he makes sure that the tree is properly rigged and decides how much pull he requires while he cuts the tree. He also decides how much holding wood should be left. When the tree is ready to be pulled and everyone is in the clear, he gives the signal to pull the tree over. The rigger's job is to spool the cable from the tree-puller winch and secure it to the tree at the height required. To do this the rigger can either climb the tree, use a ladder or pike-pole, or shoot the line with the line-throwing gun described later. The winch operator assists him on the ground and also controls the tree puller. Portable radios are used for communication between the faller and rigger at the stump and the winch operator.

Tree Puller

A tree puller consists basically of a winch mounted on a carrier. The tree puller shown in Figure F (built after the Sarita experiment was completed) has a 2-drum winch powered by a 1200-cc Toyota engine and a 2-speed automatic transmission. The winch engine develops approximately 64 hp and through reduction gearing can generate in excess of 10-tonne pull on the line at bare drum. The unit installed on a single-axle dual-wheel truck weighs a total of 6.5 tonnes. It is anchored for pulling using the backing plates shown in Figure G.

The following tree-puller characteristics would be suitable in most areas of coastal British Columbia.

<u>Winch and cables</u>

pulling capacity	:	10 t at bare drum
line speed	:	1 ft/s (0.3 m/s) at the maximum pull required
winch acceleration	:	to 3 ft/s (1 m/s) to keep up with the tree once it starts moving
power plant	:	70-80 hp engine
transmission	:	hydraulic or mechanical with a torque converter
drum capacity	:	800 ft (270 m) of 5/8-in. (16-mm) line
rigging line	:	(used as a bridle around the tree) 120 ft (40 m) of 7/16-in. (11-mm) or 3/8-in. (10-mm) cable with pressed eyes at each end
efficient brakes	:	on winch to keep pre-tension during cut

FIGURE F. Tree puller

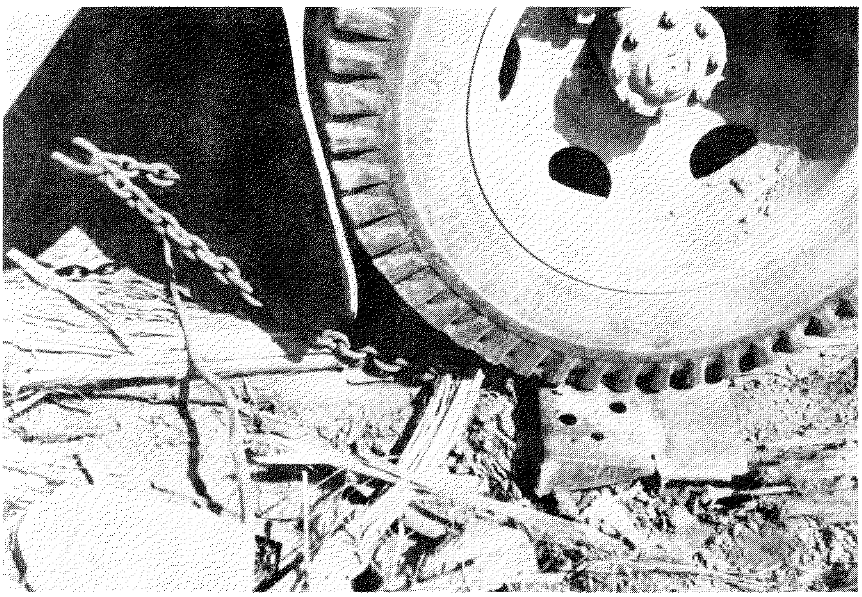

FIGURE G. Back wheels of tree puller anchored on backing plates

free-spooling drum	:	for ease of manual line-pulling
fairlead	:	in front of tree puller to help spool the line evenly and permit angle lead

<u>Carrier</u>

- light truck (12,000 lb or 6 000 kg G.V.W.) easily and quickly moved over long distances
- easy to manoeuvre in tight areas
- anchoring cable in the front
- backing plates under the back wheels
- cab with good visibility, protection, comfort and easy entry and exit

LINE-PULL AND RIGGING HEIGHT

The pulling cable should be strong enough to pull the heaviest tree of the setting uphill from a downhill lean, and do it safely. A 5/8-in. (16-mm) pulling cable is more than adequate (safety factor of 3) for the large cedars of coastal British Columbia. Smaller lines can be used (9/16 in. or 1/2 in.) (14 mm or 13 mm) but the margin of safety when pulling big trees is reduced. For a rigging cable used as a bridle around the tree, a 7/16-in. or 3/8-in. (11-mm or 10-mm) line is normally strong enough and is also easy to handle. The sizes of the cables should roughly match the available pull-power of the winch. The force (tension in the cable) required to pull a tree depends on the tree size, the amount of adverse lean and the height at which the cable is rigged on the tree. The higher the cable is attached, the more leverage one has to pull it and therefore the less the required tension in the pulling cable. A theoretical formula developed to calculate the line pull was confirmed by a FERIC test with the Menzies Bay Division of MacMillan Bloedel (Guimier, et al., 1979). From this test, nomograms were drawn for different species to help the rigger determine how high he should attach the cable to a tree to pull it over safely for a given tree size, machine characteristics and cable sizes. A nomogram is presented in Figures H and I for Western red cedar and its use explained with the following example:

Assume that the tree puller can pull 12,000 lb (5.5 tonnes) and is equipped with a 5/8-in. (16-mm) cable. The cedar to be pulled has a dbh of 80 in. (203 cm) and leans 4^{o} back (6% back lean). How high should the cable be attached to pull the tree over against the lean?

Using the nomogram (Figure H or Figure I) with the given characteristics of the tree and the machine, the cable should be rigged to a minimum height of 25 ft (8 m).

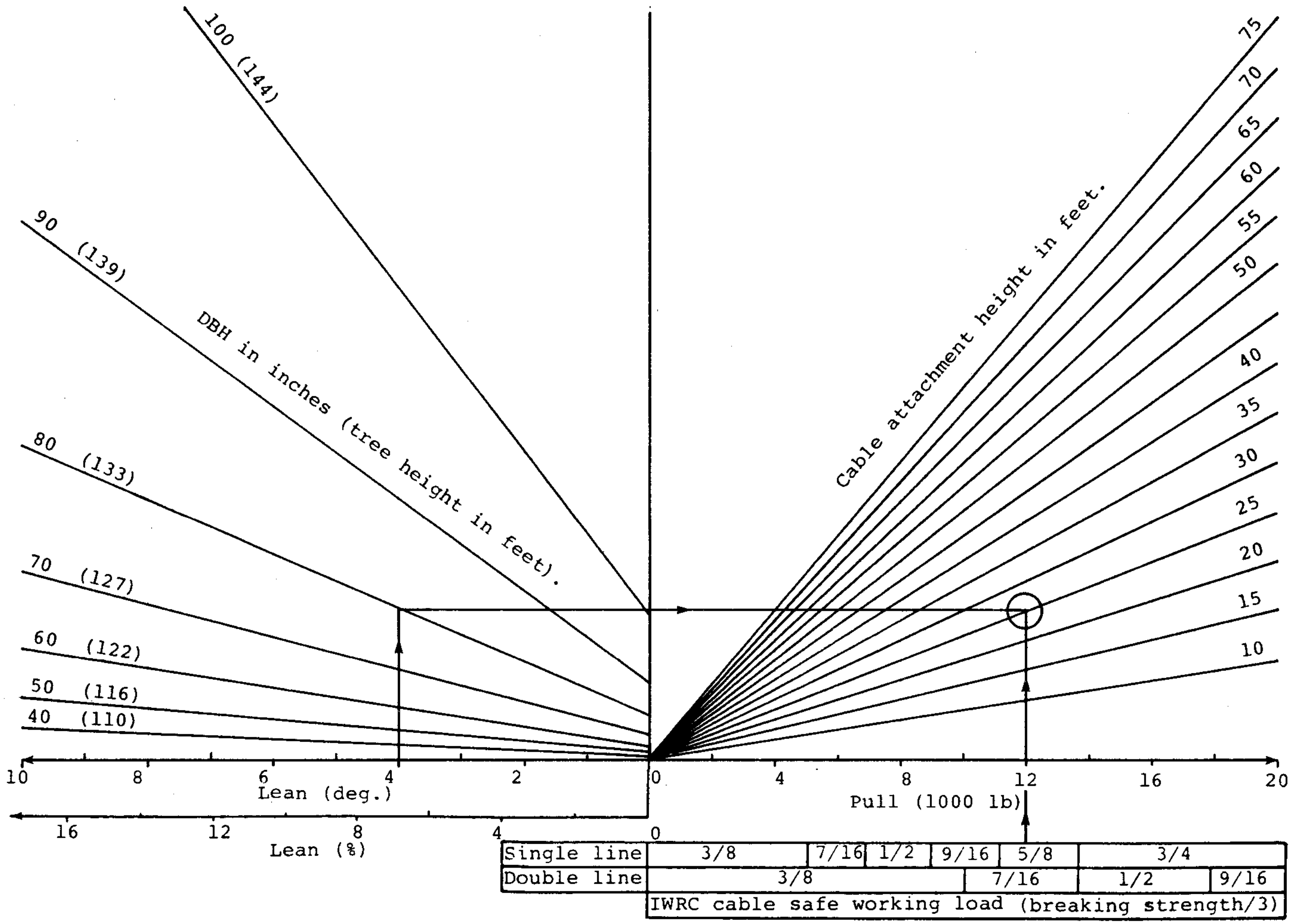

FIGURE H. Nomogram to determine cable attachment height or pull for cedar (imperial units)

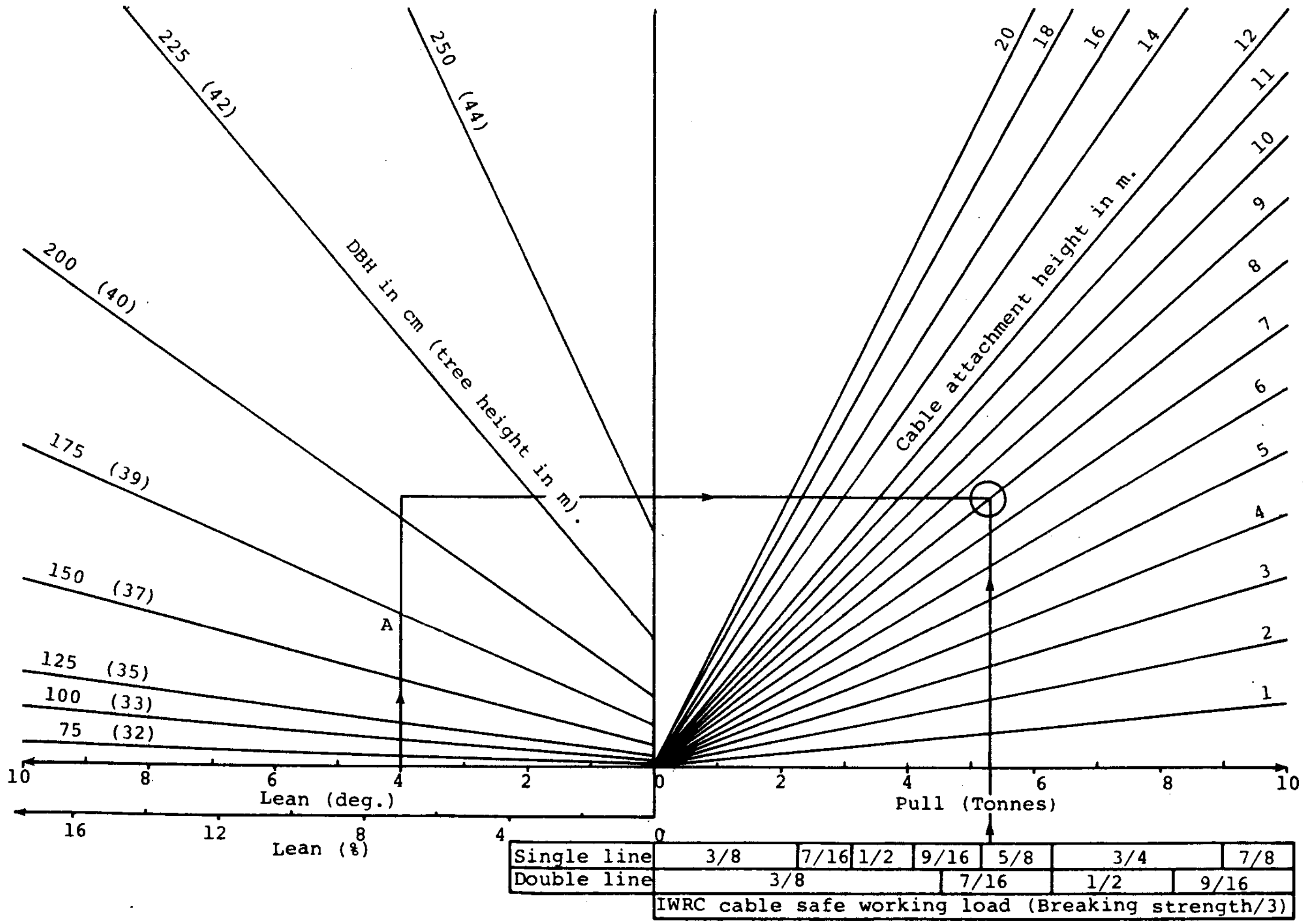

FIGURE I. Nomogram to determine cable attachment height or pull for cedar (metric units)

Rigging the Cable to the Tree

Different techniques are used to attach the pulling cable to the tree. If the tree has a clean bole like most Douglas-firs, a man can climb it easily with belt and spurs to attach a choker at the desired height. A ladder (or even a pike-pole) can also be used if the cable does not have to be rigged very high. FERIC has developed a technique using a line-throwing gun to shoot a line over a branch for higher attachments on limby trees with large sucker branches and cathedral tops like cedar (Figure J).

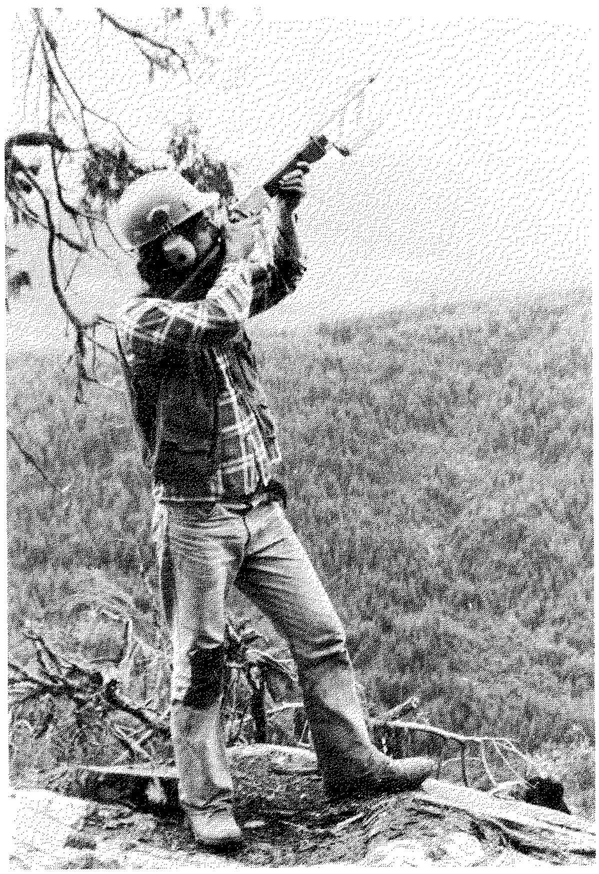

FIGURE J. Line-throwing gun being shot

The six steps are illustrated in Figure K. First a light 100-lb (45-kg) test nylon twine is shot over the limb. The projectile is heavy enough (14 oz (0.4 kg)) to pull the line down to the ground even through thick branches. In the second step a 3/8-in. (10-mm) nylon rope is connected to the twine with a special connector (Figure L) and pulled over the branch. Third, the rigging cable is pulled over the limb. Fourth, the two ends of the rigging cable are brought together around opposite sides of the tree as a bridle. Fifth, the pulling line is shackled to the two eyes of the rigging cable; and sixth, the tension is applied to the tree. If the branch is low, easy to reach and in the clear, the second step can be eliminated by shooting a heavier line initially (300-lb (136-kg) test). This is done using the gun equipped with the line frame shown in Figure M. The heavier line is strong enough to pull the rigging cable over the limb, especially if a cable smaller than 1/2 in. (13 mm) can be used to bridle the tree.

Several types of guns were tried. The Greener Mark II light harpoon gun modified for line-throwing was found to be the best for rigging trees. A complete line-throwing kit is available for about $600.* Sixteen of these guns are presently being used by the forest industry of British Columbia. No special skills are required to operate them effectively.

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*Contact Andy Audet, Site 248, RR 2, Parksville, B.C., Canada. Telephone (604) 248-9566.

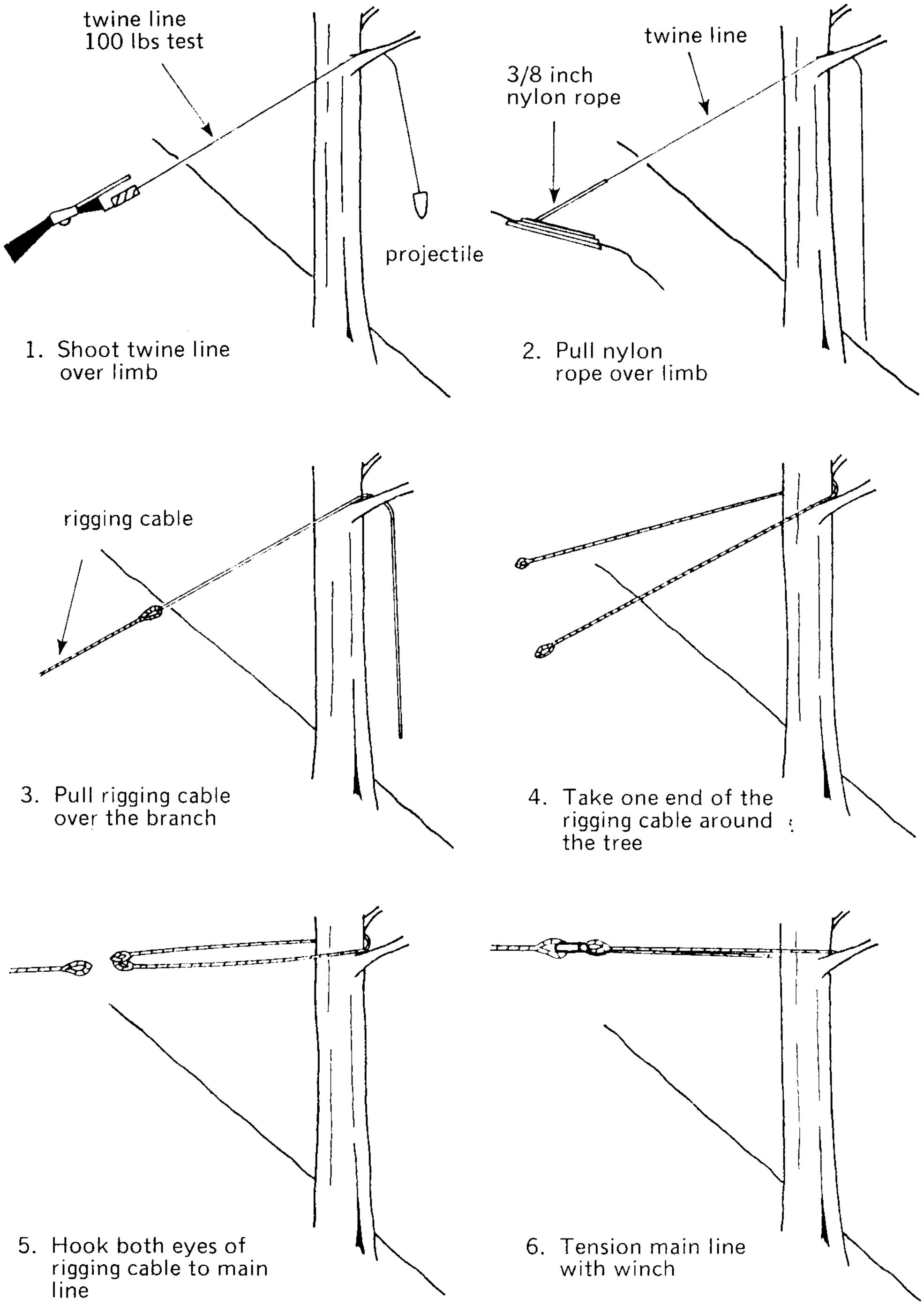

FIGURE K. Tree rigging using line gun

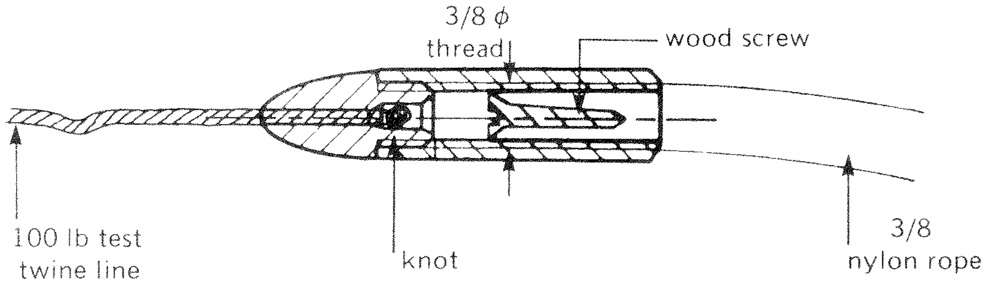

FIGURE L. Special connector for twine line and nylon rope

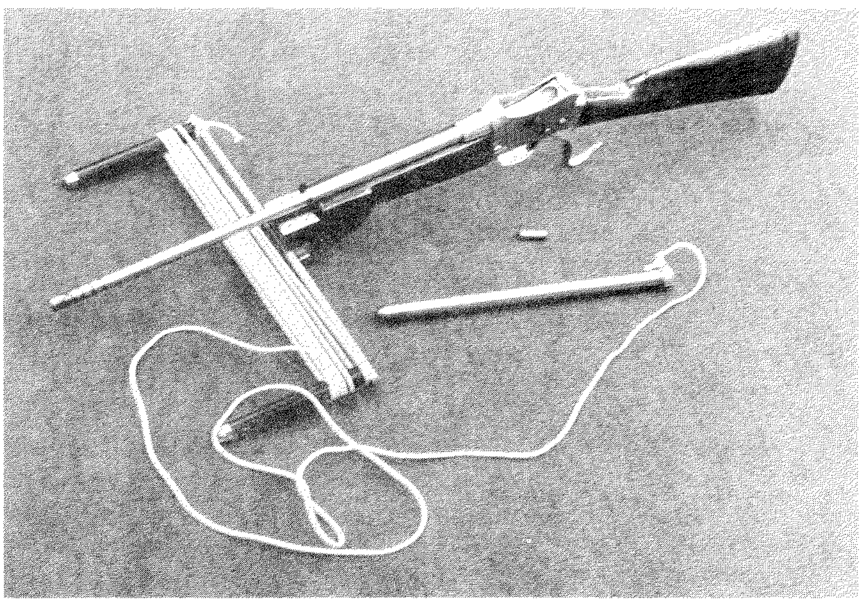

FIGURE M. Line-throwing gun with line frame

BANDING

"Banding" consists of wrapping the butts of the trees with a strong steel strap (2-in. x 0.050-in. (5-cm x 0.13-cm) steel banding) before felling. The largest and most valuable trees showing obvious signs of internal decay or external rot seams were given priority for banding in the Sarita experiment.

A band of required length (circumference of the tree at breast height) was cut and brought to the tree along with the band-tensioner, crimper, band-cutter and seals. We used standard manual strapping equipment that was light enough to be easily carried in the woods. The band was placed around the tree at breast height and tensioned (Figure N). Three seals were used in crimping each band. Banding one tree took two men an average of 40 minutes. The operation is therefore expensive and should be restricted to high-value trees with large potential savings.

In this study all banded trees were directionally felled and it is not possible to isolate the reduction in breakage attributable to banding alone. It was felt, however, that banding helped significantly on trees with rot and natural cracks by keeping the slabs together at the time of impact and reducing the propagation of splitting towards the tree top. Figure O shows a banded tree being felled.

FIGURE N. Tighting band with tensioner

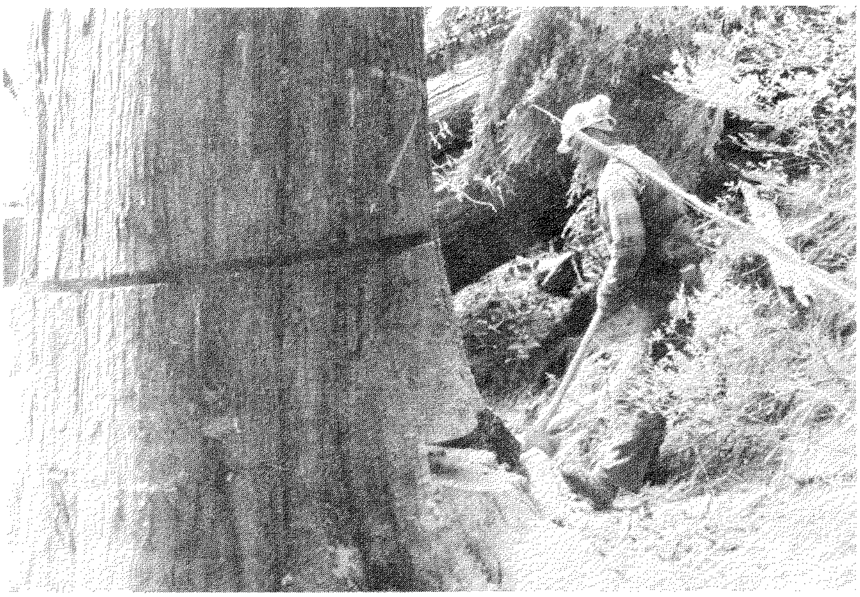

FIGURE O. Banded tree

JACKING

The tree-jacking technique is illustrated in Figure P. An opening is first cut out with a chainsaw on the downhill side of the tree to accommodate one or two (or more) hydaulic rams (Figure Q). The undercut is then sawn on the opposite side. Some upward force is applied with the jacks to keep the kerf open while the backcut is sawn. Once the faller decides that he has the right amount of holding wood left, he moves into the clear and jacks the tree over.

The hydraulic jacks commonly used have a lifting capacity of 20 tons to 90 tons and a lifting height of 3.5 in. to 6 in. (5 cm to 15 cm). They have to be light to be easily carried in the woods. A maximum of 10,000 psi (700 kg/cm^2) oil pressure is applied with a hand or power pump. Fifty feet (15 m) (or more) of hydraulic hose extension can be used to connect the jacks to the pump.

Jacking has some technical limitations, especially for cedar. The jacking technique relies on a firm and solid stump to support the reaction of the jacks. Many of the old-growth cedars are not sound and cedar wood is soft. The jacks can easily slab the butt and the stump or compress the wood without lifting the tree. Jacks cannot be used on large and heavy leaners when the maximum lift height of the jacks is not sufficient to push the tree off balance. Trees smaller than 20 in. (50 cm) at the butt are also difficult to jack because not enough space is left between the undercut and the jacks to complete the backcut.

Jacks were used in conventional felling to fell occasional problem trees. They were also used to directionally fell uphill some of the smaller cedar, hemlock and balsam trees.

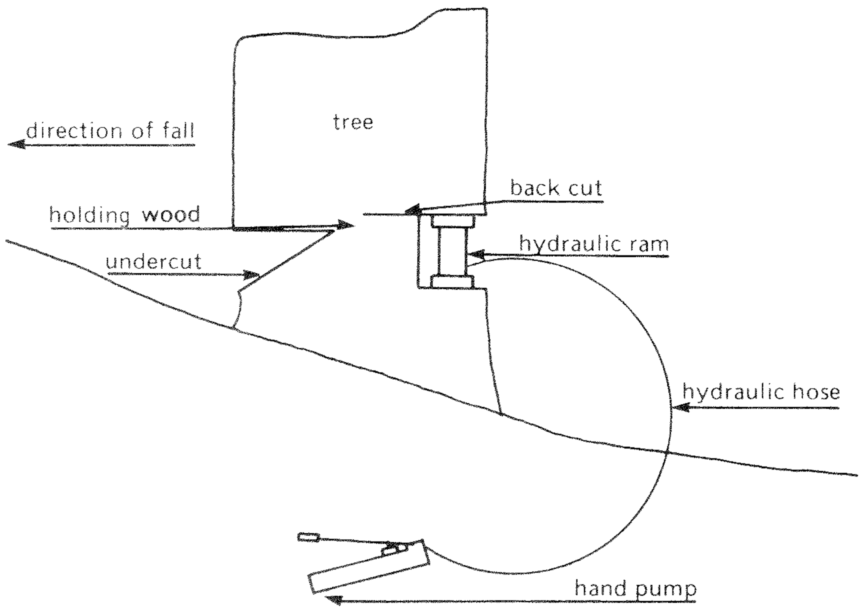

FIGURE P. Tree jacking

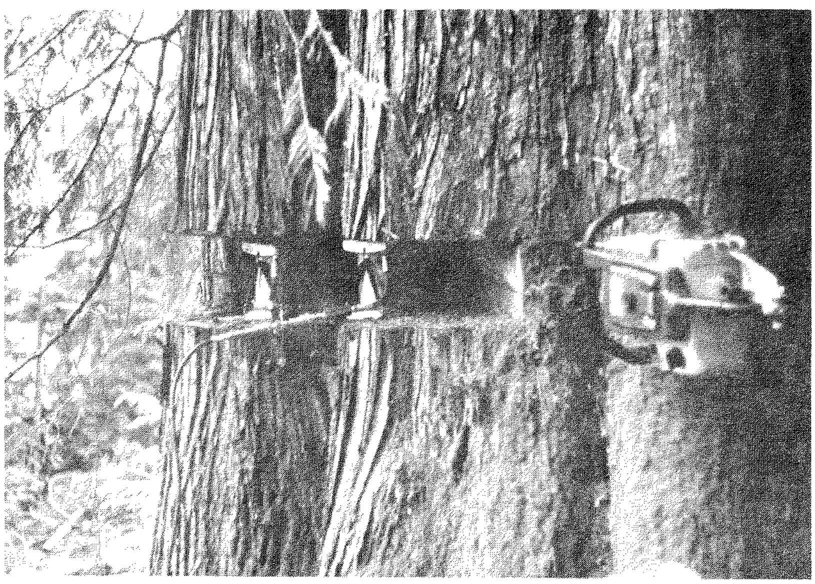

FIGURE Q. Jacks in place in the backcut of a tree

ECONOMICS OF DIRECTIONAL FELLING

This section explores the economic feasibility of directional felling based on the second field test done with the Sarita Division of MacMillan Bloedel. The results of this study are given in detail in a FERIC interim report (Guimier 1978) and will only be summarized here.

DESCRIPTION OF THE TEST

The objective of the test was to compare the cost and benefits of directional uphill felling with conventional felling. Two adjacent blocks, similar in size and timber composition, were felled for this test. One of the blocks (Block 2) was kept as a control area and was felled conventionally (trees parallel to the ground contours) by one faller and a helper. They used a hydraulic jack 20% of the time (mainly for problem trees), but felled no trees uphill. On the other block (Block 1) most of the large cedars were pulled uphill. A few were jacked and some of the trees pulled were also banded. Each block had an area of about 4 acres (1.6 ha) and a maximum width of 400 ft (120 m). The ground conditions were generally steep and rough, broken by a number of small gullies and rock bluffs. The ground slope averaged 70 percent. There was an average of 85 trees/ac (210 trees/ha). Each block contained about 30 large cedar trees (dbh greater than 50 in. (127 cm)). The gross volume per acre in the two blocks averaged 148 cunits (1 036 m^3/ha)--consisting on the average of 54% cedar, 36% hemlock and 10% balsam. Hemlock and balsam results are grouped under the heading "hembal" in the remainder of this Section.

DATA COLLECTION AND RESULTS

For the purpose of the feasibility study two types of information were collected: first, the timber recovered (in volume and quality) from each block; and second, the cost data for each method.

Timber recovery. Before felling started, each block was cruised (100%) to determine the potential gross and net volume for all species (Table 3). B.C. Forest Service regional net factors for decay, breakage and normal waste were applied to the gross volume to calculate the potential net volume. These vary according to tree diameter, tree species and visible defects and averaged 59% for cedar and 77% for hembal. The two blocks had virtually the same total volume of timber, with a slightly higher proportion of cedar in Block 1.

After felling, each log was scaled, graded and colour-painted by block. The results of this woods scale are given by species in Table 3 and are also expressed as a percentage of the net volume cruised. The volumes recovered are much greater than those predicted by the cruise; this is due partly to the exceptionally good quality of the felling in the two blocks and also to the fact that the net factors applied were conservative for this area.

The logs were then yarded with a highlead and a grapple yarder, loaded on off-highway trucks with a line-grapple loader, and hauled to the Sarita dryland sort. Final scaling and grading was done at the sort yard (Table 3). Again the volume recovery was expressed as a percent of the net cruise volume.

It can be seen from Table 3 that the recovery factors for both cedar and hembal in the block directionally felled (respectively 158 and 117) are higher than in the block conventionally felled (147 and 94).

Dollar values were calculated for each log based on its grade and volume and on the log market prices at the time of the study.* Table 3 gives the total dollar values and average price/cunit by species in each block. Although the standing timber was of similar quality in the two blocks, the cedar logs recovered from the directionally felled block (Block 1) were of better quality than the cedar logs recovered from the block conventionally felled (Block 2). The average per cunit value for cedar in Block 1 is \$9 (\$3.17/m^3) higher than for Block 2. The same can be noted for hembal (\$1 per cunit difference or \$0.35/m^3).

*Source: "Log Prices for the 30-day period ending August 15, 1978." Journal of Logging Management, September 1978.

TABLE 3. Cruise, Woods Scale and Final Scale Volumes, Timber Value and Average Price per Cunit for Blocks 1 and 2 - Sarita Experiment

	Block 1 Directionally felled			Block 2 Conventionally felled		
	Cedar	Hembal	Total	Cedar	Hembal	Total
Cruise volume						
Gross - cunits	402	200	602	327	267	594
- m^3	1 138	566	1 704	926	756	1 682
Net - cunits	234	156	390	194	204	398
- m^3	663	442	1 105	549	578	1 127
Woods scale						
Net volume - cunits	395	185	580	298	213	511
- m^3	1 119	524	1 643	844	603	1 447
% of net cruise	169	119	149	154	104	129
Final scale						
Net volume - cunits	371	182	553	285	192	477
- m^3	1 051	515	1 566	807	544	1 351
% of net cruise	158	117	142	147	94	120
Value $	66,294	12,646	78,940	48,533	13,216	61,749
Average $/cunit	179	70	143	170	69	129
$/$m^3$	63	25	50	60	24	46

Felling cost. The felling costs for directional and conventional felling are based on the daily rates for labour and equipment established in Table 4. The daily production and felling cost per cunit are calculated in Table 5.

The faller and his helper worked alone for 23 days in Block 1 and required the assistance of the tree-pulling crew and tree puller for 14 days. Block 2 was conventionally felled in 25 days. The fact that the daily production was much lower than the division's average--even for Block 2--can be explained by the difficult felling conditions and the exceptional care that the faller took to conventionally fell Block 2.

The production per day was 22% lower in Block 1 (directionally felled) compared to Block 2 (conventionally felled) and the falling cost per cunit was more than double.

Cost and Value Analysis

The costs and values calculated for Blocks 1 and 2 (Tables 3 and 5) are not directly comparable because of slight differences in volume and acreage betweeen each block. It is necessary to standardize the results before any conclusion can be drawn from the Sarita experiment. This was done by projecting to the entire setting (Block 1 and Block 2 combined) the values and costs determined in Block 1 for directional felling and the values and costs determined in Block 2 for conventional felling. This meant calculating the felling costs assuming the entire setting was directionally felled and then assuming it was conventionally felled, and determining the wood value recovered in each case. The costs and values thus calculated apply to the same setting and can be compared (Table 6).

The analysis indicates that the benefit after felling would be $117,772 if the entire setting had been directionally felled and $116,869 if it had been conventionally felled. It shows that at the end of the felling phase there is an economic advantage to directional felling. The difference between the two is small, however.

The costs of delivering the logs from the stump to the mills depend on accounting assumptions and are not included in the

TABLE 4. Daily Felling Costs: Equipment and Labour
Sarita Experiment

Cost items	Daily cost ($/day)	
	Uphill pulling and banding	Conventional felling
Equipment		
- Chainsaw, oil and gas	20.00	20.00
- Hydraulic jack ($20.00/day) 20% of the time, yields average		4.00
- Tree-puller	310.00	-
- Line-throwing gun, line, ammunition, projectiles	20.00	-
- Banding equipment and material	20.00	-
Labour (includes 25% overhead)		
- Faller	160.00	160.00
- Helper*(also helps with hydraulic jack)($8.00 x 8 hr x 1.25)		80.00
- Winch engineer ($11.00 x 9 hr x 1.25)	123.75	
- Rigger ($9.00 x 8 hr x 1.25)	90.00	
Total daily cost	$743.75	$264.00

*Not normally employed for regular felling analysis. Yarding and loading costs can be expected to be lower for directionally felled timber because of higher average piece size; total charges for road write-offs and administration would remain constant for the total setting and would be lower per cunit of wood directionally felled; conversely, costs proportional to volume such as hauling, towing and stumpage would be higher for directionally felled timber because of the increase in volume recovery. It should be noted that the calculation of stumpage used presently in B.C. does not compensate the company for the extra costs incurred to increase log grade and volume.

Conventional felling during the Sarita experiment was undoubtedly done more carefully than normal conventional felling. Had the conventional felling been more typical, felling cost would have been lower but volume and value recovery would also have been much less than found during the experiment.

The Sarita experiment was the first of this type on Vancouver Island and was therefore a learning experience. Much of the time was devoted to discussion and visitors. In addition, the line horse used was not the most suitable tree-puller. One can expect that with adequate equipment and a trained crew, production can be increased and the tree pulling in suitable areas will prove to be more profitable than conventional felling.

TABLE 5. Production and Felling Costs for Block 1 and Block 2 - Sarita Experiment

	Block 1 Directionally felled	Block 2 Conventionally felled
Final volume - cunits - m^3	553 1 566	477 1 351
Total felling days	37	25
Production - cunits/day - m^3/day	14.94 42.31	19.08 54.03
Faller and helper alone days cost	 23 (23x264) $6,072	 25 (25x264) $6,600
Faller and pulling crew days cost	 14 (14x743.75) $10,412	 0 0
Total felling cost	$16,484	$6,600
Cost/cunit $/m^3	$29.81 $10.53	$13.84 $ 4.89

TABLE 6. Directional Felling Compared with Conventional Felling Values and Costs - Sarita Experiment

	Directional felling		Conventional felling	
Gross volume cunits (m^3)		1,196 (3 387)		1,196 (3 387)
Net cruised cunits (m^3)				
Cedar		428 (1 212)		428 (1 212)
Hembal		360 (1 019)		360 (1 019)
Total		788 (2 231)		788 (2 231)
Net recovered cunits (m^3)				
Cedar	(x1.58)	676 (1 914)	(x1.47)	629 (1 781)
Hembal	(x1.17)	421 (1 192)	(x .94)	338 (957)
Total		1,097 (3 106)		967 (2 738)
Timber value $				
Cedar	(676x$179)	121,004	(629x$170)	106,930
Hembal	(421x$ 70)	29,470	(338x$ 69)	23,322
Total value		150,474		130,252
Felling cost ($) per cunit (per m^3)	29.81	(10.53)	13.84	(4.89)
Total	(x 1 097)	32,702	(x 967)	13,383
Log value less felling cost	$117,772		$116,869	

ADVANTAGES AND DISADVANTAGES OF DIRECTIONAL FELLING

The results of this study suggest a whole series of advantages and disadvantages for directional felling. The importance of each should be considered during planning for a new area before the decision to use the technique is made.

ADVANTAGES

1. <u>Wood Recovery Improvement</u>

   Table 6 shows a 13.4% increase in the volume recovered from 967 cunits (2 738 m^3) (from conventional felling) to 1,097 cunits (3 106 m^3) (from directional felling). This increase in volume (combined with the improvement in log quality) resulted in an increase of $20,222 in the total value recovered. This is an average of $20.91 per net cunit ($7.38/m^3) of wood conventionally felled.

   The volume increased by 7.5% for cedar alone, and this resulted in an increase in value of $22.37 per net cunit ($7.90/m^3) of cedar conventionally felled. A comparison of these figures with the results of the preliminary evaluation at Kennedy Lake might not be entirely valid; but if the $22.37 per cunit ($7.90/m^3) is compared to the figure of $36.80 per cunit ($13.00/m^3) calculated for the total potential saving (Table 2) we can conclude that by banding and directionally felling the cedar trees, 60% of the potential value was recovered. The remaining 40% would be much harder to reclaim.

2. <u>Wood Quality Improvement</u>

   Directional felling yields wood of higher value per cunit (see Table 3), because there is less degrading of logs from splitting and slabbing and more cedar can be graded as Number 1 Lumber. As an example, the average price of cedar was increased from $170/cunit to $179/cunit ($60/m^3 to $63/$m^3$) in the analysis presented previously.

3. <u>Reduction of Secondary Breakage of the Smaller Trees</u>

The volume of balsam and hemlock was increased by 24.6% by using directional felling instead of conventional felling (Table 6). This volume increase (combined with the improvement in log quality) resulted in an increase of $18.19 per cunit of hemlock and balsam conventionally felled ($6.42/m^3). None of the hemlock and balsam was pulled with a cable but most of the larger ones were jacked. Because the felling of the large trees was done in a regular pattern there was very little secondary breakage of the smaller trees.

4. <u>Log Length Improvement</u>

The average length for cedar lumber-grade logs from Block 1 is 36.65 ft (11.17 m) compared to 32.44 ft (9.89 m) for cedar lumber from Block 2. Lumber logs from the directionally felled trees are therefore 13% longer than logs from trees conventionally felled. This 13% can be accounted for by the fact that directional felling results in fewer breaks further up the bole of the tree and the directionally felled tree can be bucked at preferred log lengths. The greater number of standard long log lengths ("forty-footers") results in greater efficiency handling the logs in the woods and in the mill and also reduces the losses from undesirable log lengths in the sawmill.

5. <u>Safety Improvement</u>

Safety is one of the big advantages in tree-pulling. The faller and the rest of the crew have all the time needed to move to a safe location before the tree is pulled. Felling hazards from broken limbs and tops, kickback, barber-chairing and other sources are removed. When the tree is down, bucking is safer because fewer logs will roll when the trees are lying with the slope instead of parallel to the ground contours. The winch and line can be used at any time to eliminate bucking hazards. Yarding safety is also improved since the frequency of uncompleted bucking cuts is reduced.

6. <u>Yarding Productivity Improvement</u>

Logs in line with the yarder with the small end uphill can easily be highlead yarded and do not hang up behind stumps or break when swung into lead. Trees felled uphill fall closer to the yarder and do not tend to roll away from it. The average yarding distance is therefore reduced. The increased average piece size results in an increase in yarding productivity. Trees at the edge of a road right-of-way can be pulled to the road and "cherry-picked."

7. Debris Reduction

   Breakage from directional felling is greatly diminished and the amount of debris left on the ground is greatly reduced. Slash burning may be unnecessary.

8. Stream Protection

   Trees along fish creeks can be pulled away from the creek. This allows the logger to save timber that would have eventually blown down into the creek, to eliminate expensive cleanup cost, and to reduce the impact of logging on streams.

DISADVANTAGES

1. High Production Cost

   Table 6 shows that directional-felling cost was two to three times the cost of conventional felling because a larger crew and more equipment were needed. Total directional-felling cost was $19,319 higher than total conventional-felling cost. This is a cost difference of $19.98 per cunit ($7.06/m^3) of wood conventionally felled. Directional felling was also slower because of the interference between felling and line-handling.

2. Need for Specialized Equipment and Trained Crew

   Pulling trees requires a special winch or modified existing machine to perform the pulling. It also requires a good faller working in collaboration with a well trained tree-pulling crew. This imposes more constraints on the logging operation.

3. Planning

The necessity to locate the winch on the road above the setting may create more planning constraints or require additional road construction.

4. Undercut on High Side

The undercut has to be placed on the high side of the stump in uphill felling. This results in some waste, whether the undercut is taken out of the stump or out of the log.

CONCLUSION

Preliminary evaluation studies showed sizeable potential savings in large old-growth Western red cedar trees if felling damage can be reduced or eliminated. An average amount up to $36.80 could be saved for every net cunit of cedar logged--or $13.00/m^3.

FERIC then reviewed and adapted directional felling techniques used in the United States to reduce breakage in Douglas-firs and redwoods and decided to use directional felling in an old-growth stand of large cedars, along with banding as an additional measure to reduce butt splitting and slabbing.

FERIC's solution to the problem of cedar breakage is a combination of directional felling and banding. Jacking and pulling are two methods for directionally felling large trees uphill. Pulling cedar is performed by a three-man crew using a tree-pulling machine with a 10-ton (9-tonne) pulling capacity at bare drum. Cedar trees can be easily rigged using a line-throwing gun. Jacking can also be used to fell small cedars and trees of other species uphill if the lean is not excessive and the stump is sound. Banding should be used only for trees with large potential savings and obvious signs of internal decay.

Directional felling with banding increased the volume of cedar recovered by 7.5% over conventional felling; it also produced higher grade logs, and this is reflected in a $9.00 per-cunit increase over the average log price--or $3.18/m^3.

A total saving of $22.37 per net cunit of cedar--or $7.90/m^3--resulted from improved log quality and an increase in volume recovered. The volume of hemlock and balsam recovered also increased by 24.6 percent. The saving for the total stand (54% cedar, 46% hemlock-balsam) averaged $20.91 per net cunit--or $7.38/m^3.

The cost of directional felling was 2.2 times greater than the cost for conventional felling. This high cost can be explained partly by the experimental aspect of the operation and partly by the inexperience of the crew and the inadequacy of the tree puller used.

The difference between log value and cost after felling is favourable to directional felling, but marginal--\$0.93/cunit or \$0.32/m^3. This profit could be improved with a crew experienced at tree pulling, a well adapted tree-pulling machine, and a well laid-out setting.

In addition to the increase in volume recovery and wood quality, directional felling also increases the number of logs bucked at preferred lengths, reduces the amount of debris left on the setting, permits logging along fish streams without disturbing the environment, and is safer than conventional felling.

Many logging operators might reject directional felling of complete settings because of the cost and marginal overall recovery. These operators should not overlook the potential savings in directionally felling very large and valuable individual trees that would be completely destroyed if conventionally felled. Large trees along the right-of-way are also obvious candidates for directional felling because of the potential savings both in wood recovery and in yarding cost.

BOTANICAL NAMES OF SPECIES CITED

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Cedar (Western red)	*Thuja plicata* Donn
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Hemlock (Western)	*Tsuga heterophylla* (Raf.) Sarg.
Spruce (Sitka)	*Picea sitchensis* (Bong.) Carr.

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