
**TRIALS OF GROUND-SKIDDING
METHODS ON STEEP SLOPES IN THE
EAST KOOTENAYS, BRITISH COLUMBIA:
PRODUCTIVITIES AND SITE IMPACTS**

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Abstract

Between 1988 and 1990 the Forest Engineering Research Institute of Canada (FERIC) monitored a series of ground-based harvesting operations working on steep slopes in Southeastern British Columbia. Evans Forest Products Company and the British Columbia Ministry of Forests cooperated in the study. This report documents the productivities, costs, and soil-disturbance levels associated with a variety of conventional ground-skidding systems, discusses the effects of operational and environmental factors on skid-road and skid-trail related soil disturbance, and compares the benefits of preplanned, or "designated", skid-road layout to the conventional, or "operator-choice", approach to skid-road layout.

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Summary

From 1988 to 1990, Evans Forest Products Company, the Golden Forest District of the British Columbia Ministry of Forests (BCMOF), and the Forest Engineering Research Institute of Canada (FERIC) conducted a series of timber-harvesting trials to address concerns about high levels of soil disturbance resulting from ground skidding on steep slopes. The objectives of the trials were to identify opportunities, and investigate alternative ways, to apply conventional ground-skidding systems to meet soil-disturbance objectives while maintaining acceptable harvesting productivities and costs. The report documents the productivities, costs, and soil-disturbance levels associated with a variety of typical ground-skidding systems, discusses the effects of various operational and environmental factors on soil disturbance, and compares the benefits of preplanned, or "designated", skid-road layout to the conventional, or "operator-choice", approach of skid-road layout.

All treatment units in the study were clearcut. Nine treatment units were harvested in summer, and three were harvested in winter on snowpacks ranging from 0.8 to 1.1 m. Average side slopes ranged from 31 to 48%. Three pairs of treatment units were used for side-by-side comparisons of the designated and operator-choice methods of skid-road location.

Seven logging contractors participated in this study and all used ground-based harvesting systems. One contractor operated a mechanized system consisting of a feller-buncher, a mix of tracked and rubber-tired grapple skidders, and a front-end loader. Another contractor used a single small crawler-tractor for trailbuilding and skidding, and self-loading log trucks for the loading phase. The other five contractors employed variations of the conventional system, consisting of a range of models and sizes of tractors for trailbuilding and skidding, rubber-tired skidders for skidding, and front-end loaders at the landing.

Harvesting production and costs on the nine treatment units varied considerably, reflecting the variations in organizational, operational, and environmental circumstances represented by the study sites and the contractors' equipment profiles. Volume production ranged from 104.0 to 444.8 m³/8-h shift, and the cost of logs loaded onto the truck ranged from \$7.88 to \$22.29/m³ (based on 1991 costs). Of the nine contractors, three harvested two treatment units each, and all three experienced production and cost differences of more than 20% from one block to the other.

Soil disturbance levels were estimated using a traverse method, which may produce different results than the

current survey procedures used by the BCMOF. Total soil disturbance, including haul roads, landings, skid roads, and skid trails, ranged from 19.7 to 42.7% of gross cutblock area. Skid-road and skid-trail disturbance alone ranged from 11.9 to 31.9%, and accounted for much of the variability in the overall disturbance levels. Treatment units were ranked by level of skidding disturbance to explore the relationship of soil disturbance to several operational and environmental factors. No single factor had a predominant influence on disturbance levels. Low levels of skidding disturbance were associated with gentle average slopes, mechanized harvesting systems, winter harvesting on snow, and/or use of small crawler-tractors to build skid roads.

Because the area disturbed by skid roads and skid trails is the product of their length and width, this study investigated the effects of slope steepness, size of trail-building machine, and season of harvesting on these skid-road and skid-trail dimensions. Slope steepness affects the need for constructed skid trails as well as their dimensions. In this study, the density of skid roads and skid trails was relatively consistent on slopes of more than 35%, and overall width and depth of cut on skid roads were found to increase steadily with increasing slope. Likewise, skid-road widths on similar slopes were found to increase as the size of the trailbuilding machine increased. Winter skid roads were wider than summer skid roads on similar slopes, but the width of the zone of excavated and/or compacted soil was much less. The factors that influence the area disturbed by skid roads and skid trails can also affect the severity of this disturbance.

In side-by-side comparisons, the designated system had little effect on reducing skid-trail and skid-road disturbance. In two of the three side-by-side comparisons the designated skid-road units had skidding disturbance levels of 19.5 and 19.6% which compared to disturbance levels of 21.3 and 21.6% for their operator-choice counterparts. Skid-road and skid-trail densities were also lower on the designated skid-road units; however, the proportion of reductions in density did not match the reductions in the disturbance levels because of differences in skid-road and skid-trail widths on the units.

Differences in the log production of the side-by-side treatment units were not results of the method used. For similar skidding distances, skidding cycle times on one designated skid-road unit were about 12% higher than on its paired operator-choice unit, with most of the increase occurring in the hook-up phase. However, differences in average piece size, skidding distance, and other operating conditions appear to have overshadowed any potential effects of increased cycle times. Relative to the operator-choice system, shift-level production for

the designated system increased by 45% in one side-by-side trial and decreased by 18% in the other.

The implementation of the designated system differed amongst the trials in: layout criteria used, input into locating skid roads, flexibility of operators to modify skid-road locations, and restrictions to skidder travel.

Based on the results of this study, FERIC has made a number of recommendations that should be considered by forest managers when planning ground-based harvesting systems, especially on steep slopes, in order to minimize soil disturbance.

INTRODUCTION

In 1987 the British Columbia Ministry of Forests (BCMOF) introduced preliminary guidelines for establishing maximum allowable levels of soil disturbance resulting from timber-harvesting activities. Accumulated evidence documented that high levels of soil disturbance were occurring on ground-skidded sites in the Interior of the province, especially on slopes steeper than 30% (Schwab and Watt 1981, Smith and Wass 1976).

Furthermore, on skid roads and skid trails, where most of the disturbance occurred, tree growth was often significantly less than on adjacent undisturbed soils (Smith and Wass 1979, 1980). An analysis estimated that, in the Interior, soil disturbance generated by conventional ground-skidding practices resulted in potential site productivity losses of 400 000 m³/year between 1976 and 1986 (Utzig and Walmsley 1988).

Although alternative harvesting systems that use cable yarders and small crawler-tractors have been shown to generate less soil disturbance than conventional ground-based systems, these alternatives cost more to operate (Krag and Webb 1987, McMorland 1980). Any substantial shift to alternative harvesting systems and equipment would have to be implemented gradually to allow for the training of harvesting contractors and to accommodate higher wood costs. Therefore, the forest industry is interested in developing innovative ways to apply conventional ground-skidding systems to meet soil-disturbance objectives while maintaining acceptable harvesting productivities and costs.

In 1987 Evans Forest Products Company and the BCMOF agreed to conduct a series of harvesting trials in the Golden Forest District. In particular, the harvesting trials proposed to assess and compare the use of preplanned, "designated" skid roads (Froehlich et al 1981) to the conventional Interior "operator-choice" practice of allowing harvesting contractors and/or machine operators to establish skid-road and skid-trail networks. Finally, the study was restricted to harvesting operations on 30-55% slopes, the sites on which the industry and BCMOF most often debate harvesting system selection.

Forestry Canada and the Forest Engineering Research Institute of Canada (FERIC) agreed to monitor and report on the trials. Forestry Canada investigated the biophysical aspects of harvesting-related soil disturbance. FERIC's task was to assess the performance of conventional ground-skidding systems, in terms of harvesting costs and soil-disturbance levels, and to identify opportunities to improve on current practices.

Objectives

The specific objectives of FERIC's study were to:

- Determine productivities, costs, and soil-disturbance levels when harvesting steep slopes with conventional ground-skidding systems including: rubber-tired skidder and crawler-tractor combinations; a mechanized system employing a feller-buncher and grapple skidders; and a small crawler-tractor system.
- Investigate the effects of various operational and environmental factors—such as trailbuilding and skidding practices, weather, slope, and terrain—on soil-disturbance levels.
- Compare productivities, costs, and soil-disturbance levels of the "designated" skid road planning system with the "operator-choice" approach in a subset of side-by-side trials.
- Identify opportunities to reduce soil disturbance when using conventional ground-skidding systems on steep slopes, and determine the operational requirements for pursuing these opportunities.

STUDY METHOD

Selection of Study Sites

Personnel from Evans Forest Products Company and the Golden Forest District of the BCMOF selected suitable study blocks from their respective operating areas. Emphasis was given to areas scheduled for harvesting during the following summer and winter operating seasons, as well as to providing a sample that was representative of typical operating conditions within the District. Evans Forest Products Company retained responsibility for determining operating schedules and assigning harvesting contractors to its study blocks. The BCMOF provided one cutblock from its Small Business Forest Enterprise Program (SBFEP), and the harvesting contractor was determined through the normal bidding process.

Three of the study blocks—the SBFEP block and two of Evans Forest Products' blocks—were each subdivided into two treatment units to provide side-by-side comparisons of designated-skid-road and operator-choice trail-building methods. The contractor assigned to each block used the same equipment to harvest both the designated and operator-choice units.

Data Collection

FERIC representatives collected data on harvesting productivity and costs; surveyed haul roads, landings, skid roads, and skid trails on all cutblocks; and recorded weather and other relevant operational factors during the course of harvesting operations.

Shift-Level Monitoring. All skidders and trailbuilders, and one feller-buncher, were equipped with Servis Recorders to track daily machine statistics and production. Every day, machine operators recorded their work activities: numbers of trees felled, numbers of turns and stems skidded, and lengths of skid roads built. Additional information included crew complements, shift lengths, and reasons for machine downtime. Average shift figures were used in cases where shift information was not available.

The total volume delivered to the mill from each treatment unit was obtained from the weigh-scale returns at the mill yard. Average piece volumes were calculated from the scale volumes and records of numbers of pieces skidded. Cruise information was used only for site descriptions.

Detailed Timing. A sample of skidding cycles underwent detailed timing to provide additional information on skidding activities and to compare cycle times of the designated treatments to the operator-choice treatment units. Travel distances and the number of logs per turn were recorded, and the following cycle elements were timed: travel empty, hookup (consisting of manoeuvring, choking, and winching), travel loaded, landing duties, and delays (mechanical and operational).

Costing. Hourly machine costs were calculated using standard FERIC procedures. Because the contractors used equipment of various makes, models, and ages, tractor and skidder costs were based on equivalent new Caterpillar models with similar weight, power, and attachments. Repair, maintenance, and fuel costs were estimated using the *Caterpillar Performance Handbook* (1990). The cost of operating the Timbco feller-buncher was estimated from information provided by the owner.

Hourly wages were based on the IWA Southern Interior Master Agreement for 1991 plus 35% for fringe benefits. Costs include only on-site shift time spent on the study blocks. Allowances for travel time, crew transportation, supervision, and other overhead are not included.

Soil-Disturbance Data. Soil disturbance caused by haul roads, fireguards, landings, skid roads, and skid trails was estimated using the traverse method (BCMOF 1987). These structures were measured by traversing the lengths and measuring widths of cross sections at fixed intervals of 25 to 100 m, depending on the size of treatment unit. Total cross-section width extended from the top of the cutbank to the toe of the sidecast, and was the sum of the horizontal measurements of the cutbank, running surface, and sidecast slopes (Figure 1). The area disturbed by each source was calculated by multiplying

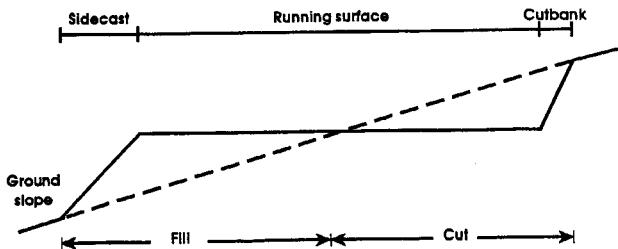


Figure 1. Components of a skid-road cross section.

total horizontal length by average horizontal cross-section width. For landings with a regular shape, areas were determined using the above method; for landings with an irregular shape, a direct area traverse method was used.

When this study was initiated, the current *Soil Conservation Guidelines for Timber Harvesting - Interior British Columbia* (BCMOF 1992) were not yet in place; however, the definitions of skid roads and skid trails in this report are the same as for the current guidelines. That is, skid roads are "continuous bladed structures constructed to facilitate ground-based skidding"; and skid trails are "unbladed travel routes identified by the presence of wheel ruts . . . , and/or extensive uniform compaction indicative of heavy machine traffic over an area." FERIC's surveys differ from the current guidelines, however, in that only skid trails with depths of 5 cm or greater in mineral soil were surveyed, and skid-road and skid-trail areas included the total width of these structures from the top of the cut to the toe of the sidecast—not to a 15-cm depth in the sidecast as described in the guidelines.

All skid roads and skid trails were surveyed immediately after harvesting. On winter-harvested sites, skid roads and skid trails were remeasured the following summer to observe if changes had occurred after the snow had melted. Treatment unit boundaries were surveyed following harvesting to establish final areas and to express soil disturbance as a percentage of treatment unit area.

STUDY SITES

The study sites consist of eight cutblocks subdivided into twelve treatment units. All study sites were located in the Golden Forest District in southeastern British Columbia (Figure 2). Physical and biogeoclimatic features of the sites are presented in Table 1.

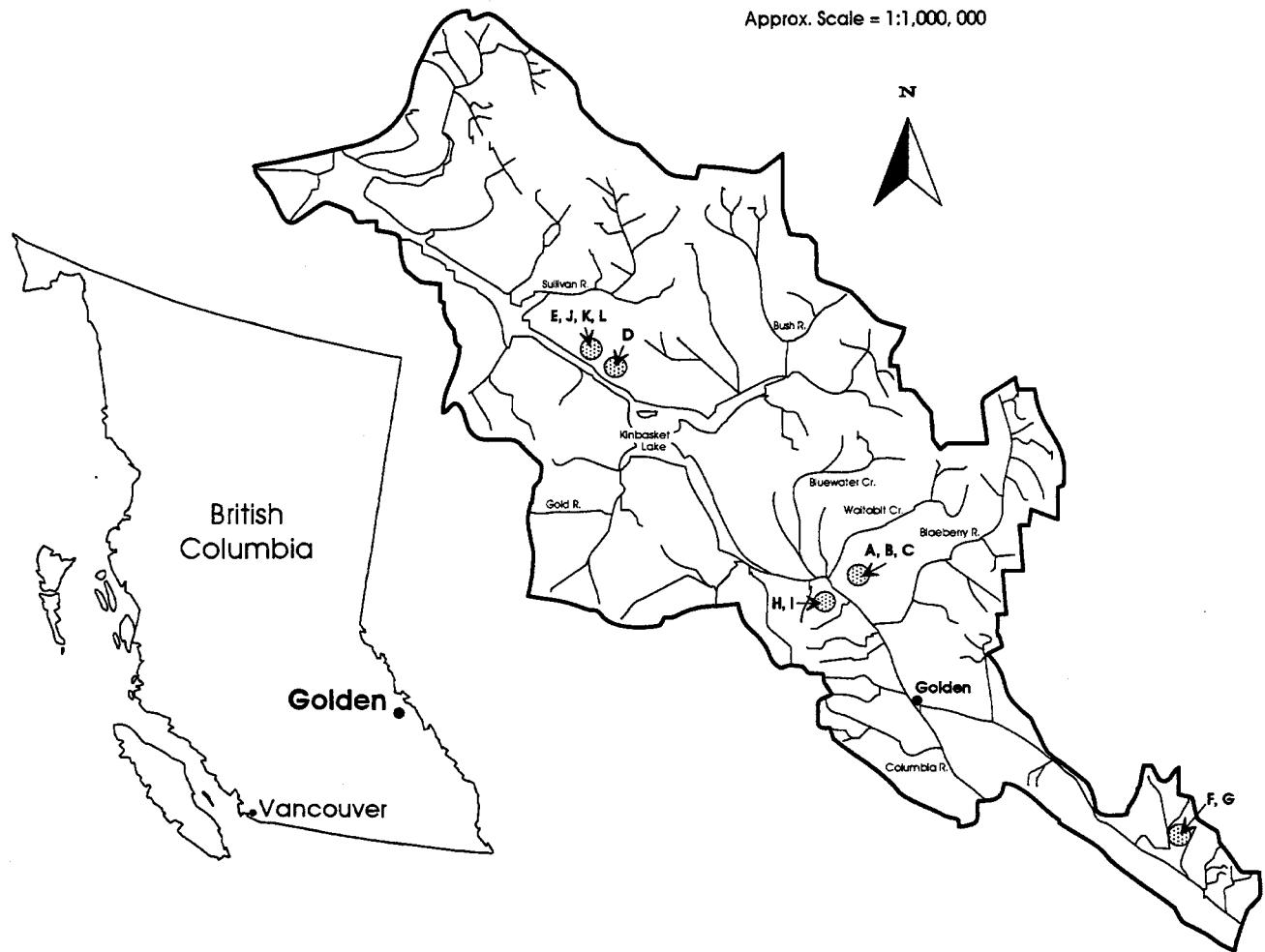


Figure 2. Locations of study sites.

Terrain on the study sites was mostly even to rolling, although portions of one site were gullied. Slopes averaged from 31 to 48%. Soils were predominantly silty to sandy loams. The Interior Cedar Hemlock and Englemann Spruce-Subalpine Fir biogeoclimatic zones were about equally represented in the sample.

HARVESTING METHODS AND SYSTEMS

All cutblocks selected for this study were clearcut. Three cutblocks were separated into two or more treatment units to allow production information to be tracked separately for each contractor working on the same block. One pair of treatment units on each of three cutblocks was reserved for side-by-side comparisons of designated

and operator-choice trailing methods. Nine treatment units were harvested between late spring and late fall on bare or unfrozen ground, and are referred to as "summer-harvested" blocks. Three treatment units were harvested during the winter operating season on snowpacks ranging from 0.8 to 1.1 m, and are referred to as "winter-harvested" blocks.

Seven harvesting contractors participated in this study. Machinery and crew complements for each contractor are listed in Table 2. This list includes crew and equipment involved in falling, trail building, skidding, and loading activities, but excludes equipment used only for road and landing construction.

With minor exceptions, all contractors skidded full-tree to the landing where bucking and delimiting were performed.

Table 1. Site and Stand Descriptions

	Treatment Unit									
	A	B	C	D	E	F,G	H	I	J	K,L
Season of harvesting	Winter	Winter	Winter	Summer	Summer	Summer/ Fall	Summer	Summer/ Fall	Summer	Summer/ Fall
Opening area (ha)	19.8	24.0	12.2	18.5	25.0	8.2	13.4	12.9	46.1	73.6
Slope range (%)	30-75	5-45	5-55	20-65	15-50	25-55	20-55	20-55	20-65	25-65
Slope average (%)	45	31	31	45	31	42	43	42	42	46
Terrain	Even to rolling	Even	Even to slightly rolling	Even to slightly rolling	Even to rolling	Even	Even to rolling	Even to rolling	Rolling to gullied	Even to rolling
Slope position	Mid	Upper & bench	Upper & bench	Mid	Mid	Mid	Upper	Upper	Mid	Mid
Aspect	NW-W	SW	SE-E	SW	S	SW	E	E	SW	SW
Average elevation (m)	1250	1400	1400	1700	1100	1750	1650	1800	1050	1000
Soils	SiL	SiL	SaL-L	SiL-L	SiL-SaL	SiL	SaL-L	SaL-L	SiL-SaL	SiL-SaL
Ecological classification	ESSFc-1	ICHa2-1/ ESSFc-1	ICHa2-1/ ESSFc-1	ESSFc-4	ICHa2-3	EssFa-4	ICHa-2/ ESSFc-4	ESSFc-4	ICHa2-1,3	ICHa2-1,3
Species composition ^a	S ₅ F ₂ B ₁ (HP1) ₂	SP1BF	SP1BF	S ₈ B ₂	PL ₅ F ₃ Pw ₁ S ₁	Pl ₇ B ₁ (FS) ₂	S ₇ B ₂ H _{W1}	S ₇ B ₂ H _{W1}	F ₇ Pl ₁ S ₁ C ₁	F ₇ Pl ₁ S ₁ C ₁
Volume ^a (m ³ /ha)	347	444	523	461	228	419	356	356	307	307
Density (merch. stems/ha) ^a	501	1109	495	296	381	1074	521	521	433	433
Avg. volume ^a (m ³ /tree)	0.69	0.40	1.06	1.56	0.60	0.39	0.68	0.68	0.71	0.71
Avg. dbh ^a (cm)	31.0	26.0	38.6	43.7	28.8	25.0	32.7	32.7	32.3	32.3
Avg. total height ^a (m)	28.1	<28.0	>28.0	34.1	27.4	25.0	26.8	26.8	29.2	29.2

^a From cruise compilation summaries.

Table 2. Contractors' Machinery and Crew Complements

Contractor/Machines ^a /Crew	No.
Contractor 1	
Caterpillar D8H crawler/skid-road builder	1
Caterpillar D7G tracked line skidder	1
Caterpillar 518 rubber-tired line skidder	2
Caterpillar 966C front-end loader	1
Machine operator	5
Bucker	2
Faller	2
Chokerman	1
Contractor 2	
Caterpillar D7G crawler/skid-road builder/line skidder	1
Caterpillar D6C tracked line skidder	1
Caterpillar 518 rubber-tired line skidder	2
Caterpillar 966C front-end loader	1
Machine operator	5
Bucker	2
Faller	2
Chokerman	1
Contractor 3	
International TD20 (D7) crawler/skid-road builder/grapple skidder	1
Timbco 2520 tracked feller-buncher	1
John Deere 740A (528) rubber-tired grapple skidder	1
Caterpillar 518 rubber-tired line skidder	1
Dresser 530 front-end loader	1
Machine operator	5
Bucker	2
Contractor 4	
Komatsu D41A (D4) crawler/skid-road builder/line skidder	1
International TD8E (D3) tracked line skidder	1
Caterpillar 518 rubber-tired line skidder	1
Komatsu WA300 front-end loader	1
Machine operator	3
Chokerman/machine operator	1
Faller	1
Bucker	1
Contractor 5	
Caterpillar D5H crawler/skid-road builder	1
Komatsu D41A (D4) tracked line skidder	1
Clark 667 (518) rubber-tired line skidder	2
Caterpillar 950 front-end loader	1
Machine operator	5
Bucker	1
Faller	2
Chokerman	1
Contractor 6	
International TD15 (D6) crawler/skid-road builder/line skidder	1
Timberjack 380A (518) rubber-tired line skidder	2
Caterpillar 966C front-end loader	1
Machine operator	4
Bucker	1
Faller	1
Contractor 7	
John Deere 550 (D4) crawler/skid-road builder/line skidder ^b	1
Machine operator	1
Faller	1
Bucker	1

^a Numbers in brackets refer to Caterpillar-equivalent skidders and crawler-tractors that are used for costing in subsequent tables.

^b This system used a self-loading truck.

All contractors used ground-based harvesting systems. One contractor operated a mechanized system consisting of a feller-buncher, both tracked and rubber-tired grapple skidders, and a front-end loader (Figure 3). Another contractor used a single small crawler-tractor for trailbuilding and skidding, and self-loading log trucks for the loading phase. The other five contractors used variations of the conventional system, consisting of a range of models and sizes of tractors for trail building and skidding, rubber-tired skidders for skidding, and front-end loaders at the landing.

RESULTS AND DISCUSSION

Productivity

Production data for nine of the treatment units is summarized in Table 3. (Production data were insufficient for Treatment Units E, F and G, and are therefore not included.) Skidding and trail-building activities were closely related and were therefore combined into a single phase for each block. "System shifts" refer to the number of scheduled shifts. The "average number of machines per shift" does not equal the actual number of (skidding and trailbuilding) machines in the system because not every machine worked every shift. Production rates have been standardized for an eight-hour shift.

As would be expected with a variety of stand and site conditions and machine complements, system production values varied widely. The mechanized system of Contractor 3 had the highest piece production of 690 pieces/shift and Contractor 6 on Treatment Unit I had the lowest at 186 pieces/shift. Based on volume production, Contractor 1 on Treatment Unit D had the highest production ($445 \text{ m}^3/\text{shift}$) and Contractor 6 on Treatment Unit H had the lowest ($104 \text{ m}^3/\text{shift}$); these results are a



Figure 3. Feller-buncher and grapple skidder operating on a 40% slope (Contractor 3, Table 2).

Table 3. Productivity of Rubber-Tired Skidders and Crawler-Tractors: Summary

	Treatment Unit ^a									
	A	B	C	D	H	I	J	K	L	
Contractor	5	3	4	1	6	6	1	2	2	
Treatment ^b	OC	OC	OC	OC	OC	D	OC	OC	D	
System shifts (no.)	27	32	22	15	34	30	37	23	51	
Average shift length (h)	7.6	7.3	7.3	9.6	8.3	8.6	9.0	9.8	9.3	
Average machines/shift ^c (no.)	3.8	2.4	2.0	3.7	2.3	2.8	3.6	3.7	3.6	
Mechanical availability (%)	96.9	97.8	97.9	96.7	94.2	93.2	95.6	97.3	98.1	
Utilization (%)	92.9	96.4	94.7	92.4	84.4	84.3	91.5	91.9	95.3	
Total volume (m ³)	8891	12601	5746	8034	3684	4890	14195	9634	16833	
Average volume/piece (m ³)	0.72	0.62	1.19	0.98	0.55	0.81	0.67	0.87	0.70	
Average pieces/turn (no.)	7.7	12.5	7.0	8.7	5.4	5.2	8.7	8.1	10.4	
Average volume/turn (m ³)	5.5	7.8	8.3	8.5	3.0	4.2	5.8	7.0	7.3	
System production/8-h shift										
Volume (m ³)	344.8	429.6	286.4	444.8	104	151.2	341.6	343.2	283.2	
Pieces (no.)	478.4	689.6	241.6	454.4	188	186.4	512	396.8	406.4	
Turns (no.)	62.4	55.2	34.4	52.8	34.4	36	58.4	48.8	39.2	
Average skidding distance (m)	159	235	181	n/a	165	195	225	250	345	

^a Production data were insufficient for Treatment Units E, F, and G.

^b OC = Operator choice; D = Designated

^c Includes skidding and trailbuilding machines.

function of the differences in average piece volume. No single factor, including the average number of machines per shift, seems to have a dominant influence on overall system production, indicating that production is affected by a combination of factors.

It is difficult to compare production rates for all blocks and contractors because of variations in equipment complements and site conditions; however, some comparisons can be made for the units of the side-by-side trials.

Costs

Harvesting costs include the costs of machine ownership and operation, and labour, and exclude the costs of supervision, overhead, development, interest, and crew transportation. Examples of the machine cost analysis are included in Appendix I.

In Table 4, system and phase operating costs are presented on a cost/m³ basis for each treatment unit. Total harvesting costs ranged from just under \$8 to more than \$22/m³ by contractor; similar proportional variations are also shown for individual phases. Contractor 6 had unusually high costs for both the units he worked on; however, even when these costs are excluded, the range in costs still varied by 75% from a low of \$7.88 to a high of \$13.75/m³.

Table 5 shows the costs of skid-road construction (\$/m³) based on timber volume removed and on the cost per lineal metre of trail constructed. Costs ranged from \$0.39 to \$2.50/m³, and from \$0.49 to \$3.51/lineal metre of skid road. Some of these costs may be overstated as some operators may have included the time spent skidding right-of-way logs from the skid roads as trailbuilding time. On Treatment Units B and L, time spent trailbuilding was not separated from skidding time and, therefore, costs could not be estimated.

The high cost of \$3.51/lineal metre on Treatment Unit I occurred because wet soil conditions made trail building difficult; the situation was further complicated because the operator was inexperienced. The higher-than-average cost on Treatment Unit H may also be the result of wet conditions during skid-road construction. The season or type of machine used for skid-road construction does not appear to correlate with the cost per unit.

Soil Disturbance

Areas disturbed by haul roads, landings, fireguards, skid roads, and skid trails are summarized and compared for all twelve treatment units (Table 6). It should be remembered that these estimates were determined using the traverse method and not the current BCMOF survey procedures (BCMOF 1992). For the three cutblocks

Table 4. Harvesting Costs, by Phase: Comparison of Contractors' Operating Costs

Treatment Unit ^a	Contractor	Skidding/trailbuilding (\$/m ³)	Falling/bucking (\$/m ³)	Loading (\$/m ³)	Total (\$/m ³)
A	5	5.49	2.51	2.06	10.06
B	3	3.17	3.39	1.82	8.38
C	4	3.56	2.11	2.21	7.88
D	1	4.99	2.28	1.69	8.96
H	6	9.97	5.50	6.82	22.29
I	6	8.66	4.43	5.30	18.39
J	1	6.12	2.81	1.79	10.72
K	2	5.94	3.02	2.32	11.28
L	2	7.85	3.02	2.88	13.75

^a Production data were insufficient for Treatment Units E, F, and G.

Table 5. Trailbuilding Costs

Treatment Unit ^a	Contractor	\$/m ³	\$/m
A	5	0.97	1.32
B	3	n.a.	n.a.
C	4	0.39	0.56
D	1	0.88	0.85
H	6	1.86	1.87
I	6	2.50	3.51
J	1	0.48	0.49
K	2	1.26	1.44
L	2	n.a.	n.a.

^a Production data were insufficient for Treatment Units E, F, and G.

subdivided into two or more treatment units, haul-road and landing areas (and fireguard area in the case of F and G, H and I) that were common to two or more treatment units were prorated on the basis of treatment unit area.

Estimated soil disturbance levels for the twelve treatment units range from 19.7 to 42.7% of total cutblock area. Skid roads and skid trails represent the largest source of disturbance on every treatment unit, and account for about half to three-quarters of all soil disturbance. Haul roads represent the next largest source, followed by landings. Fireguards were constructed on only six of the treatment units, usually only around landings; overall, fireguards were a minor component of disturbance. Except for two units having high haul-road values, disturbance levels in the haul-road, landing, and fireguard categories are relatively consistent across all treatment units. Most of the variation in overall disturbance levels occurs in the skid-road and skid-trail category.

Influence of Haul Roads, Landings, And Fireguards. Table 7 summarizes dimensions of haul roads and fireguards, and numbers and average areas of landings, for the twelve treatment units.

Variations in haul-road disturbance among the treatment units are explained by differences in average road widths and densities. Average haul-road widths, including sidecast, range from 12.4 m on Treatment Unit F to 19.9 m on Treatment Unit D. Haul-road densities range from 9.9 m/ha on Treatment Unit E to 77.6 m/ha on Treatment Unit C. E, F and G, with the least road-related disturbance, have low road densities and narrow average widths, while Treatment Units A and C have the highest road densities and relatively wide roads.

Haul roads on Treatment Units E, F, G, H, and I were low-standard spur roads and, therefore, narrower on average than on the other treatment units, which contained varying proportions of higher-standard branch and mainline roads. Steep slopes, wet ground at the time of construction, and the use of a large bulldozer contributed to the high average road width on Treatment Unit D. Variations in road densities among the study sites are primarily due to the influences of terrain on options for developing cutblocks.

Landing disturbance is a function of numbers and sizes of landings per cutblock, and these in turn are influenced by cutblock size, terrain, and organizational factors. Each cutblock (but not necessarily each treatment unit) had at least two landings. Even on small cutblocks, operators often prefer to have two landings for reasons of safety and logging efficiency because falling, skidding, delimiting, bucking, and loading activities can be segregated to reduce interference. On larger cutblocks, terrain and organizational factors influence the numbers and locations of additional landings required, but their effects

Table 6. Type of Soil Disturbance by Treatment Unit: Summary

Type of disturbance	Treatment Unit											
	A	B	C	D	E	F	G	H	I	J	K	L
Area (ha)	19.8	24.0	12.2	18.5	25.0	5.5	2.6	13.4	12.9	46.1	25.4	48.2
Haul roads												
ha	2.40	1.62	1.63	0.76	0.36	0.19	0.09	0.97	0.94	2.23	1.23	2.33
%	12.1	6.8	13.3	4.1	1.4	3.4	3.4	7.3	7.3	4.8	4.8	4.8
Landings												
ha	1.00	0.93	0.67	1.04	0.92	0.27	0.13	0.69	0.86	1.45	0.80	1.52
%	5.1	3.9	5.5	5.6	3.7	4.9	4.9	5.2	6.7	3.1	3.1	3.1
Fireguards												
ha	0.43	0.55	0	0	0	0.08	0.04	0.08	0.07	0	0	0
%	2.2	2.3	0	0	0	1.5	1.5	0.6	0.6	0	0	0
Skid roads & skid trails												
ha	4.62	2.86	1.95	5.89	3.64	0.98	0.51	2.86	2.52	9.87	5.48	9.45
%	23.3	11.9	16.0	31.9	14.6	17.7	19.4	21.3	19.5	21.4	21.6	19.6
Total area disturbed												
ha	8.45	5.96	4.25	7.69	4.92	1.52	0.77	4.60	4.39	13.55	7.51	13.30
%	42.7	24.8	34.8	41.6	19.7	27.5	29.6	34.3	34.0	29.4	29.6	27.6

Table 7. Dimensions of Haul Roads, Landings, and Fireguards

	Treatment Unit											
	A	B	C	D	E	F ^a	G ^a	H ^a	I ^a	J ^a	K ^a	L ^a
Contractor	5	3	4	1	3	7	7	6	6	1	2	2
Opening area (ha)	19.8	24.0	12.2	18.5	25.0	5.5	2.6	13.4	12.9	46.1	25.4	48.2
Haul roads						—	—	—	—	—	—	—
Length within study area (m)	1371	971	949	380	248	228		1282			3619	
Average total width (m)	17.5	16.7	17.1	19.9	14.4	12.4		14.9			16.0	
Density (m/ha)	69.2	40.5	77.6	20.6	9.9	27.9		48.7			30.2	
Landings												
Area developed/landing (ha)	6.6	12.0	4.7	9.3	12.5	4.1	6.7	6.5			15.0	
Landings (no.)	3	2	3	2	2	2	2	2			8	
Average landing size (ha)	0.33	0.47	0.22	0.52	0.46	0.20	0.35	0.43			0.44	
Fireguards												
Total length (m)	630	518	0	0	0	279		303		0	0	0
Average width (m)	6.9	7.7	0	0	0	4.4		5.0		0	0	0

^a The following treatment units have common roads, landings, and/or fireguards: F and G; H and I; J, K and L. Road, landing, and fireguard areas have been prorated on the basis of treatment unit area.

are site-specific and not easily generalized or separated. Average area developed per landing reflects the combined effects of these factors and ranges from 4.1 to 15.0 ha over the twelve treatment units.

Average landing sizes range from 0.20 ha on Treatment Unit G to 0.52 ha on Treatment Unit D. Note that landings located on haul roads include road running surface. In general the average area developed per landing increases as landing size increases, from 4.1 to 4.7 ha/landing for the smallest landings to 9.3 to 15.0 ha/landing for the largest landings. Large landings were preferred by contractors with several skidders and where several log sorts were required (e.g. Contractors 1 and 2 on Treatment Units D, J, K, and L). Small landings were preferred by contractors with fewer skidders and minimal sorting requirements (e.g. Contractor 7 on Treatment Units F and G).

Fireguards were prescribed on a site-specific basis and were built by the logging contractor as required. Two winter-harvested treatment units (A and B) required perimeter fireguards and, therefore, had higher levels of disturbance than the other treatment units, which required fireguards around landings only.

Influence of Skid Roads And Skid Trails.

This section considers a variety of environmental and operational factors that could potentially influence skid-road and skid trail-related soil disturbance, referred to here as "skidding" disturbance. Table 6 shows that skid roads and skid trails constitute not only the single largest source of soil disturbance on ground-skidded cutblocks in this study, they also account for much of the observed variability in overall disturbance levels. On all treatment units, skidding networks were comprised mostly of constructed skid roads, with only minor amounts of non-constructed skid trails. Off-trail skidding occurred only in a few treatment units, and produced little measurable soil disturbance.

Table 8 summarizes environmental and operational characteristics, and associated soil-disturbance levels, for the twelve treatment units. The treatment units are ranked in order of increasing skidding disturbance. It is apparent from this table that no one factor predominates as the principal contributor to skidding disturbance. Among the parameters shown, slope, season of harvesting, and size of crawler-tractor for skid-road building, alone or in combination, appear to be the most influential.

Slope. The average slope of the treatment unit shown in Table 8 is the average of the side slopes recorded at all the skid-road and skid-trail cross sections measured on that treatment unit. With minor exceptions, the average

Table 8. Relationships of Operational and Environmental Factors to Levels of Skid-Road and Skid-Trail Disturbance

	Treatment Unit ^a											
	B	E	C	F	G	I	L	H	J	K	A	D
Contractor	3	3	4	7	7	6	2	6	1	2	5	1
Treatment ^b	OC	OC	OC	OC	D	D	D	OC	OC	OC	OC	OC
Harvesting system	Mech.	Mech.	Conv.	Small Cat	Small Cat	Conv.	Conv.	Conv.	Conv.	Conv.	Conv.	Conv.
Crawler-tractor	Large	Large	Small	Small	Small	Medium	Large	Medium	Large	Large	Small	Large
Average sideslope (%)	31	31	31	42	46	42	46	43	42	48	45	45
Season of harvesting	Winter	Summer	Winter	Summer/ Fall	Summer/ Fall	Summer/ Fall	Summer/ Fall	Summer	Summer	Summer/ Fall	Winter	Summer
Skid-roads and skid-trails												
Disturbance												
Incl. sidecast (%)	11.9	14.6	16.0	17.7	19.4	19.5	19.6	21.3	21.4	21.6	23.3	31.9
Excl. sidecast (%)	3.7	13.2	3.9	10.6	13.8	12.9	13.7	15.2	15.8	15.3	6.6	22.5
Density (m/ha)	143	270	325	335	505	287	311	362	310	332	329	449
Width												
Incl. sidecast (m)	8.3	5.4	4.9	5.2	3.8	6.8	6.3	5.9	6.9	6.5	7.1	7.1
Excl. sidecast (m)	2.6	4.9	1.2	3.1	2.7	4.5	4.4	4.2	5.1	4.6	2.0	5.0
Depth (cm)	65	20	45	70	25	60	65	40	70	80	80	90

^a Listed, left to right, in order of increasing soil disturbance.

^b OC = Operator choice; D = Designated

slope is near the midpoint of the range of true ground slopes observed on each treatment unit (see Table 1).

Generally, a side slope of about 35% is considered to be the upper limit at which rubber-tired skidders can work safely off the trail; generally, on steeper slopes, skid roads must be constructed (Figure 4). The results of this study are consistent with this view. Treatment Units B, E, and C have the lowest average side slopes (all 31%), and the lowest levels of skidding disturbance (11.9, 14.6, and 16.0%, respectively). The low levels of disturbance on Treatment Units B and E are attributed to low skid-road and skid-trail densities. These units were harvested with a mechanized feller-buncher/grapple-skidder system, which in normal practice is reserved for favourable terrain where trailbuilding is not necessary. Although skid roads were required on the steeper sections, the low density indicates that dispersed skidding on the gentler portions effectively reduced overall disturbance (Figure 5), although the combined average skid-road and skid-trail width on Treatment Unit B was the highest recorded in this study.

The density of skid roads and skid trails on Treatment Unit C was comparable to the other conventionally harvested treatment units, but the average total width was the second lowest of the twelve treatment units. Therefore, the low skidding disturbance relative to the other conventionally harvested units is attributed to a combination of moderate slopes, the use of a small trailbuilding tractor, and winter harvesting.

Skidding disturbance does not correlate well with side slope on the remaining nine treatment units, which had average side slopes in excess of 40%. Combined skid-road and skid-trail densities for Treatment Units F, L, H, J, K, and A are comparable within a range of 310-362 m/ha. (Treatment Unit C, discussed above, also falls within this range.) Combined average skid-road and skid-

trail widths for these units range from 5.2 to 7.1 m and encompass small, medium, and large trailbuilding tractors. Therefore, among these units, any effect of slope on skidding disturbance appears to be overshadowed by other influences.

To further examine the role of slope, skid-road cross sections were combined and averaged for all treatment units except D and J (where the Caterpillar D8H operated) and summarized into four slope classes. Figures 6, 7, and 8 illustrate resulting trends in average width and depth by slope class. (The distribution of cross sections by trailbuilder size class was similar for each slope class, so differences due to trailbuilder size are minor.) The graphs show that average widths and depths increase steadily as slope increases for both summer- and winter-built skid roads. The rate of increase in width is greater for winter-built than summer-built skid roads, and depth of cut increases at a faster rate than width.

Over a slope range of approximately 25 to 55%, combined width of cut-plus-running surface increases only 0.3 m in summer and 0.5 m in winter (Table 8, and Figures 6 and 7, respectively). This demonstrates that once slopes are steep enough to require the skidders to travel on constructed skid roads, the running surface must be wide enough to accommodate the skidder regardless of side slope. The rapid increase in depth of cut suggests that the running surface is moved further into the sidehill as slopes become steeper. The width of the sidecast increases at a faster rate than the cut-plus-running surface because of the steeper slope and increased volume of excavated soil.

Season of Harvesting. Levels of skidding disturbance on the three winter-logged sites were: Treatment Unit B-11.9%, Treatment Unit C-16.0%, and Treatment Unit A-23.3% (see Table 8). (Note that skidding disturbance on these treatment units was measured after snow had



Figure 4. Medium-sized rubber-tired skidder hooking up a turn from skid road.

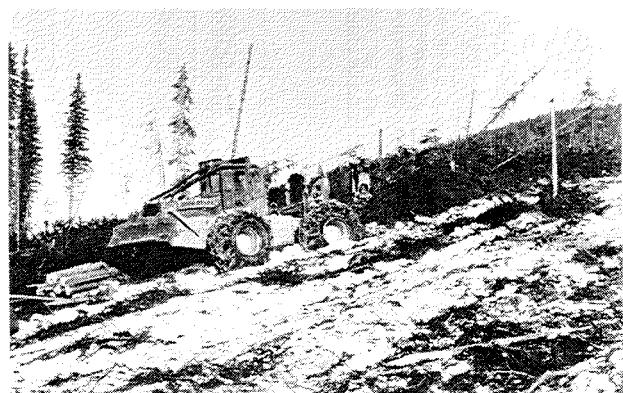


Figure 5. Grapple skidder working in a dispersed downhill pattern between skid roads.

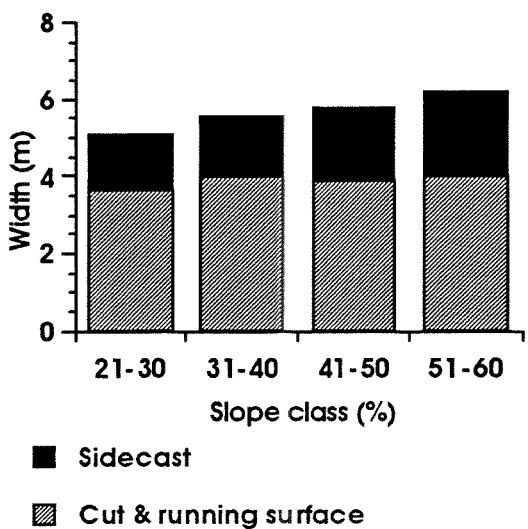


Figure 6. Width of summer-built skid roads, by slope class.

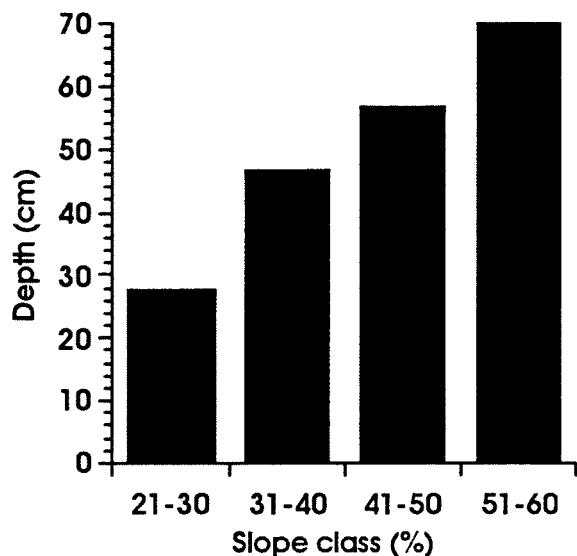


Figure 8. Depth of summer-built skid roads, by slope class.

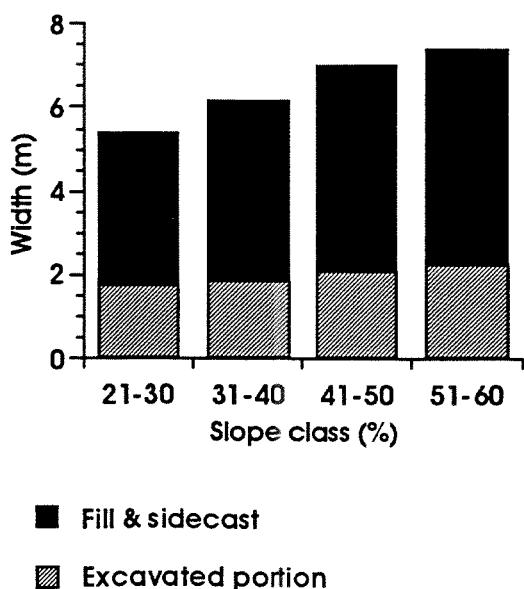


Figure 7. Width of winter-built skid roads, by slope class.

melted.) The low disturbance levels on B and C were attributed earlier to favourable terrain and low skid-road and skid-trail densities associated with the mechanized harvesting system on Treatment Unit B, and the use of a small trailbuilding machine on Treatment Unit C, rather than to harvesting on winter snow packs. The contractor on Treatment Unit A also employed a small trailbuilder and achieved virtually the same skid-road and skid-trail density as the contractor on Treatment Unit C, but built much wider skid roads. On Treatment Unit A,

skid roads and skid trails had a combined average width of 7.1 m; in comparison, combined average width on Treatment Unit C was 4.9 m.

However, disturbance estimates that are based on average widths alone do not account for substantial differences observed in the character of summer- and winter-built skid roads. Figures 6 and 7 show that winter-built skid roads were consistently wider than summer-built skid roads for every slope class. However, in contrast to summer-built skid roads, which have compacted running surfaces, most of the running surface of winter-built skid roads disintegrates into a loose, uncompacted mixture of organic debris and mineral soil once the snow melts. Thus a much smaller proportion of winter-built skid roads consists of excavated and compacted mineral soil. Figure 9 shows a typical winter-built skid road on a deep snow pack, and Figure 10 compares dimensions of summer and winter skid roads built on similar slopes with a Caterpillar D7G bulldozer.

Trailbuilder Size. Although Figures 6, 7, and 8 show that slope steepness influences skid-road dimensions, there appears to be little correlation between average skid-road widths, side slope, and trailbuilder size in Table 8. To examine the influence of trailbuilder size, therefore, skid-road cross sections were grouped and averaged by machine class and slope class. As with slope steepness, a trend of increasing skid-road width with increasing size of machine emerged. The trend illustrated in Figure 11, which compares average widths of skid roads built on 31-40% side slopes by four different machine sizes, is typical.



Figure 9. Cut-away of winter-built skid road showing snow mixed in the fill portion of the running surface.

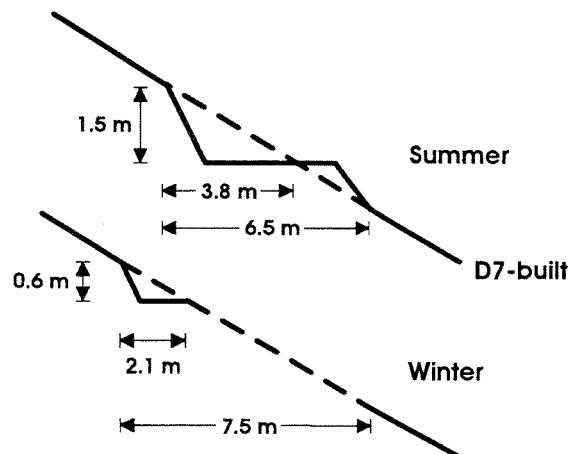


Figure 10. Profiles of summer- and winter-built skid roads on a 50% slope.

This demonstrates that there is a relationship between skid-road dimensions and the size of crawler-tractor used for skid-road construction, but this relationship alone does not explain the wide variation in average skid-road and skid-trail widths observed among the twelve treatment units shown in Table 8. (Although widths are expressed as averages for skid roads and skid trails combined, the proportion of skid trails for all units was very minor and had little effect on these averages.) Even for units on which similar-sized machines operated, the range of widths was large. For instance, on units where only small crawler-tractors operated, widths varied from 3.8 to 7.1 m. Differences were also evident for similar-sized machines operating on units harvested in the same season, and also for those units on similar slopes; however, these ranges were not as large. It appears that the influences of other factors overshadowed some of the effects of machine size.

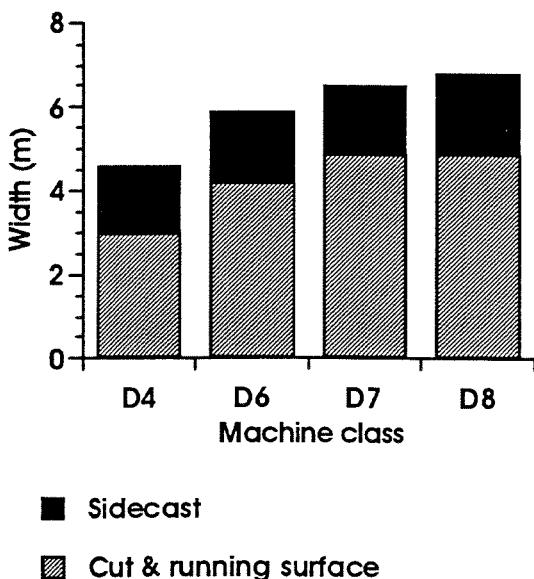


Figure 11. Widths of skid roads, by machine class.

Other Observations

Other important factors that probably influence skid-road and skid-trail widths, but are difficult to quantify, are the types and sizes of skidders used and the experience of the trailbuilder operator both in locating and building skid roads. In choosing equipment, logging contractors are careful to ensure that trailbuilders and skidders are well matched. The trailbuilder must be capable of building skid roads that are wide and firm enough to fully support the rubber-tired skidders. Switching to a smaller trailbuilding machine will not necessarily reduce skid-road dimensions if the skidders are not downsized also. It is important for the trailbuilder operator to construct skid roads that ensure efficient skidding and that are safe to operate on, especially on steep side slopes. The experience and skill of the trailbuilder operator in selecting skid-road locations that take advantage of the terrain can affect both the width and total length of skid roads and skid trails needed to harvest a given site.

The focus of this discussion has been primarily on the amount of area occupied or disturbed by skid roads and skid trails. While not all disturbance is detrimental, processes such as compaction, displacement, and erosion increase the likelihood of site degradation. The sensitivity of a site to these processes can depend on soil texture, terrain, and climatic conditions (Lewis 1991). Although these processes were not assessed as part of the study, it is obvious that the factors that influence the level of soil disturbance also affect its severity. For example, displacement is directly influenced by the amount of soil excavated, which increases with the size of the

trailbuilder and with slope steepness, and is more predominant with summer-built skid roads than with winter-built skid roads. Another example is soil compaction that is affected by the frequency and weight of machine traffic; obviously skidding in winter on a snow pack or frozen ground can decrease the impacts of machine travel. As well, the incidence of surface erosion is affected by the extent of soil exposure (i.e. level of soil disturbance) and the slopes of these exposed surfaces. Finally, slumping and ravelling can occur when slopes are loaded with sidecast material, and therefore these processes can be influenced by the amount of soil excavated.

Comparisons of Designated and Operator-Choice Skid-Road Location Methods

Rationale For Trials. In order to test the hypothesis that preplanning and designating skid roads reduces the total length, or density, of skid roads required to harvest a given site, three cutblocks were subdivided into side-by-side units for comparative trials. On one unit in each pair, skid roads were preplanned (designated) and marked in the field prior to harvesting, and on the other unit the contractor located and built skid roads according to standard practice (operator-choice). On each designated skid-road unit, the contractor was permitted to build additional skid roads if deemed necessary. The contractor assigned to the cutblock harvested each unit consecutively using the same equipment on each unit. It was expected that the side-by-side comparisons would eliminate contractor differences and minimize site differences that might otherwise influence the results.

Procedures For Designating Skid Roads. Designated skid roads were used on Treatment Units G, I and L. The same layout engineer located the skid roads on all three treatment units, but the procedures for locating skid roads varied from treatment unit to treatment unit. On Treatment Unit L, skid roads were located to take advantage of minor benches and dry gullies that traversed the treatment unit (Figure 12). Only the main skid roads were located, and the goal was to space skid roads one tree length or more apart. Only the area supervisor had input into the location of the designated skid roads prior to layout and the location could be changed only with his permission. However, wherever the trailbuilder operator felt that skid roads were spaced too far apart to retrieve stems from the skid roads, he was permitted to construct additional branch or secondary skid roads. Some changes to the main skid-road locations were made because rock impeded construction, and some minor changes to skid-road junctions were also made. Nine mandays were required to locate approximately 14 km of skid roads on Treatment Unit L, including return visits to make location amendments.

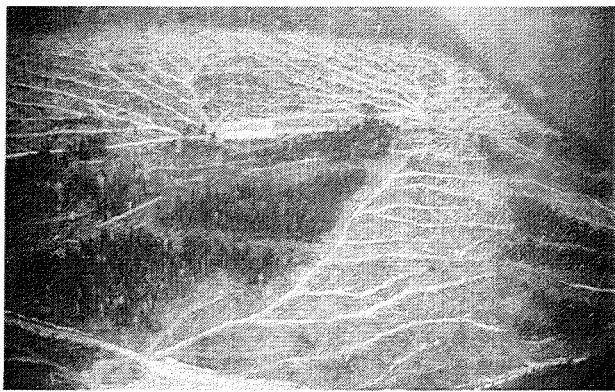


Figure 12. Skid-road patterns: upper area—operator-choice skid roads on Treatment Unit J, lower area—designated skid roads on Treatment Unit L.

On Treatment Unit I, skid-road layout occurred in only a portion of the unit at a time and progressed with the construction of the haul roads and landings, which were not completed prior to the commencement of harvesting. As a consequence, the layout engineer had to make five visits to locate almost 4 km of skid road. However, frequent visits to the site proved to be beneficial as they allowed the engineer the opportunity to locate skid roads with direct input from the trailbuilder and faller. It was also easier to identify problem areas, such as wet soils, as skidding progressed. In addition, the engineer felt that better skid-road entry and exit points could be located after completion of haul-road and landing construction.

The BCMOF area supervisor and the contractor initially provided input to the location of skid roads, with the goal of reducing soil disturbance by spacing trails wider apart than normal. The average distance between skid roads was to be about 40 m. Spacings were closer where trees were shorter, and wider where trees were taller. The layout was also to take advantage of benches and slope breaks wherever possible (Figure 13).

On Treatment Unit G, skid roads were laid out prior to harvesting at a spacing of about 1.5 tree lengths. The terrain was fairly even and tree height fairly uniform throughout the block.

Effect of Skid-Road-Location Method on Harvesting Practices. Standard falling and skidding techniques were used on the operator-choice units. On most treatment units a narrow 5-m band of trees immediately above contour skid roads was felled parallel to the skid road. Above this, the wide band of trees that extended up to the next skid road were felled in a herringbone pattern with tops landing on or very close to the skid road. Crews



Figure 13. Designated skid roads on Treatment Unit I.

were split on their preference to skid stems with butts or tops first; however, the majority of stems were top-skidded due to the pattern of falling. In some areas where skid roads were spaced further apart than normal, or where the stems were short or felled away from the skid road, the skidder operator travelled off-trail to push stems onto the lower skid road or to hook up stems between skid roads. This practice was usually restricted to slopes under 45%. Another option was to pull more winch line up-slope from the lower skid road to reach these logs; however, operators were usually more reluctant to do this because of the extra effort required, particularly in snow. On some units, a chokerman assisted the crawler-tractor skidder operator to hook stems.

For designated Treatment Unit I, the wider-than-normal spacing of skid roads plus the BCMOF requirement for skidders to stay on the skid roads resulted in changes in skidding and falling practices. The falling patterns varied from the above-mentioned operator-choice treatment units by having an additional 10-m band of trees immediately below the skid roads felled parallel to and with the butts in lead with the skidding direction. Although pulling winch line downslope is less strenuous than pulling upslope for the same distance, and despite the modified falling pattern, the skidder operators still felt they were pulling more line than on conventional treatment units.

Some skidders were also modified with longer-than-normal winch lines. The trailbuilder was equipped with a radio-controlled, power "spool-out" winch (with a reach of 26 m). Conventional winch systems are spooled out manually by pulling the line when the winch is in neutral, and they can be operated only from inside the cab. The radio-controlled winch allowed the operator to winch in and spool out line from outside of the cab (by way of a mobile radio). Reducing the "drag" on the line-out and being able to avoid getting in the cab to operate the winch

every time made it easier to hook stems that were well off the skid road. Because the trailbuilder spent most of its time constructing skid roads, the system was used infrequently for skidding and was primarily reserved for situations where the other skidders could not reach the stems from the skid road.

On designated Treatment Unit L the lean of the timber and the prevailing winds on the site sometimes prevented trees from being felled in a herringbone pattern, which made hookup difficult. If this problem had been identified during planning, skid-road and possibly landing locations could have been altered to accommodate the lean of the trees.

On Treatment Unit G, the single small crawler-tractor was not restricted to the designated skid roads. The operator felt that the grade of some of the designated skid roads was too gentle. The crawler would often travel downhill between skid roads to hook up stems or to access the landings more directly, similar to the conventional portion. This practice created additional skid trails and increased overall lengths and densities of skid roads and skid trails.

Productivity And Cost: Shift-Level Results. Table 3 compares log production for the side-by-side trials of two of the contractors (production information was not collected for Contractor 7 on Treatment Units F and G). For Contractor 6, piece production was almost identical for both the operator-choice Treatment Unit H and designated Treatment Unit I. However, volume production of 151 m³/shift (8 h) on the designated unit was almost 50% higher than the 104 m³/shift of the operator-choice unit because of the larger piece size.

Although the number of machines per shift was higher on the designated unit, the number of skidded turns were comparable on both. This was due to the trailbuilder spending a higher proportion of the time skidding on the operator-choice unit, rather than constructing skid roads.

With Contractor 2, the low number of turns per shift on designated Treatment Unit L was offset by the high number of pieces in each turn and resulted in production comparable with Treatment Unit K. However, volume production was 18% lower on the designated unit—283 m³/shift compared to 343 m³/shift for the operator-choice unit. This difference was due to the smaller piece size on the designated unit.

To improve production, which had declined from the operator-choice unit, an extra chokerman was added to assist the crawler-tractors. This may account for the higher number of stems choked and skidded per turn on the designated unit than on the operator-choice unit. The

fewer turns per shift experienced on the designated unit may be due to longer cycle times, especially travel times that occurred as a result of the increased skid distances (see section on detailed timing).

For both side-by-side trials, the analysis indicates that the differences in production rates were due mainly to piece size and skidding distance, and not to the method of skid-road layout.

Phase costs of the paired treatment units can be compared in Table 4. Note that these costs exclude the additional costs of skid-road layout on the designated skid-road units. The total harvesting costs per m³ on designated Treatment Unit I were 17% lower than its operator-choice counterpart Treatment Unit H. Similar cost reductions were evident in all phases. Cost reductions are attributable to the higher productivity rate on the designated unit. However, the percent cost reduction did not match the proportional increase in productivity because,

although the same system was used, the number of machines used per shift on Treatment Unit I, and therefore the total machine cost, was higher.

Total costs on designated Treatment Unit L were 22% higher than on the paired operator-choice Treatment Unit K. Lower volume production rates on Treatment Unit L accounted for most of the differences. Skidding costs were also higher because of the addition of another chokerman for many of the shifts. There were no differences in falling and bucking costs because a second full-time buckerman was added on Treatment Unit K, thus offsetting the effects of the low production rates on Treatment Unit L.

Detailed-Timing Results. A comparison of skidder cycle times and elements for Treatment Units H and I is shown in Table 9 (cycle element definitions are included in Appendix II). The table summarizes detailed-timing information for the rubber-tired skidders only. The

Table 9. Comparison of Skidding Cycle Times

	Treatment Unit	
	H	I
Treatment ^a	OC	D
Cycles timed (no.)	79	49
Average skidding distance		
Empty (m)	213	221
Loaded (m)	205	197
Total pieces skidded (no.)	396	259
Average pieces/cycle (no.)	5.0	5.3
	Time (min)	% of total
	Time (min)	% of total
Cycle time elements ^b		
Travel empty	2.08	12.2
Hookup		
Manoeuvre	0.71	4.2
Set chokers	6.24	36.4
Winch	<u>1.05</u>	<u>6.1</u>
Subtotal	8.00	46.7
Travel loaded	2.21	12.9
Landing activity	3.67	21.5
Delay	<u>1.16</u>	<u>6.8</u>
Total cycle time	17.12	100.0
	19.25	100.0

^a OC = Operator choice; D = Designated

^b Cycle time elements are defined in Appendix II.

results are based on 79 turns for Treatment Unit H and 49 turns for Treatment Unit I.

Total cycle time was 17.1 min for the operator-choice unit and 19.2 min, or 12% longer, for the designated unit. A small portion of the extra cycle time was due to delays. However, the delays that were recorded were not caused by the treatment.

Both travel empty and travel loaded time elements were very similar and did not seem to be affected by the type of treatment.

The "loading" elements (manoeuvre, choke, and winch), as might be expected, showed the greatest difference between the treatments. Total loading time was 22% greater for the designated skid-road unit. Most of this time difference was due to longer manoeuvring time and some of it was due to additional winching time. Manoeuvre time included not only backing up to or positioning the skidder adjacent to a load, it also included time spent moving while loading (i.e., with only a partial load the skidder would re-position to hook up additional stems). Each time the skidder moved to hook a partial load, further winching was usually necessary. This increased turn (cycle) time measured on the designated unit was not evident in the shift-level summary.

Detailed timing was done only on designated Treatment Unit L, and was not done on Treatment Unit K. To illustrate the possible effect on travel time of the different skidding distances for Treatment Units K and L, average skidding distances for both were put in the same regression equation derived from the designated unit's cycle times. The 95-m longer average skidding distance for the designated skid-road unit resulted in an increase in cycle time of 1.2 min, which represents about a 5% increase in total cycle time. This could partially explain the lower number of turns per shift recorded for Treatment Unit L in the shift-level productivity summary (Table 3).

The differences in volume production and costs of the side-by-side treatment units were largely due to differences in piece size. Other factors that appeared to influence the results were differences in skidding distances, differences in the number of machines scheduled per shift, and the shifting of crew activities (i.e. between the buckerman and chokerman). The detailed-timing analysis on Treatment Units H and I showed increased cycle times for the designated units. However, the use of designated skid roads may not be the only factor influencing the results. Although the contractor's equipment didn't change between paired units, there were changes in operating personnel, weather and soil conditions, as well as in piece size.

Soil Disturbance. Table 10 summarizes soil disturbance caused by skid roads and skid trails for two of the paired trials (Treatment Units F and G were excluded because their small areas did not allow for good comparisons). The results show that for both of the designated units (I and L) skid-road and skid-trail disturbance was only slightly lower than their operator-choice counterparts.

Skid-road and skid-trail densities were also lower on the designated units and represented reductions of 21% within the H and I pair, and 6% within the K and L pair. Average spacing for skid roads and trails combined was 28 and 35 m for Treatment Units H and I respectively, and 30 and 32 m for Treatment Units K and L respectively. The percentage reductions in skid-road and skid-trail densities from Treatment Unit H to Treatment Unit I did not match the reduction in disturbance levels because of the offsetting effect of having wider skid roads and skid trails; they averaged 6.8 m on Treatment Unit I compared to 5.9 m on Treatment Unit H.

The main reason for the differences in skid-road and skid-trail widths and densities of Treatment Units H and I was the change in skidding patterns. Designated skid roads were constructed mostly across the slope, with very few additional skid trails established; on the operator-choice unit, many skid trails ran downhill between main contour skid roads (Figure 14). The downhill trails were generally very narrow with shallow cuts and very little sidecast. These trails reduced the overall combined average widths of skid roads and skid trails in Treatment Unit H. The close spacing of these downhill trails resulted in higher trail densities on Treatment Unit H. On both Treatment Units K and L, skidding patterns remained similar and skid roads and skid trails ran mostly with the contour, resulting in only minor differences in the operator-choice and designated treatments.

Although skid-road and skid-trail disturbance for the designated blocks was less than on the adjacent operator-choice treatment units, the disturbance was still within the wide range found on the other conventional treatment units in the study.

CONCLUSIONS

This study was initiated to address concerns about high levels of soil disturbance associated with ground skidding on steep slopes. Evans Forest Products Company and the Golden Forest District of the BCMOF conducted a series of harvesting trials from 1988 to 1990. FERIC monitored the trials and investigated the performance, in terms of productivities and soil-disturbance levels, of several typical or "conventional" ground-skidding systems on steep slopes in the East Kootenays, and consid-

Table 10. Soil Disturbance Caused by Skid Roads and Skid Trails on Side-By-Side Treatment Units: Summary

	Treatment Unit			
	H	I	K	L
Treatment ^a	OC	D	OC	D
Treatment unit area (ha)	13.4	12.9	25.4	48.2
Average sideslope (%)	43	42	48	46
Skid roads and skid trails				
Dimensions (width)				
Cutslope (m)	0.6	0.6	1.0	0.9
Running surface (m)	3.6	3.9	3.6	3.5
Sidecast (m)	1.7	2.3	1.9	1.9
Total width (m)	5.9	6.8	6.5	6.3
Average trail gradient (%)	22	10	10	11
Depth of cut (cm)	40	60	80	65
Percent of area disturbed by skid roads and skid trails				
Total (incl. sidecast) (%)	21.3	19.5	21.6	19.6
Cut and running surface only (%)	15.2	12.9	15.3	13.7
Skid-road and skid-trail density				
Metres of trail per ha	362	287	332	311

^a OC = Operator choice; D = Designated

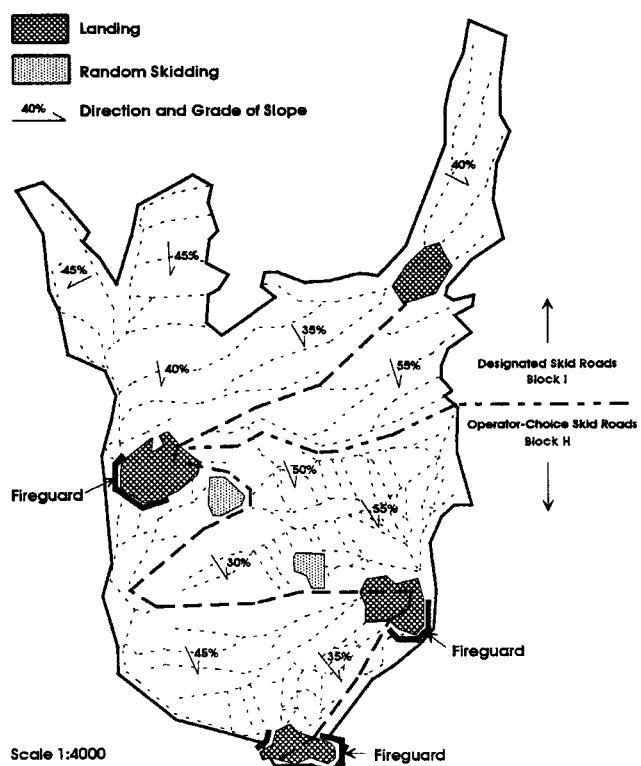


Figure 14. Map of Treatment Units H and I.

ered the opportunities and limitations of the concept of designated skid-road planning relative to conventional practice of operator-choice skid roads.

The principal conclusions of the study are summarized here and discussed in further detail in the following paragraphs.

- Log production and harvesting costs of conventional ground-skidding systems working on steep slopes vary widely because of the great variety of operating and site conditions present in Interior forests; the values found in this study are representative of this range. For the same reasons, soil-disturbance levels likewise exhibit a large variation, and skid roads and skid trails account for the majority of harvesting-related disturbance.
- Slope steepness, season of harvesting, and machine size all influence skid-road disturbance levels, but no one factor predominates. However, in examining the individual effects of these factors on soil disturbance, it was shown that there is potential to reduce skid-road and skid-trail occupancy by reducing their dimensions.
- In the side-by-side comparisons tested by FERIC, the designated skid-road system had very little effect on reducing skid-trail and skid-road disturbance, or

on increasing harvest costs due to the offsetting effects of other operational and site factors.

- Soil disturbance caused by conventional ground-skidding systems working on steep slopes can be reduced through careful planning, which includes consideration of the interactions and effects of various operational and environmental factors on disturbance levels.

Log production and harvesting costs varied widely among the nine operations and six harvesting contractors. Volume production ranged from 104.0 to 444.8 m³/8-h shift, and the cost of logs loaded onto the truck ranged from \$7.88 to \$22.29/m³ (based on 1991 costs). Three contractors harvested two blocks each, and all experienced production and cost differences of more than 20% from one block to the other.

Excluding the contractor who experienced the lowest productivity levels and highest costs due to special circumstances, productivity still ranged from 283.2 to 444.8 m³/8-h shift and costs from \$7.88 to \$13.75/m³. This range in costs is considered typical for conventional ground-skidding systems operating on steep slopes in the Interior of British Columbia.

The large range in both the productivity and cost results reflects the interaction of the wide variety of organizational, operational, and environmental circumstances represented in the study sites. First, the conventional system itself encompasses a large range of equipment types, sizes, and numbers—from single small- or medium-sized skidders or tractors to fleets of large machines—and the productive capacity of the conventional system varies accordingly. The productivity and cost results presented here cover a substantial range of equipment options, including one contractor with a mechanized feller-buncher/grapple-skidder system and five contractors with varying combinations and sizes of tracked and rubber-tired skidders. Operational and environmental circumstances also varied widely between the study sites. For example, average skidding distances ranged from 159 to 345 m, average side slopes from 31 to 48%, timber volumes from 228 to 523 m³/ha, and average piece sizes from 0.55 to 1.19 m³; harvesting occurred in all seasons and weather conditions; and terrain varied from simple to complex. Therefore, the large range in both production and costs in this study is not unusual.

Skid roads and skid trails accounted for about 50 to 75% of all soil disturbance and explained most of the variation in overall disturbance levels among the twelve treatment units. Soil disturbance caused by skid roads and skid trails (i.e. skidding disturbance) ranged from

11.9 to 31.9% of total cutblock area. It should be noted that these values were derived using the traverse method, and that the surveying procedures described in the current BCMOF measurement guidelines (Curran and Thompson 1991) could result in different estimates. Low levels of skidding disturbance were associated with gentle slopes, mechanized harvesting systems (with dispersed skidding where feasible), winter harvesting on snow, and/or use of small crawler-tractors to build skid roads. The highest skidding disturbance occurred on a cutblock of steep average slope; skid roads had been constructed in wet spring weather by a large tractor and the cutblock then harvested using a technique that required a dense network of skid roads.

Skidding disturbance is the cumulative effect of many environmental and operational factors that influence both the width and the total length (or density) of skid roads and skid trails. Results of this study indicate that several factors do influence skidding disturbance, but no one factor is a reliable predictor by itself. Of the parameters investigated, slope steepness, size of machine used to build skid roads, and season of harvesting, alone or in combination, were found to influence skid-road and skid-trail width. Slope steepness affects the need to construct skid roads for reasons of efficiency and safety, and it affects skid-road dimensions. In this study the density of skid roads and skid trails was relatively consistent on slopes of more than 35%, and overall widths and depths of cuts on skid roads were found to increase steadily with increasing slope. Likewise, skid-road widths on similar slopes were found to increase as machine size increased. Winter skid roads were wider than summer skid roads on similar slopes, but the width of the zone of excavated and/or compacted soil was much less. The factors that influence the area disturbed/occupied by skid roads and skid trails also affect the processes that contribute to site degradation.

The implementation of the designated skid-road location method for each trial unit differed in the layout criteria used, input into skid-road location (i.e. contractor, machine operator, faller, harvesting supervisor), the amount of flexibility in modifying the planned skid-road network, and whether the skidders were restricted solely to constructed skid roads.

In two paired comparisons, the designated units had reduced skid-road and skid-trail densities and thus less skidding disturbance (19.5 to 19.6%) relative to the operator-choice counterparts (21.3 to 21.6%). However, the reductions in density were not proportionate to the reductions in the disturbance levels due to differences in skid-road and skid-trail widths on the units. If the method of designating skid-road location is to be used to reduce soil disturbance, the influence and interaction of

various site factors on total length and dimensions of skid roads and skid trails have to be considered in designing a layout plan.

It must be remembered that the study sites were on steep and difficult terrain that constrained skid-road locations. The field planner attempted to maintain wide skid-road spacings, but also had to ensure that skid roads took advantage of benches and slope breaks, and avoided rocky areas and wet ground.

The effects of the designated skid-road location method on log production and costs could not be concluded. For similar skidding distances, skidding cycle times on one designated unit were about 12% higher than on its paired operator-choice unit, with most of the increase occurring in the hook-up phase. Other factors being equal, production should decrease and costs should increase for the designated system relative to conventional practice. However, shift-level production for the designated system increased by 45% in one side-by-side trial and decreased by 18% in the other, i.e. relative to the operator-choice method. Differences in average piece size, skidding distances, and other operating conditions appear to have overshadowed any potential effects of increased cycle times. In designating skid-road locations the following factors should be considered to optimize harvesting efficiency and maintain safety: contractor equipment profiles, skidding patterns, skid-road alignment and grade, tree height, lean of trees, falling direction, and season of operation.

Two good references that discuss some general skid-road design considerations are: *Handbook for Ground Skidding and Road Building in British Columbia* (Forest Engineering Research Institute of Canada 1976), and *Designated Skid Trails to Minimize Soil Compaction* (Garland 1983).

RECOMMENDATIONS

When considered against the backdrop of production and soil-disturbance results of the conventional or operator-choice method of skid-road location, the designated method did not significantly reduce skid-road-related disturbance or increase harvesting costs. Although improvements are possible, it is probably unrealistic to expect dramatic reductions in disturbance levels relative to conventional practice simply by applying the designated method more rigidly, at least for the steep and difficult sites considered in this study. However, a benefit of using designated skid roads on difficult terrain is that the site is thoroughly inspected and the most favourable locations for the skid roads are identified in advance. It is important on such sites to ensure that main skid roads

are located to form an efficient skidding network, and to avoid sensitive areas and reduce excessive cuts and fills.

If the need to reduce skid-road and skid-trail disturbance is the main reason for designating skid roads in advance of harvesting, the designated skid-road concept must be part of a more comprehensive approach that includes area planning, development, and operational strategy. Since the study commenced, forest industry and BCMOF personnel have become increasingly aware of the effects of harvesting activities on soil disturbance and have initiated some changes to harvesting operations. Recent cutblock surveys (Thompson and Osberg 1992) have shown that throughout the Interior of British Columbia disturbance levels have generally decreased since this trial was undertaken. However, still of concern are ground-based harvesting systems operating on steep slopes. FERIC believes that a reduction of disturbance levels, and a higher frequency of compliance with the current guidelines, are possible especially on sites of low and moderate degradation sensitivity. The following recommendations suggest a process and identify the critical elements of a program to accomplish this goal when using ground-based harvesting systems. Some of these recommendations are discussed in greater detail in *Planning and Operational Strategies for Reducing Soil Disturbance on Steep Slopes in the Cariboo Forest Region, British Columbia* (Krag et al 1991).

- Larger-scale, total-chance planning must be undertaken to ensure that haul-road and landing locations are optimized for the entire development area, not just for individual cutblocks. Cutblocks should be configured around the road network.
- A soil-disturbance target must be established for each cutblock, and options for achieving this target must be reviewed before block boundaries are finalized. In assessing the feasibility of a harvesting option it is necessary to estimate how much soil disturbance is likely to be caused. The option selected must also ensure that harvesting can be done safely and efficiently. Alternative harvesting systems or techniques may be indicated, such as:
 - Use of smaller tractors or skidders on steeper slopes within the cutblock.
 - Roadside harvesting where possible to reduce landing construction and to shorten skidding distances.
 - Use of small excavators rather than bulldozers to build skid roads.
 - Use of low-ground-pressure skidders.
 - Harvesting in winter rather than summer.
- Within cutblocks that are prescribed for ground-based systems, skidding patterns must be considered carefully, and from this the locations of the main skid roads should be determined. The process

- should involve the harvesting contractor, especially on difficult sites where compromises between harvesting productivity and soil disturbance are required.
- Harvesting plans, including skid-road and skid-trail layouts, must be discussed and reviewed with the contractor and harvesting crews before operations begin. Specific points that should be discussed and agreed upon at this time are:
 - Degree of latitude the contractor has to build extra skid roads.
 - Opportunities for, and constraints on, travelling off skid roads (e.g. taking shortcuts between skid roads when travelling loaded or empty).
 - Widening or repairing skid roads for reasons of safety.
 - What to do if unforeseen problems arise.

In conclusion, this study has shown that many inter-relating factors affect productivity, cost, and soil-disturbance levels when ground skidding on steep terrain. This makes planning difficult and trade-offs must be made. Plans must be tailored to site-specific conditions and still be flexible enough to allow modification in the event of unforeseen problems.

An assumption could be made from this study that all soil disturbance has an equal and negative effect on site productivity. This is clearly not the case and research must continue to establish the consequences of all forms of disturbance on tree growth. Furthermore, this research must be presented in a manner that field planners can use to guide their decisions when planning conventional harvesting operations.

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APPENDIX I

Machine Cost Analysis: Caterpillar D7G Crawler-Tractor (1991 Costs)

Ownership costs - input	
Purchase price (P), f.o.b. Cranbrook, B.C. (\$)	295 300
Salvage value (S), (30% of P) (\$)	88 590
Expected life (y) (y)	5.9
Expected life (h) (h)	10 000
Interest rate (Int) (%)	12.5
Insurance rate (Insur) (%)	2
Ownership costs - results	
Average investment (AVI) = $(P+S)/2$ (\$)	191 945
Loss in resale value = $(P-S)/h$ (\$)	20.67
Interest = $(\text{Int} \cdot \text{AVI})/(h/y)$ (\$)	14.16
Insurance = $(\text{Insur} \cdot \text{AVI})/(h/y)$ (\$)	2.26
Operating and repair costs - input	
Hourly fuel consumption (L) (L/h)	27.5
Fuel cost (fc) (\$/L)	0.35
Annual operating supply cost (O) (\$)	8 860
Track & undercarriage life (TL) (h)	5 000
Track & undercarriage replacement cost (T) (\$)	31 350
Annual repair & maintenance cost (R) (\$)	12 138
Wages (W) (\$/h)	19.34
Wage benefit loading (WBLLK) (%)	35
Operating and repair costs - results	
Hourly fuel cost = $(L) \cdot (\$/L)$ (\$/h)	9.63
Lube & oil cost = 10% of hourly fuel cost (\$/h)	0.96
Operating supply cost = $O/(h/y)$ (\$/h)	5.23
Track & undercarriage cost = (T/TL) (\$/h)	6.27
Repair & maintenance cost = $R/(h/y)$ (\$/h)	7.16
Labour cost = $(W) \cdot [1+(WBL/100)]$ (\$/h)	26.11
Total operating and repair cost (\$/h)	55.36
Total cost - results	
Loss in resale value (\$/h)	20.67
Insurance (\$/h)	2.26
Operating and repair costs (\$/h)	55.36
Total machine cost (excluding interest cost) (\$/h)	78.29
Interest cost (\$/h)	14.16
Total machine cost (including interest cost) (\$/h)	92.45

Machine Cost Analysis: Caterpillar 518 Rubber-Tired Skidder (1991 Costs)

Ownership costs - input

Purchase price (P), f.o.b. Cranbrook, B.C. (\$)	128 100
Salvage value (S), (30% of P) (\$)	38 430
Expected life (y) (y)	4.7
Expected life (h) (h)	8 000
Interest rate (Int) (%)	12.5
Insurance rate (Insur) (%)	2

Ownership costs - results

Average investment (AVI) = (P+S)/2 (\$)	83 265
Loss in resale value = (P-S)/h (\$)	11.21
Interest = (Int • AVI)/(h/y) (\$)	6.11
Insurance = (Insur • AVI)/(h/y) (\$)	0.98

Operating and repair costs - input

Hourly fuel consumption (L) (L)	15
Fuel cost (fc) (\$/L)	0.35
Annual operating supply cost (O) (\$)	3 440
Annual tire consumption (T) (no.)	2
Tire replacement cost (\$/T)	1 250
Annual repair & maintenance cost (R) (\$)	11 271
Wages (W) (\$/h)	18.79
Wage benefit loading (WBLLK) (%)	35

Operating and repair costs - results

Hourly fuel cost = (L) • (\$/L) (\$/L)	5.25
Lube & oil cost = 10% of hourly fuel cost (%)	0.53
Operating supply cost = O/(h/y) (\$/h)	2.02
Tire cost = T • (\$/T)/(h/y) (\$/h)	1.47
Repair & maintenance cost = R/(h/y) (\$/h)	6.62
Labour cost = (W) • [1+(WBL/100)] (\$/h)	25.37

Total operating and repair cost (\$/h)	41.25
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Total cost - results

Loss in resale value (\$/h)	11.21
Insurance (\$/h)	0.98
Operating and repair costs (\$/h)	41.25

Total machine cost (excluding interest cost) (\$/h)	53.44
Interest cost (\$/h)	6.11

Total machine cost (including interest cost) (\$/h)	59.55
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APPENDIX II

Cycle Elements: Definitions

Time element	Begins	Ends
Travel empty	When skidder starts to travel away from landing.	When skidder stops travel near target turn.
Manoeuvre	End of travel empty.	When skidder is in position and operator leaves machine.
Hookup	End of manoeuvre.	When turn is hooked up and operator re-enters skidder.
Winch	End of hookup.	When skidder starts steady travel towards landing.
Travel loaded	End of winch.	When turn reaches unhooking location on landing.
Landing	End of travel loaded.	When skidder moves away from the landing.
Delay	When a productive function is interrupted.	When a productive function recommences.