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PLANNING AND OPERATIONAL STRATEGIES FOR REDUCING SOIL DISTURBANCE ON STEEP SLOPES IN THE CARIBOO FOREST REGION, BRITISH COLUMBIA

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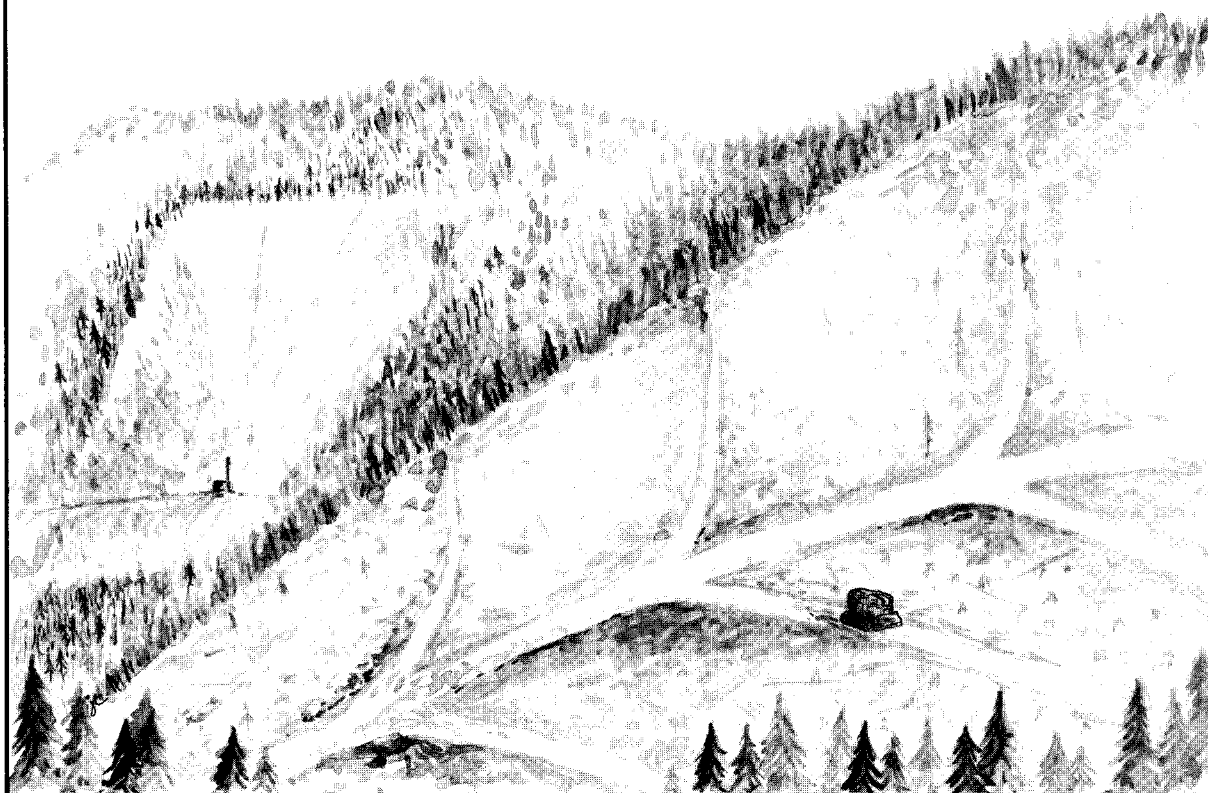

Technical Report

TR–103

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Abstract

Maintaining productivity of commercial forest land has become increasingly important in British Columbia in the past twenty years. As part of the search for economical ways to reduce soil disturbance and site degradation, trials involving three steep-slope harvesting systems were undertaken by the Forest Engineering Research Institute of Canada (FERIC) in the mid-1980s at Cariboo Lake in the Cariboo Forest Region. This report builds on these logging trials to outline a process which helps timber-harvesting planners, supervisors, and contractors work together to minimize soil disturbance caused by harvesting. The goal of the process is to ensure that steep-slope harvesting operations satisfy the recently introduced *Interim Harvesting Guidelines for the Interior of British Columbia* (British Columbia Ministry of Forests 1989) on a consistent basis. Procedures are modelled after the *Handbook for Ground Skidding and Road Building in British Columbia* (FERIC 1976). The report presents methods for forecasting soil disturbance and modifying Logging Plans to meet disturbance goals, and describes road-building and timber-harvesting techniques for minimizing soil disturbance.

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Summary

In 1984, the Williams Lake Operations of Weldwood of Canada Limited, the Cariboo Forest Region of the British Columbia Ministry of Forests (BCMOF), and the Forest Engineering Research Institute of Canada (FERIC) participated in logging trials near Cariboo Lake in the Interior of British Columbia. The study compared skidding with small crawler-tractors to conventional ground-skidding systems and cable-yarding systems. The principal goal of the trials was to determine whether the small crawler-tractor system could achieve acceptable costs and soil-disturbance levels when used to harvest timber on steep slopes.

A second important goal, and the purpose of this report, was to identify strategies that could be applied to any steep-slope harvesting operation to minimize soil disturbance, regardless of the harvesting system. The suggested approach is based on the *Handbook for Ground Skidding and Road Building in British Columbia* (FERIC 1976) and is discussed in the context of the recently introduced *Interim Harvesting Guidelines for the Interior of British Columbia* (British Columbia Ministry of Forests 1989). A procedure is outlined for preparing Logging Plans that satisfy the *Guidelines*, and a variety of practices are described for minimizing disturbance during road building and harvesting, with emphasis placed on ground-skidding systems.

A brief literature review establishes the rationale for reducing harvesting-related soil disturbance by describing the linkages between soil disturbance, soil compaction, and loss of site productivity. Ground-skidding systems cause more soil disturbance than cable or aerial harvesting systems. Most of this disturbance occurs in the form of haul roads, landings, and skid trails and is usually associated with high soil bulk densities and poor chemical properties which are unsatisfactory for tree growth.

The *Interim Harvesting Guidelines for the Interior of British Columbia,* developed by a joint committee of the forest industry and the BCMOF, set allowable limits for these degrading forms of disturbance. Allowable soil disturbance limits decrease as the site's sensitivity to various forms of soil degradation increases. A review of many studies in British Columbia suggests that ground-skidding operations on steep slopes will be challenged to satisfy the disturbance targets specified in the *Guidelines*. This has significant implications for the Cariboo Forest Region where 21% of mature commercial timber supply is estimated to be on slopes steeper than 33%.

Achieving significant reductions in soil disturbance requires sound planning, good harvesting techniques, and good communications between the planner, supervisor, and logging contractor. The process begins with the development of a realistic Logging Plan that reconciles the prescribed harvesting practices with the *Interim Harvesting Guidelines*. This involves several steps. First, the planner identifies the preferred and other feasible harvesting options and establishes allowable soil disturbance limits by determining the site's sensitivity rating. Next, the planner estimates how much soil disturbance the preferred harvesting method is expected to generate. If expected disturbance is less than the allowable limit, the planner can proceed with the normal sequence of activities to produce an approved Logging Plan. If expected disturbance exceeds the allowable limit, the planner modifies the proposed Logging Plan through a series of iterations until a satisfactory compromise is achieved. Techniques for estimating disturbance due to the construction of haul roads, landings, bladed skid roads, and unbladed skid trails, and a variety of alternative harvesting options, are presented in this report to assist the planner.

The logging supervisor should be involved whenever possible during preparation of the Logging Plan, especially if the logging site is difficult and special actions are required to meet the *Guidelines.* When the Logging Plan is finalized the planner must communicate the Plan's final details and specific instructions to the logging supervisor, who then passes this information to the logging contractor.

During the logging operations, decisions must be made on a day-to-day basis to accommodate changing circumstances and unforeseen problems. The supervisor and logging contractor must consider the impact that these decisions will have on soil-disturbance objectives and make every attempt to ensure that the goals of the Logging Plan are achieved. A range of options and techniques are presented as suggestions for reducing disturbance during the construction and use of roads, landings, and skid trails, and during falling, skidding, and post-harvesting cleanup.

Sommaire

En 1984, la Division de Williams Lake de Weldwood of Canada Limited, la Région de Cariboo Forest du Ministère des Forêts de Colombie-Britannique (BCMOF), et l'Institut canadien de recherches en génie forestier (FERIC) participèrent à

des essais d'exploitation près de Cariboo Lake en Colombie-Britannique intérieure. L'étude consistait à comparer le débardage au moyen de petits tracteurs à chenilles à des systèmes traditionnels de débardage par traînage et de téléphérage. Le principal objectif de ces essais était de déterminer si le système utilisant de petits tracteurs à chenilles permettait d'obtenir des coûts et des niveaux de perturbation du sol acceptables, quand il était utilisé pour récolter des arbres situés dans de fortes pentes.

Un second objectif important, qui fait l'objet du présent rapport, visait à identifier des stratégies susceptibles d'être appliquées à n'importe quelle opération de récolte dans de fortes pentes pour minimiser la perturbation du sol, indépendamment du système d'exploitation. La méthode suggérée est basée sur le manuel traitant du débardage par traînage et la construction de routes en Colombie-Britannique (Handbook for Ground Skidding and Road Building in British Columbia) publié par FERIC en 1976; elle est traitée dans le contexte du programme provisoire des modalités d'intervention (Interim Harvesting Guidelines for the Interior of British Columbia) récemment mis en vigueur par le BCMOF en Colombie-Britannique intérieure (1989). Le rapport expose les grandes lignes d'une marche à suivre pour préparer des plans d'exploitation qui répondent aux normes du programme d'intervention, et décrit diverses techniques visant à minimiser la perturbation durant la construction des routes et la récolte, en insistant surtout sur les systèmes de débardage par traînage.

Une brève revue de la documentation explique pourquoi il est important de réduire la perturbation du sol liée à la récolte, en décrivant les liens entre la perturbation du sol, le compactage du sol, et la perte de productivité du site. Les systèmes de débardage par traînage causent davantage de perturbation que les systèmes de récolte aériens ou systèmes de téléphérage. La plus grande partie de cette perturbation prend la forme de routes de camionnage, de jetées et de pistes de débardage, et est habituellement liée à une forte densité du sol et à des propriétés chimiques médiocres qui se prêtent mal à la croissance des arbres.

Elaboré par un comité conjoint formé de représentants de l'industrie forestière et du BCMOF, le programme provisoire des modalités d'intervention pour la Colombie-Britannique intérieure établit des limites admissibles pour ces formes de perturbation qui mènent à la dégradation du sol. Ces limites admissibles diminuent à mesure qu'augmente la sensibilité du site à diverses formes de dégradation. Une revue de plusieurs études en Colombie-Britannique laisse croire que les opérations de débardage par traînage sur de fortes pentes auront de la difficulté à rencontrer les objectifs de perturbation spécifiés dans les normes. Cela a des conséquences importantes dans la région de Cariboo Forest, où on estime que 21% de l'approvisionnement de bois commercial à maturité est situé sur des pentes supérieures à 33%.

L'obtention de réductions importantes de la perturbation du sol demande une planification soignée, des techniques de récolte appropriées, et de bonnes communications entre le planificateur, le surveillant, et l'entrepreneur chargé de l'exploitation. Le processus commence par la préparation d'un plan d'exploitation réaliste qui concilie les techniques de récolte prescriptes avec les normes du programme d'intervention. Cela implique plusieurs étapes. Premièrement, le planificateur identifie les méthodes de récolte qui ont la préférence et les autres options possibles et établit les limites admissibles de perturbation du sol en déterminant les taux de sensibilité du site. Ensuite, le planificateur estime le degré de perturbation du sol qui sera généré par la méthode de récolte préférée. Si la perturbation prévue est inférieure à la limite admissible, le planificateur peut passer à la série normale d'activités qu'implique la préparation d'un plan d'exploitation approuvé. Si la perturbation prévue dépasse la limite admissible, il doit alors modifier le plan d'exploitation proposé par une série d'itérations, jusqu'à ce qu'il ait atteint un compromis acceptable. Des techniques permettant d'estimer la perturbation due à la construction de routes de camionnage, de jetées, de chemins de débardage nivelés et de pistes de débardage non nivelées, de même que diverses méthodes de récolte possibles, sont présentées dans ce rapport pour faciliter la tâche du planificateur.

Le surveillant devrait dans la mesure du possible être associé à la préparation du plan d'exploitation, particulièrement si le site est difficile et que des dispositions spéciales sont requises pour satisfaire aux normes. Quand le plan d'exploitation est finalisé, le planificateur doit en communiquer les derniers détails au surveillant et lui faire part des instructions spécifiques, et le surveillant transmet ensuites ces renseignements à l'entrepreneur chargé de l'exploitation.

Dans le cours des opérations d'exploitation, des décisions doivent être prises au jour le jour tenir compte de changements dans les conditions et de problèmes imprévus. Le surveillant et l'entrepreneur doivent alors considérer l'impact que ces décisions auront sur les objectifs de perturbation du sol et faire tous les efforts nécessaires pour s'assurer que les objectifs du plan d'exploitation sont atteints. Un éventail d'options et de techniques sont présentées à titre de suggestions pour réduire la perturbation durant la construction et l'usage des routes, des jetées et des pistes de débardage, ainsi que durant l'abattage, le débardage, et le nettoyage après coupe.

INTRODUCTION

The purpose here is to present and describe a strategy for planning and managing steep-slope harvesting operations that will consistently satisfy environmental and economic goals. The proposed strategy is based on, and expands on, the *Handbook for Ground Skidding and Road Building in British Columbia* (FERIC 1976).

Mountain forests are an important component of the timber supply in the Interior of British Columbia, but steep slopes are difficult to harvest and are environmentally sensitive. To maintain access to the province's mountain forests, therefore, the Interior forest industry must constantly strive to develop environmentally and economically acceptable methods of harvesting timber on steep slopes.

In 1984, the Forest Engineering Research Institute of Canada (FERIC) participated, with the Williams Lake Operations of Weldwood of Canada Limited and the British Columbia Ministry of Forests (BCMOF), in a study of three harvesting systems on steep slopes in the Central Interior of British Columbia (Krag and Webb 1987) (Figure 1). Known as the Cariboo Lake logging trials, the study addressed growing concerns at that time about steep-slope harvesting and soil disturbance, and was part of a larger search for practical and workable solutions. Concerns about soil disturbance and site degradation, or loss of site productivity, have increased dramatically since the logging trials were completed, and these concerns are now expressed in the *Interim Harvesting Guidelines for the Interior of British Columbia* (British Columbia Ministry of Forests 1989). Meeting the requirements of the *Guidelines* and maintaining cost-effective operations will require constant effort on the part of everybody involved in steep-slope harvesting.

This report fulfils the final objectives of the Cariboo Lake logging trials and is a companion to the earlier report (Krag and Webb 1987) which describes the operational results of the logging trials.

OBJECTIVE AND SCOPE

The objective of this report is to present a practical approach to planning and implementing steep-slope harvesting operations in the Cariboo Forest Region to ensure that the *Interim Harvesting Guidelines* are consistently met. This report is for BCMOF and industry planners and supervisors in the Cariboo Forest Region whose actions and decisions are affected by the *Interim Harvesting Guidelines*. To achieve its objective, the report draws upon results, observations, and discussions with BCMOF and industry planners, logging supervisors, and logging contractors involved in the Cariboo Lake logging trials and other FERIC harvesting studies undertaken in the Interior of British Columbia.

The suggested approach to reducing site disturbance is based on the *Handbook for Ground Skidding and Road Building in British Columbia.* This report emphasizes prevention rather than rehabilitation, it presents a variety of operational methods for reducing soil disturbance, and it describes a process for minimizing harvesting-related soil disturbance. After the areas scheduled for harvesting are identified in an approved Development Plan, the following steps are carried out:

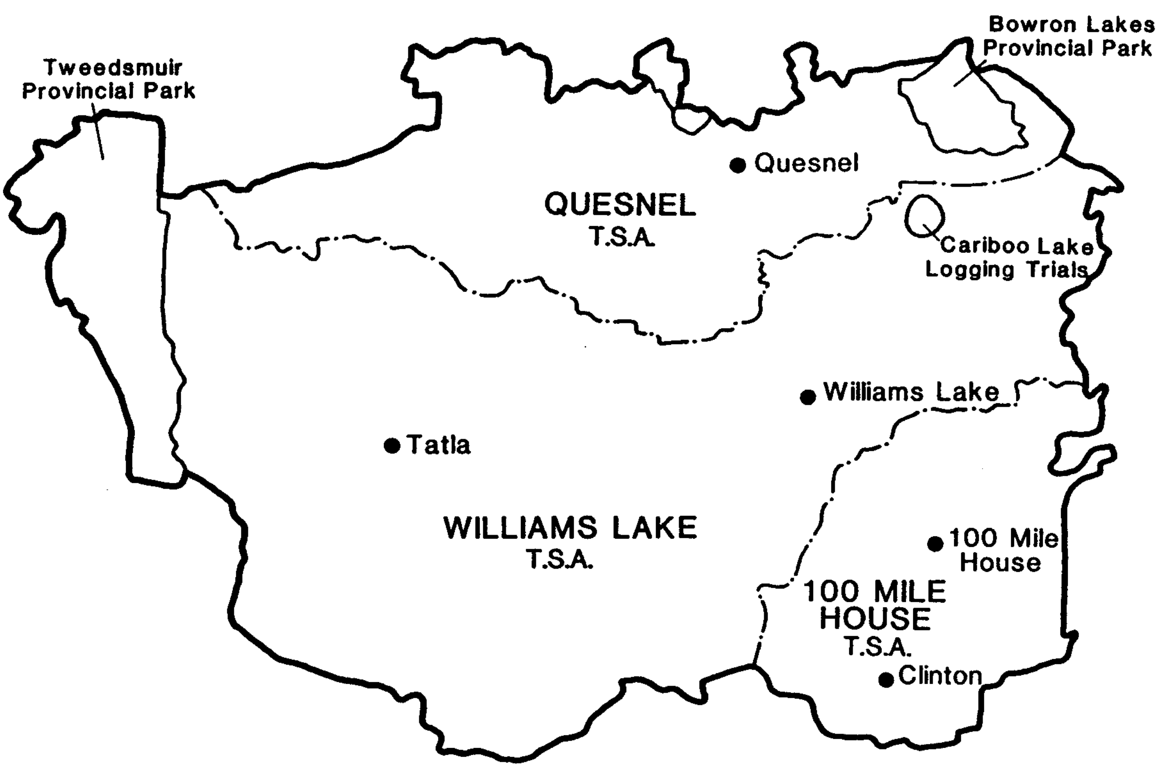
- Initial reconnaissance of the harvesting area.
- Development of Preharvest Silviculture Prescriptions (PHSPs).
- Planning and layout of the cutblock.
- Processing of Cutting Permit applications.
- Road construction, harvesting, and post-harvesting activities up to the site-preparation stage.

The report concentrates on sites that are typical of Interior steep-slope harvesting operations; i.e. slopes average 30% or more, terrain varies from uniform to complex, and other timber and site conditions fall within normal Interior ranges. Clearcutting followed by some form of site preparation and planting are assumed to be the standard, though not necessarily the only, treatments routinely prescribed.

Finally, the report assumes the effects of harvesting on other resource values, both on and off the site, have been considered and resolved through the process of long-range integrated resource planning. This process is necessary to achieve a satisfactory balance between forest and nonforest resource values, but a discussion of its impact on the soil-disturbance issue is largely beyond the scope of this report.

The report contains four major sections. The first section reviews pertinent literature to inform the reader about relationships between forest harvesting practices, soil disturbance and compaction, and site productivity. The second section describes the *Interim Harvesting Guidelines* and compares past steep-slope harvesting performance with the standards outlined in the *Guidelines.* Third, the Cariboo Forest Region is described and the contribution of steep-slope forests to the Regional timber supply is discussed. Finally, the fourth section presents a strategy for planning and conducting steep-slope harvesting operations to reduce soil disturbance.

Forest Regions in British Columbia



Cariboo Forest Region

Figure 1. The Cariboo Lake logging trials (Krag and Webb 1987) took place in the Cariboo Forest Region in the Interior of British Columbia.

TIMBER HARVESTING AND SOIL DISTURBANCE: LITERATURE REVIEW

The significance of soil disturbance caused by timber harvesting has been a subject of considerable debate among foresters in the Interior of British Columbia since the early 1970s. At that time the BCMOF became concerned that steep-slope harvesting practices were causing unacceptable levels of soil disturbance and resulting in significant site degradation (loss of site productivity). Guidelines (British Columbia Forest Service 1973) were therefore introduced for the Nelson Forest Region that restricted the use of conventional ground-skidding equipment on steep terrain. The intent of the guidelines was to reduce soil disturbance by encouraging forest companies to use cable-yarding systems rather than ground-skidding systems on steep sites. However, many foresters questioned the need to reduce soil disturbance, citing the general lack of local information linking soil disturbance to reduced tree growth and loss of site productivity.

Initially, evidence for the BCMOF's concerns came largely from studies conducted in the northwestern United States. Subsequent research in the Interior has generally supported the findings of the American literature. The following synopsis summarizes the findings of relevant research undertaken in the Pacific Northwest and British Columbia about the impacts of forest harvesting on soil disturbance, soil compaction, tree growth, and site productivity. Additional information on these and other related subjects can be found in Lousier's annotated bibliography (1990).

Soil Disturbance

Early studies of the effects of timber harvesting on forest sites consistently found that harvesting with crawler-tractors (tractor logging) caused more soil disturbance than cable yarding. On sites in Washington, Idaho, Oregon, and northern California, tractor logging typically disturbed between 20 and 35% of the harvested area, whereas jammer, highlead, and skyline-crane cable systems disturbed only 11 to 16% of the harvested area (Dyrness 1965; Fowells and Schubert 1951; Garrison and Rummell 1951; Haupt 1960; Steinbrenner and Gessel 1955; Wooldridge 1960). Later studies reported soil disturbance levels of 5 to 14% for sites harvested with skyline systems (Amaranthus and McNabb 1983; Dyrness 1965, 1967; Ruth 1967), 6% for a site harvested with a balloon (Dyrness 1972), and 5% for a site harvested with a helicopter (Clayton 1981).

Surveys of soil disturbance in the southern Coastal and Interior regions of British Columbia have reported similar trends, but usually with higher overall levels of soil disturbance than studies in the Pacific Northwest of the United States (Bockheim et al 1975; Krag and Webb 1987; Schwab and Watt 1981; Standish 1984; Utzig and Herring 1975). For example, soil disturbance levels on steep-slope sites in southeastern British Columbia averaged between 15 and 45% for ground skidding, 22 and 30% for grapple yarding, and 11 and 16% for highlead yarding (Krag et al 1986; Smith and Wass 1976; Thompson 1988). In the Central Interior, Schwab and Watt (1981) reported that soil disturbance (excluding haul roads and landings) averaged 45 to 49% on ground-skidded sites and 12% on grapple-yarded sites.

Krag (1984) found that skid trails accounted for most of the soil disturbance on ground-skidded areas and explained why a higher level of site disturbance is associated with ground-skidding than with cable-yarding systems. In efforts to reduce skid-trail disturbance, researchers have experimented with small crawler-tractors, low-ground-pressure flexible-tracked skidders, and techniques for reducing the total length of skid trail constructed during harvesting. In a study in southeastern British Columbia, soil disturbance due to skid trails on three sites harvested with small crawler-tractors (i.e., equivalent to a Caterpillar D5 crawler-tractor or smaller) ranged from 12.3 to 14.2%, compared to an average of approximately 28% for sites harvested with larger crawler-tractors (i.e., a Caterpillar D6 tractor or larger) (McMorland 1980). In Oregon, only 13.6% of a site harvested with an FMC flexible-tracked skidder was occupied by skid trails (Sidle and Drlica 1981). Finally, trials conducted by researchers at Oregon State University showed that skid-trail disturbance could be reduced substantially by locating skid trails before harvesting and by ensuring that skidders travel only on designated trails (Froehlich et al 1981; Olsen and Seifert 1984).

Soil Compaction

Soil disturbance is usually accompanied by some degree of soil compaction. Roads, landings, and heavily travelled skid trails are usually severely compacted (Froehlich et al 1981). Studies in the western United States and British Columbia have reported that the bulk densities of soils on skid trails are often significantly higher than for adjacent undisturbed soils (Dyrness 1965; McLeod 1988; Sidle and Drlica 1981; Steinbrenner and Gessel 1955; Watt and Krag 1988; Youngberg 1959). The severity of compaction generally increases as the number of trips made by the skidder over a given trail increases (Burger et al 1985; Greene and Stuart 1985; Shetron et al 1988), with most compaction occurring in the first few passes (Adams and Froehlich 1984). Furthermore, high bulk densities can persist for several years to several decades after harvesting (Froehlich et al 1985; Smith and Wass 1985; Wert and Thomas 1981).

Effects on Site Productivity

Researchers in the western United States have reported varying but generally significant reductions in growth rates of tree seedlings on compacted skid trails; this is true for Douglas-fir (Steinbrenner and Gessel 1955; Wert and Thomas 1981; Youngberg 1959), ponderosa pine (Cochran and Brock 1985; Froehlich 1979; Froehlich et al 1986), and lodgepole pine (Clayton et al 1987).

In the Interior of British Columbia, Smith and Wass (1979, 1980) found that growth rates for Englemann spruce, subalpine fir, and Douglas-fir seedlings on contour skid trails on steep slopes were usually slower, but in isolated instances slightly better, than for seedlings on adjacent undisturbed soils. Almost invariably, growth rates for seedlings on the inner, deeply cut portion of the skid trail were significantly lower than for the same species on other positions across the profile. This pattern was probably due to very high soil bulk densities and unfavourable soil chemistry in this area of the skid trail (Smith and Wass 1985) caused by displacement of surface soils during trail construction—which exposed less-fertile, denser soils—and subsequent skidder travel.

INTERIM HARVESTING GUIDELINES FOR THE INTERIOR OF BRITISH COLUMBIA

The *Interim Harvesting Guidelines for the Interior of British Columbia* (British Columbia Ministry of Forests 1989) are the product of almost twenty years of joint effort by the BCMOF and industry to address the issues of soil disturbance and site degradation in the Interior. The *Guidelines* set the performance standard that licensees must meet during harvesting operations to comply with the current Silviculture Regulations, which require licensees to state expected soil disturbance levels on Preharvest Silviculture Prescriptions.

Background

In 1973, the Nelson Forest District (now Region) of the British Columbia Forest Service issued guidelines for the District that restricted conventional ground skidding activities on slopes between 50 and 70%, and prohibited it entirely on slopes steeper than 70% (British Columbia Forest Service 1973). At the time, more than 95% of the annual cut in the District was harvested with skidders and tractors (Wellburn 1975). The Forest Service hoped the guidelines would encourage the forest industry to harvest steep terrain with cable-yarding systems rather than ground-skidding systems, and thus decrease site disturbance.

The Nelson Steep Slopes Committee was formed in 1974 in response to the guidelines. This Committee, representing the British Columbia Forest Service, regional forest industry, and forest research groups, initiated research into steep-slope harvesting methods and environmental impacts of Interior harvesting operations, and produced a handbook for planning, developing, and harvesting steep slopes (FERIC 1976). At about the same time, the Interior Forest Harvesting Steering Committee, consisting of senior representatives from the Forest Service and industry, was established to provide a forum for discussing timber-harvesting issues that affected all of the Interior of British Columbia. One of its goals was to promote the development of harvesting equipment and methods that maintained site productivity and satisfied environmental, economic, and social goals. The two Committees continued to address site degradation until the early 1980s, when an economic recession forced their attention to other issues.

In the mid 1980s, the BCMOF began several new initiatives on the site-degradation issue. The Forest Site Degradation and Rehabilitation Committee, with representatives from the Research Branch of the BCMOF and the Forest Regions, was created. This Committee collaborated with the BCMOF's Timber Harvesting, Engineering, and Silviculture Branches to develop Interior-wide soil-disturbance limits for harvesting operations, and these were incorporated into a Silviculture Branch policy statement "Reduction of Productivity Losses from Logging Operations" (British Columbia Ministry of Forests and Lands 1987a). Other publications by the Engineering and Silviculture Branches promoted soil conservation during harvesting (British Columbia Ministry of Forests and Lands 1987b, 1987c), and several Forest Regions initiated studies to define the scope and nature of regional site-degradation problems.

The Interior Forest Harvesting Steering Committee was restructured in the late 1980s to create the Interior Forest Harvesting Council (IFHC), with representatives from the BCMOF, industry, FERIC and

Forestry Canada. The IFHC created five Regional Forest Harvesting Subcommittees, composed of local BCMOF and industry personnel, to implement its directives.

Because the IFHC's terms of reference included responsibility for ensuring the maintenance of site productivity, it struck a Technical Advisory Committee to review the proposed soil-disturbance guidelines. The Technical Advisory Committee, assisted by the Forest Site Degradation and Rehabilitation Committee, submitted a revised set of soil-disturbance guidelines to the IFHC in late 1988. The IFHC accepted the proposals and recommended that they be implemented for a two-year trial period and then modified if necessary. The BCMOF formally approved and released the *Interim Harvesting Guidelines for the Interior of British Columbia* in April 1989.

Interim Harvesting Guidelines

The goal of the *Interim Harvesting Guidelines* is to keep loss of forest site productivity (site degradation) due to timber harvesting within acceptable limits by preventing unnecessary soil disturbance during harvesting operations. This is achieved by limiting the area that may be used for (and therefore degraded by) haul roads, landings, and skid trails (or backspar trails, in the case of grapple-yarding operations), including cutbanks and sidecast, to a proportion or percentage of the total cutblock area. These features are considered to be the main factors contributing to *detrimental soil disturbance,* that is, soil disturbance that reduces site productivity.

The *Guidelines* stress that prevention of soil disturbance is preferable to site rehabilitation, and that careful and thorough planning is the best way to minimize harvesting-related disturbance. Harvesting plans for proposed cutblocks must show enough detail to demonstrate the feasibility of meeting the soil-disturbance targets. Road locations, skidding patterns and directions, and numbers, locations, and approximate dimensions of all landings within proposed cutblocks must be indicated. To encourage more forward planning, haul roads that are identified and approved by the BCMOF in advance of harvesting are excluded from allowable disturbance totals, but spur roads that are added during harvesting are included. This provides planners with an incentive to consider road and block layout well before harvesting is scheduled to begin.

Finally, the *Interim Harvesting Guidelines* also embody the important concept that forest sites vary in their susceptibility to degradation due to topographic, soils, and climatic factors. Using the methodology developed by Lewis et al (in press), sites are rated as having Low, Moderate, High, or Very High sensitivities to degradation for four types of degrading impacts: surface soil erosion, mass wasting, soil compaction, and soil displacement. The *Guidelines* specify allowable soil-disturbance levels of up to 19% for sites of Low and Moderate sensitivity, 9% for sites of High sensitivity, and only 4% for sites of Very High sensitivity.

Steep-Slope Harvesting and the *Interim Harvesting Guidelines*

Every phase of harvest planning and operations must be conducted and monitored carefully if the *Interim Harvesting Guidelines* are to be satisfied on a consistent basis. This applies to both ground-skidding and cable-yarding operations. However, ground-skidding operations on steep slopes especially will be challenged because, historically, soil-disturbance levels associated with harvesting on steep slopes have generally exceeded the current guideline limits. Table 1 summarizes results of several soil-disturbance studies undertaken in the Interior of British Columbia. The disturbance figures have been adjusted where necessary to reflect the levels that would be recorded if the cutblocks were surveyed to assess compliance with the current *Guidelines.* Thus only sources of disturbance that are relevant to the *Interim Harvesting Guidelines* (i.e., haul roads, landings, and skid and backspar trails) are presented. Also, where possible, only data for cutblocks having average slopes of more than 30% are given. These figures should also be interpreted cautiously because differences in defining and measuring soil disturbance, and in some cases small sample sizes, preclude direct comparisons of the studies. (It should be noted that none of these studies measured soil disturbance using the assessment method recommended in the *Guidelines.*)

To comply with the *Interim Harvesting Guidelines,* total soil-disturbance levels, excluding haul roads, should be 19% or less for sites of Low or Moderate sensitivity, and 9% or less for sites of High sensitivity. Even assuming Low or Moderate sensitivities, Table 1 indicates that conventional ground-skidding operations on steep slopes in Interior British Columbia have generally exceeded the maximum limits allowed under the current *Guidelines.* On average, only conventional winter operations measured by Smith and Wass (1976) and McLeod and Hoffman (1988) met the 19% limit for Low and Moderate sites. None of the conventionally harvested cutblocks in the listed studies, whether harvested in the winter or the summer, achieved the 9% limit for

Table 1. Soil Disturbance Studies Undertaken in the Interior of British Columbia: Summary

Researchers/ Harvesting systems	Forest Region	Source of disturbance: Haul roads (%)	Landings (%)	Skid roads (%)	Backspar trails (%)	Perimeter roads/ Fireguards (%)	Total disturbance: Incl. roads (%)	Excl. roads (%)
Smith & Wass 1976[a]	Nelson							
Ground, summer		7.6	0.7	31.5	-[e]	0.1	39.9	32.3
Ground, winter		2.9	0.6	17.8	-	-	21.3	18.4
Highlead, summer		6.6	2.0	2.0	-	0.5	11.1	4.5
Highlead, winter		5.0	-	5.0	-	6.4	16.4	11.4
Grapple, summer		-	-	-	27.1	-	27.1	27.1
Grapple, winter		-	-	2.8	19.0	-	21.8	21.8
Hammond 1978[a]	Nelson							
SCT, summer[b]		2.4	3.0	23.8	-	-	29.1	26.7
SCT, winter		7.6	9.5	21.3	-	-	38.4	30.8
McMorland 1980[a]	Nelson							
SCT, summer		4.4	6.1	14.2	-	-	24.7	20.3
SCT, winter		6.0	7.7	12.3	-	-	26.0	20.0
Schwab & Watt 1981[a]	Cariboo							
Ground, summer & winter		5.6	2.3	36.0	-	2.7	46.6	41.0
Grapple, summer & winter		8.0	1.2	4.3	4.3[f]	-	17.8	9.8
Krag 1984[a]	Nelson							
Ground, summer		9.1	2.3	29.5	-	-	40.9	31.8
Ground, winter		8.5	3.5	29.0	-	-	41.0	32.5
Highlead, summer		9.3	0.8	3.5	-	-	13.6	4.3
Highlead, winter		16.6	-	6.4	-	-	23.0	6.4
Grapple, summer		8.5	2.3	1.5	-	-	12.3	3.8
Grapple, winter		16.6	0.7	0.9	-	-	18.2	1.6
Krag & Webb 1987[a]	Cariboo							
SCT, summer		6.6	3.4	12.4	-	-	22.4	15.8
SCT, winter		4.9	2.7	16.2	-	-	23.8	18.9
Ground, summer		4.9	2.7	26.3	-	-	33.9	29.0
Highlead, summer		6.6	3.4	-	-	-	10.0	3.4
Highlead, winter		4.9	2.7	-	-	-	7.6	2.7
Smith 1988[a]	Kamloops							
Ground, summer & winter		nm[d]	nm	37.0	-	-	37.0	37.0
SCT, winter		nm	nm	17.0	-	-	17.0	17.0
Thompson 1988[a]	Nelson							
Ground, summer		6.2	3.3	24.1	-	-	33.6	27.4
McLeod & Hoffman 1988[a,c]	Prince George							
Ground, summer		4.9	3.6	16.6	-	-	25.1	20.2
Ground, winter		2.5	0.4	15.9	-	-	18.8	16.3

[a] See References
[b] SCT = Small crawler-tractor
[c] Haul road and landing disturbance is presented for entire block, but skid-trail disturbance applies only to slopes over 30%
[d] nm = not measured
[e] - = not applicable
[f] Includes some Perimeter roads/Fireguards

High sensitivity sites. Even in the case of the blocks that satisfied the cumulative allowable total of 19% for Low or Moderate sensitivity sites, average soil-disturbance levels for skid roads exceeded the allowable subtotal of 15% by type. Most studies indicate that skidding with small crawler-tractors in summer or winter can achieve soil disturbance targets for Moderate sites (Krag and Webb 1987; McMorland 1980; Smith 1988), although soil disturbance due to skid roads sometimes exceeds the type limit. Finally, with the notable exception of summer and winter grapple-yarded sites surveyed by Smith and Wass (1976), cable-yarding systems appear to be generally successful in meeting the limits set by the *Guidelines,* even for sites of High sensitivity.

Benchmark surveys recently completed in the Kamloops Forest Region to assess the performance of conventional harvesting operations with respect to the *Interim Harvesting Guidelines* demonstrate that well-planned ground-skidding operations on steep slopes can meet soil-disturbance targets for Low and Moderate sensitivity sites.

CARIBOO FOREST REGION

Regional Overview

The Cariboo Forest Region (Figure 1), with an area of 8 676 965 ha, lies mainly within the Fraser Plateau, a sub-unit of the Interior Plateau physiographic region (Holland 1976). The Region is bordered by the Coast Mountains to the southwest and the Quesnel Highlands and Cariboo Mountains to the east. Terrain is characteristically gentle and rolling in the Plateau area and steeper and more rugged in the mountains. Elevations range from less than 900 m to 1800 m in the Fraser Plateau and to more than 2500 m in the Coast and Cariboo Mountains. Annual precipitation averages less than 50 cm over much of the Cariboo Forest Region because of the rain-shadow effect of the Coast Mountains, and increases eastward from the Fraser River to 150 to 250 cm in the Cariboo Mountains (Farley 1979).

On the Fraser Plateau, Bunchgrass and Interior Douglas-fir biogeoclimatic zones occupy dry warm valleys in the south, and the Sub-Boreal Spruce zone occupies valleys and lower elevations in the north (British Columbia Ministry of Forests 1988). On the relatively dry, higher Plateau surface, extensive stands of lodgepole pine dominate the Sub-Boreal Pine-Spruce zone at intermediate elevations, and Englemann spruce occurs in the Montane Spruce zone at higher elevations. In the Quesnel Highlands to the east, the Interior Cedar-Hemlock zone occupies lower and middle elevations and the Englemann Spruce-Subalpine Fir zone occupies high-elevation sites.

Regional Timber Supply

The Annual Allowable Cut (AAC) for the Cariboo Forest Region is 8 277 510 m^3, not including Weldwood of Canada Limited's Tree Farm License #5.[1] Three Timber Supply Areas (TSAs) contribute to the Region's AAC: TSA #23 (100 Mile House TSA), with an AAC of 1 250 000 m^3; TSA #29 (Williams Lake TSA), with an AAC of 4 092 510 m^3; and TSA #26 (Quesnel TSA), with an AAC of 2 935 000 m^3. The AAC for the Williams Lake TSA, currently elevated to allow salvage of timber damaged by the Douglas-fir bark beetle, is scheduled for review in 1990. The AAC for the Quesnel TSA includes 40 000 m^3 for Stocking Class 4 stands and 50 000 m^3 for deciduous forest types.

Figure 2 summarizes the distribution of mature timber by slope class for each Interior Forest Region and for the Interior as a whole (Hedin 1978). Hedin estimated from a subsample of Public Sustained Yield Units that, as of 1978, about 30% of remaining mature timber in the Interior was on slopes of more than 33%. Approximately 21% of the remaining mature timber in the Cariboo Forest Region was on steep slopes. Most of the Region's steep-slope timber is probably concentrated in the wetter and colder biogeoclimatic zones, particularly the Interior Cedar-Hemlock and Englemann Spruce-Subalpine Fir zones, of the Quesnel Highlands and Cariboo Mountains.

REDUCING SOIL DISTURBANCE ON STEEP SLOPES

This section outlines a process for assisting timber-harvesting planners and managers in the Cariboo Forest Region in planning and conducting safe and efficient harvesting operations that consistently satisfy the *Interim Harvesting Guidelines.*

Specific strategies and techniques for reducing soil disturbance when harvesting on slopes between 30 and 50%, where both ground-based and cable-logging systems are potentially feasible options, are described. These strategies have been drawn from the Cariboo Lake logging trials, other FERIC studies

[1]W.J. Watt, Regional Research Pedologist, Cariboo Forest Region, BCMOF; personal communication, May 1990.

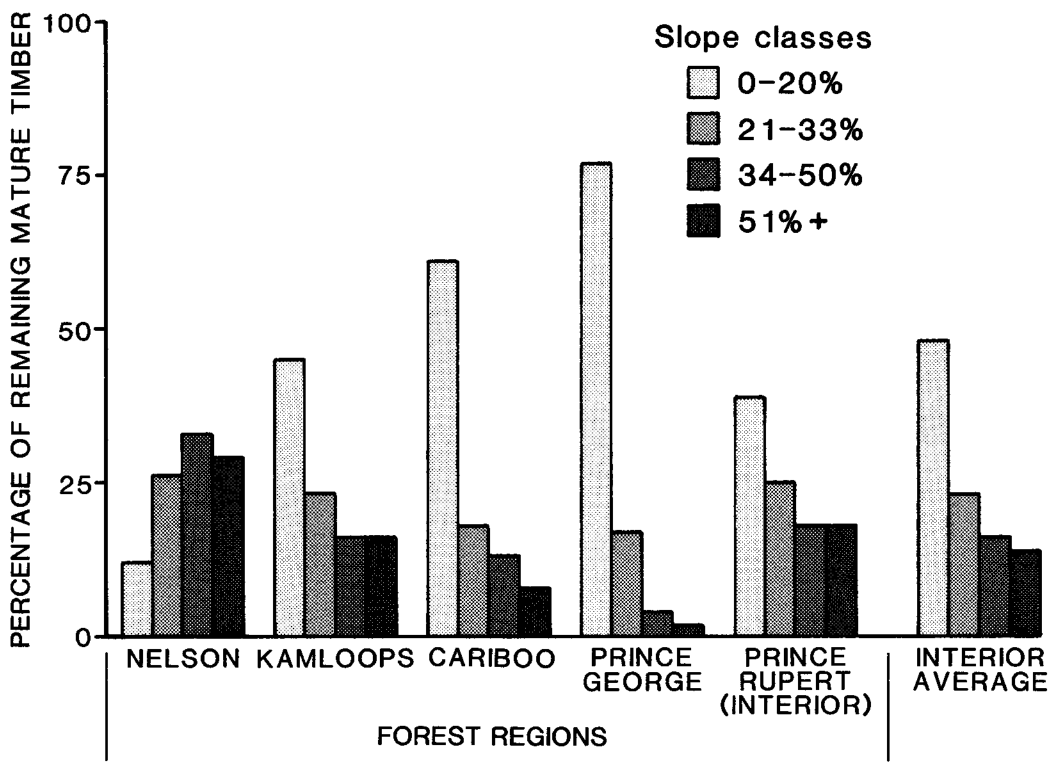


Figure 2. Distribution of mature timber by forest slope classes for each Interior Forest Region and the whole Interior: Summary

of Interior British Columbia harvesting operations, and, most importantly, from discussions with the many BCMOF and industry planners, logging supervisors, and logging contractors involved in FERIC studies over the years. For the most part, the strategies are common-sense techniques that are being used by many Interior operations today, but usually for reasons other than reducing soil disturbance. Undoubtedly there are many other techniques that are being applied today which could also help reduce soil disturbance.

While the particular strategies described here may not be practical or appropriate for steeper or gentler slopes, the principles behind them can be extrapolated to almost any timber-harvesting situation where soil disturbance is a concern. It is hoped that by illustrating some basic or well-known methods, harvesting planners and managers will be encouraged to search for opportunities within their own operations for reducing soil disturbance.

Elements of a Soil-Disturbance Reduction Program

The *Handbook for Ground Skidding and Road Building in British Columbia* (FERIC 1976) presents the framework for a successful soil-disturbance reduction program. The program integrates soil-disturbance goals into planning and harvesting operations, and outlines the responsibilities of and relationships between planners, supervisors, and contractors. The complete program consists of four elements: sound planning, careful operations, consistent follow-up, and good communications.

The planner is responsible for developing a workable Logging Plan. To do this the planner must understand the management goals and the requirements of the supervisor and contractor. In the context of the *Interim Harvesting Guidelines,* the Logging Plan must meet or exceed the standards set in the *Guidelines.* From the licensee's perspective, the Logging Plan must be safe, practical, and economic, and it must meet other management goals in addition to the *Guidelines.*

If the Logging Plan prepared by the planner is realistic, its success then depends upon effective implementation. The logging supervisor is responsible for ensuring that the goals of the Logging Plan are achieved. He must understand these goals and familiarize himself with the details of the Logging Plan, and communicate these to the logging contractor. But he must also recognize that, in the final analysis, the Logging Plan is simply a strategy for realizing management goals, and that it is intended to be flexible to accommodate changes that occur in the daily conditions. He must deal with the reality that logging operations often must deviate from the plan because circumstances change every day. It is the supervisor's responsibility to make necessary on-site adjustments to the Logging Plan with due consideration of soil disturbance as well as production and cost.

The logging contractor must ensure that he understands the Logging Plan and specific instructions from the supervisor. Regardless of how carefully a Logging Plan is prepared, actual production and soil disturbance are the products of events that occur during road building and harvesting. Good road-building and harvesting techniques and attention to detail are required on the part of the contractor and his crew. The contractor must encourage his machine operators to constantly look for ways to improve their practices.

Above all, the planner, supervisor, and logger must communicate regularly and effectively with each other. As the *Handbook* states "The logger can only log without damage if he has been told the correct way to do the job. The supervisor can only pass on the correct instructions if he has received a properly prepared plan, and the planner can only prepare a proper plan if he is familiar with the methods of operations and problems of the logger." Consistent follow-up is the best way to ensure that lessons learned on the last site are applied to the next, and mistakes are not repeated. Soon after an area is finished, the planner, supervisor, and logger should review soil-disturbance and production expectations and discuss ways to improve planning, road-building, and harvesting.

Planning Strategies to Minimize Soil Disturbance

The process of forest management planning defines, in a series of progressively more detailed steps, where, when, and how timber harvesting will take place. The decisions made at each step gradually constrain the range of options available to the planner for minimizing soil disturbance. Thus, to a large degree, the planning process will have a significant effect on the overall levels of soil disturbance that will result from harvesting.

Long-Range (Total-Chance) Planning

One of the goals of long-range planning is to define road requirements over large planning areas; it is the first step in minimizing harvesting-related soil disturbance.

The role of long-range planning is to define specific courses of action—in this case, harvesting operations—that will realize broad forest management goals. Forest planning is required in British Columbia by the Ministry of Forests Act, the Forest Act, and the Range Act. The BCMOF employs a hierarchical five-stage planning system to fulfil its planning mandate (British Columbia Ministry of Forests 1983). The two highest levels of planning are concerned with provincial policies and regional priorities, and are not area-based. The next three planning levels—forest management planning, local resource use planning, and resource development planning—are area-based and apply to progressively smaller geographic units. The process culminates in the Resource Development Plan, commonly referred to as the Development Plan or Five-Year Plan. This plan forecasts where and when, and in what sequence, harvesting operations will occur in a five-year period.

The total-chance planning approach can be applied to the latter three planning stages to reconcile resource conflicts and assess harvesting opportunities (logging chance) within large development areas such as drainages. The role that total-chance planning fulfils depends entirely upon management needs. It can be used to determine how forestry and other resource users can coexist within the development unit, or it can be used for more specific functions such as developing long-term harvesting plans that will efficiently access all merchantable timber.

With regard to minimizing soil disturbance, total-chance planning can be applied to designing efficient transportation networks for forest development. Preparing harvesting plans for large units with natural topographic boundaries is the best way to identify the most efficient network of main and branch roads. Individual cutblocks are then designed around this transportation framework, with only spur roads required to complete the access system. Block-by-block development may optimize haul-road locations for individual cutblocks but it usually results in building more road than is necessary.

The following publications are recommended to readers who want to learn more about long-range forest planning:

- *Handbook for Ground Skidding and Road Building in British Columbia* (FERIC 1976)
- *Resource Planning Manual* (British Columbia Ministry of Forests 1983)

- *Timber Development Planning for the British Columbia Interior: The Total-Chance Concept* (Breadon 1983)
- *Forest Harvesting and Renewal Planning for the British Columbia Interior: An Extension of the Total-Chance Concept* (Breadon 1990)

Area Planning and Development
Area planning and development is an area-specific and field-intensive process. Its goal is to determine site-specific harvesting and silvicultural strategies that are consistent with the Development Plan and that reconcile forest-management objectives with other resource constraints for particular sites. It is at this stage that the planner makes the key decisions about harvesting methods and road and landing locations that effectively determine how much of the area will be disturbed by harvesting.

Area planning and development begins one to three years before harvesting is scheduled to occur, and culminates in a Logging Plan. The Logging Plan details how the site is to be harvested and regenerated, and it forms the basis of the Cutting Permit application. Activities included in this phase of planning are:
- Initial reconnaissance of the harvesting area.
- Development of Preharvest Silviculture Prescription (PHSP).
- Joint field inspections.
- Timber cruising.
- Preparation for advertising and public comment.
- Revisions to PHSP and Logging Plan.
- Field layout.
- Preparation of Cutting Permit application.

Reconciling Logging Plans and Soil Disturbance
The task of preparing a Logging Plan that satisfies the *Interim Harvesting Guidelines* is accomplished in the following steps:
(i) Determine allowable soil-disturbance levels.
(ii) Identify and prioritize feasible harvesting alternatives.
(iii) Estimate soil-disturbance levels for the preferred options and refine harvesting prescriptions to ensure the *Guidelines* are met.
(iv) Finalize layout and Logging Plan for the chosen alternative.
(v) Transfer the approved Logging Plan to the logging supervisor and contractor.

Determine Allowable Soil-Disturbance Levels. British Columbia Silviculture Regulation 147/88 now requires licensees in the Interior of British Columbia to specify in the Preharvest Silviculture Prescription (PHSP) the expected level of soil disturbance that will result from proposed harvesting operations. The maximum disturbance level that can be entered on the PHSP is stipulated by the *Interim Harvesting Guidelines.* It can be established by determining the site's sensitivity rating (using Lewis et al (in press) or a recognized equivalent). Exceptions to the *Guidelines* may be permitted, so planners should be familiar with local requirements before finalizing the PHSP.

A cutblock must be stratified into "treatment units" if it contains two or more terrain units that have differing sensitivities and meet certain minimum size standards. Each treatment unit must be recorded on the PHSP and delineated on the Logging Plan. To comply with the *Guidelines,* soil disturbance within each treatment unit must not exceed the specified maximum for its sensitivity rating.

Treatment-unit boundaries established on the basis of site sensitivity may not correspond well with operationally practical boundaries, particularly on steep slopes where topography often controls layout. Generally, there will be fewer feasible harvesting alternatives capable of meeting soil-disturbance limits for the more sensitive treatment units, so these units will tend to determine area development. Several common situations may be encountered:
- The site has a uniform site sensitivity and does not need to be stratified. One type of system can be used to harvest the entire block, provided the chosen harvesting strategy is capable of meeting the soil-disturbance limit. Area development is straightforward.
- The site consists of two or more treatment units which are large enough to consider as adjacent but separate cutblocks. Area development is straightforward, but each unit may require a different harvesting strategy to meet the *Interim Harvesting Guidelines.* The units should be considered together when planning access routes.
- The site is dominated by one sensitivity class (e.g., Moderate) but contains small isolated patches of a higher sensitivity class. If the higher sensitivity areas are on the margins of the cutblock, consider excluding them from the current cutblock and developing them later in adjacent openings. If the sensitive patches must be included, identify them in the field and modify road and landing locations and skidding patterns to minimize disturbance to these areas.
- The site falls between two sensitivity classes (e.g., Moderate and High), and it is difficult to segregate large units of either class. The simplest approach may be to treat the entire area

as the higher sensitivity class, but since this may rule out conventional harvesting methods, this decision must be carefully considered. Logging Plans for such sites should be carefully reviewed in joint field inspections to ensure everyone agrees with the harvesting prescriptions and layout.

- The site consists of a mix of clearly definable treatment units of differing sensitivities which, individually, are too small (i.e., less than a few hectares) to develop as separate cutblocks. These are usually the most contentious and difficult sites to plan and harvest. The use of two or more harvesting strategies or systems is indicated, but it is difficult to optimize development for either and still satisfy the *Guidelines.* Again, BCMOF and industry planners should review these sites in the field to agree on harvesting strategies.

Identify Feasible Harvesting Options. Considering only the *Interim Harvesting Guidelines,* a feasible harvesting alternative is one that has a realistic chance of achieving a level of soil disturbance within the maximum allowable for the site in question. In practice, many other factors in addition to soil disturbance affect which harvesting method is finally chosen, but at this stage it is important to ensure that no technically feasible alternatives are overlooked. Planners should also arrange to systematically inspect proposed cutblocks in the field at the earliest possible opportunity, such as when the PHSP is done, to determine whether the general harvesting proposals outlined in the Development Plan are appropriate to the site.

Estimate Soil Disturbance. When site-sensitivity and soil-disturbance limits are known, the planner must develop harvesting prescriptions that meet the *Guidelines.* To do this, the planner requires techniques for reliably estimating how much soil disturbance is likely to be caused by planned harvesting operations. A systematic approach to estimating disturbance allows the planner to refine the Logging Plan through a series of iterations to reconcile allowable and expected disturbance. By the time the process is completed the planner will have a clear understanding of what must be done to meet the *Guidelines* and what special instructions must be communicated to the logging supervisor and contractor. Also, a systematic approach to estimating disturbance can help the planner to identify additional opportunities for reducing disturbance even in situations where compliance is readily achieved.

All cutblocks require sufficient care in planning and layout to ensure that harvesting goals and constraints are met, but not all sites will necessarily require a detailed estimation of expected soil disturbance. If a proposed cutblock is sufficiently similar to previously harvested areas where soil disturbance surveys show that the *Guidelines* have been met, the planner may decide that a detailed estimate is not necessary and proceed with layout. This will allow the planner to concentrate on more difficult or sensitive sites, which as a rule require more planning effort.

To determine whether a proposed harvesting operation will meet the *Interim Harvesting Guidelines,* the planner must understand how soil disturbance is defined and what activities cause soil disturbance. Currently, the definition of **soil disturbance** in the *Guidelines* includes widening of, or compacted areas adjacent to approved haul roads resulting from roadside harvesting; cutbanks, running surfaces, and sidecast associated with unapproved haul roads; landings; bladed skid roads; heavily used (but unbladed) skid trails; and backspar trails.

At present, perimeter or landing fireguards and disturbance caused by mechanical site preparation are not considered soil disturbance. The Interior Forest Harvesting Council is studying options to incorporate these forms of disturbance into the *Guidelines,* however, so the definition may be modified in the near future.

Unapproved Haul Roads. The planner has no need to estimate road-related disturbance provided that all necessary haul roads are identified on an approved Logging Plan. Haul roads that are approved by the BCMOF prior to harvesting are not considered as soil disturbance under the *Interim Guidelines.* However, haul roads built during harvesting but not indicated on the Logging Plan or covered by a Minor Amendment are classed as **unapproved haul roads.** These *are* counted as soil disturbance for the purpose of determining compliance with the *Guidelines.*

Thus the planner's task is to ensure that a cutblock's haul road and landing requirements are identified clearly at an early stage of area planning and development. Normally the need for main and branch roads will be evident from the Development Plan. Short spur roads and landing stubs, however, are sometimes overlooked at this stage, and decisions on whether or not they are needed are often deferred until harvesting is underway. More field inspections may be needed to identify necessary spurs on proposed Logging Plans, but doing so will guard against possible misunderstandings about their status afterward. In difficult terrain it is especially worthwhile to verify *all* road and landing locations in the field prior to submitting the Logging Plan. If necessary, joint field inspections should be arranged to resolve any disagreements about proposed road networks before the Logging Plan is finalized.

Unforeseen circumstances may necessitate making substantial changes to a Logging Plan between the time it is first approved by the BCMOF and the time operations actually start. In situations where roads are built well in advance of harvesting, changes can also arise between the start of road construction and the start of harvesting. Even if only minor changes to approved Logging Plans are contemplated, the proposed road network should be re-evaluated as well. Revisions to an approved Logging Plan will normally require a Minor Amendment or resubmission of the Logging Plan, depending upon the scale of the changes, before operations can start.

Landings. All landings are included in the calculation of soil disturbance. Under the *Interim Harvesting Guidelines,* landings—including cutbanks, working surface, sidecast, and debris piles—can occupy a maximum of 4% of the cutblock area, regardless of the total allowable soil disturbance for the site. To meet this limit, therefore, a landing that occupies a total area of 0.4 ha must develop at least 10 ha of timber.

The first step in estimating landing disturbance, determining the number and locations of landings required to harvest the cutblock, is done as part of the process of locating the haul-road network. Landing sites are important control points for cutblock development, especially on steep or difficult terrain. Landing locations must be marked on the Logging Plan.

The next step, estimating the total area of the cutblock that will be occupied by landings, is most easily done by assuming all landings are about the same area. First, estimate the average dimensions for the landing's working surface, using available historical information or by considering the probable needs of the logging contractor. (Only an approximation is needed at this stage, because several factors such as topography, tree size, number and size of skidders, and type of loader, among others, will obviously affect the final size of each landing.) Measurements taken in previous FERIC studies indicate that on slopes between about 30% and 50%, the total area occupied by a landing is usually between 1.5 and 2.0 times larger than the area of the working surface. Therefore, a rule of thumb for estimating total landing area is to multiply the average work-surface area per landing by the number of landings required, then double this total. This may overstate total landing area on gentle or uniform slopes, but should be reasonably close for steeper slopes. A larger factor, perhaps 2.2 or 2.3, is suggested for slopes steeper than 50%.

If the total landing area is less than 4% of the cutblock area, the proposed Logging Plan meets the *Guidelines.* If landing disturbance is more than 4%, however, the proposed plan must be reconsidered. The planner must then adjust landing size and/or number until the Logging Plan is reconciled with the *Interim Harvesting Guidelines.* Table 2 shows the maximum number of landings feasible under the *Guidelines* for various combinations of work-surface dimensions and cutblock area.

Special circumstances, such as very small or irregular cutblocks or broken terrain, may necessitate extra landings and result in the 4% limit being exceeded. Such circumstances should be noted and explained on the submitted Logging Plan. The planner and BCMOF staff should then try to agree on a compromise at the field inspection stage.

Bladed Skid Roads and Heavily Used Skid Trails. Skid roads and trails typically represent the largest single source of soil disturbance on harvested areas, so it is important to be able to estimate skid-trail disturbance reliably.

The *Interim Harvesting Guidelines* define two types of skid trails. **Bladed skid roads** are trails that are built by cutting into or excavating the soil. A common example is a contour trail crossing a steep sideslope. **Heavily used skid trails** are routes that are not excavated but have been travelled enough times by skidders or tractors that wheel or track impressions *at least five centimetres deep in mineral soil* are created. This occurs more commonly on gentle ground but may occur on steep slopes if the logging contractor uses a return-trail system. The maximum percentage of a site that can be occupied by bladed skid roads or heavily used skid trails is the residual percentage remaining after disturbance due to unapproved haul roads, landings, and backspar trails has been subtracted from the maximum amount allowed by the site's sensitivity rating. The area occupied by skid trails is the product of the average trail width, expressed as the horizontal distance from the top edge of the cut to the bottom edge of the sidecast, and total horizontal length of skid trail. Therefore, the planner must estimate the width and length of trails to design a skid-trail network that will meet soil-disturbance targets.

Although a variety of factors, including slope, soil

Table 2. Maximum Numbers of Landings Permitted by the Interim Harvesting Guidelines, Relative to Landing Size and Cutblock Size

Landing Size: Work surface dimensions (m)	Landing Size: Total area[a] (ha)	Cutblock size: 5 ha (no.)	10 ha (no.)	15 ha (no.)	20 ha (no.)	25 ha (no.)	30 ha (no.)	35 ha (no.)	40 ha (no.)
20 x 30	0.12	1	3	5	6	8	10	11	13
20 x 40	0.16	1	2	3	5	6	7	8	10
25 x 30	0.15	1	2	4	5	6	8	9	10
25 x 40	0.20	1	2	3	4	5	6	7	8
25 x 50	0.25	-	1	2	3	4	4	5	6
30 x 30	0.18	1	2	3	4	5	6	7	8
30 x 40	0.24	-	1	2	3	4	5	5	6
30 x 50	0.30	-	1	2	2	3	4	4	5

[a] Assumes total area is twice the working surface area.

type, season of harvesting operator experience, and amount of traffic, will affect overall width, the size of the trail-building and skidding equipment is probably the most important determinant of skid-trail width. Averages and ranges of skid-trail widths for trails built on bare ground by trail-building bulldozers of different sizes, based on unpublished FERIC data, are summarized in Table 3. These averages cover a range of slopes (20 to 50%), site conditions, operator experience, and amount of traffic, and should be used as general guides only. If more precise width estimates are desired, the planner should sample skid trails on previously harvested areas that are similar to the areas for which estimates are needed.

Total skid-trail length is usually indirectly estimated. When designing skidding patterns to reduce soil disturbance, planners usually speak of increasing **trail spacing** (the average horizontal distance between adjacent skid trails) rather than reducing the total length of skid trail. This approach is appropriate for steep, uniform sites where regular spacings can be maintained and only bladed skid trails are planned. For complex or broken terrain, however, average trail spacing may be difficult to estimate. An alternative index of trail spacing, **trail density** (the average horizontal length of skid trail per hectare), may be simpler to use. Trail density is inversely related to average trail spacing, i.e., the total length, or density, of skid trail per hectare decreases as the average distance or spacing between trails increases.

Table 3. Ranges and Averages of Skid-Trail Widths for Different Trail-Building Bulldozers

Machine	Skid-trail width
Caterpillar D4 or equivalent	5.0 +/- 0.4 m
Caterpillar D6 or equivalent	6.0 +/- 0.4 m
Caterpillar D7, D8, or equivalent	7.5 +/- 0.8 m

Figure 3 graphs the relationships between skid-trail width, skid-trail spacing (bottom) or density (top), and soil-disturbance level. The graphed lines represent combinations of skid-trail width and spacing (or density), which yield a specified level of soil disturbance. To apply this graph, the planner must first estimate the expected residual amount of disturbance (site maximum less sources other than skid trails) to define the maximum level of skid-trail disturbance. Next, initial assumptions about expected trail width (based on the type and size of skidding equipment to be used) and the anticipated average trail spacing (or density) are made. This process defines the starting point for calculating and comparing expected against allowable skid-trail disturbance.

When using Figure 3, it is important to recognize that trail spacing refers to *horizontal* (not slope) distance between trails. Also, it is necessary to account for connector or feeder trails and areas of converging trails near landings when choosing an average skid-trail spacing.

If the intersection of skid-trail width and spacing lies below the line representing the maximum allowable disturbance level for skid trails, expected disturbance is less than the residual available and the proposed skidding pattern satisfies the *Guidelines.* For example, if allowable skid-trail disturbance is 14%, a skid-trail network with 5-m wide trails will satisfy the *Guidelines* if trails are spaced 35 m or more apart. If the intersection lies above the line (i.e., expected disturbance exceeds

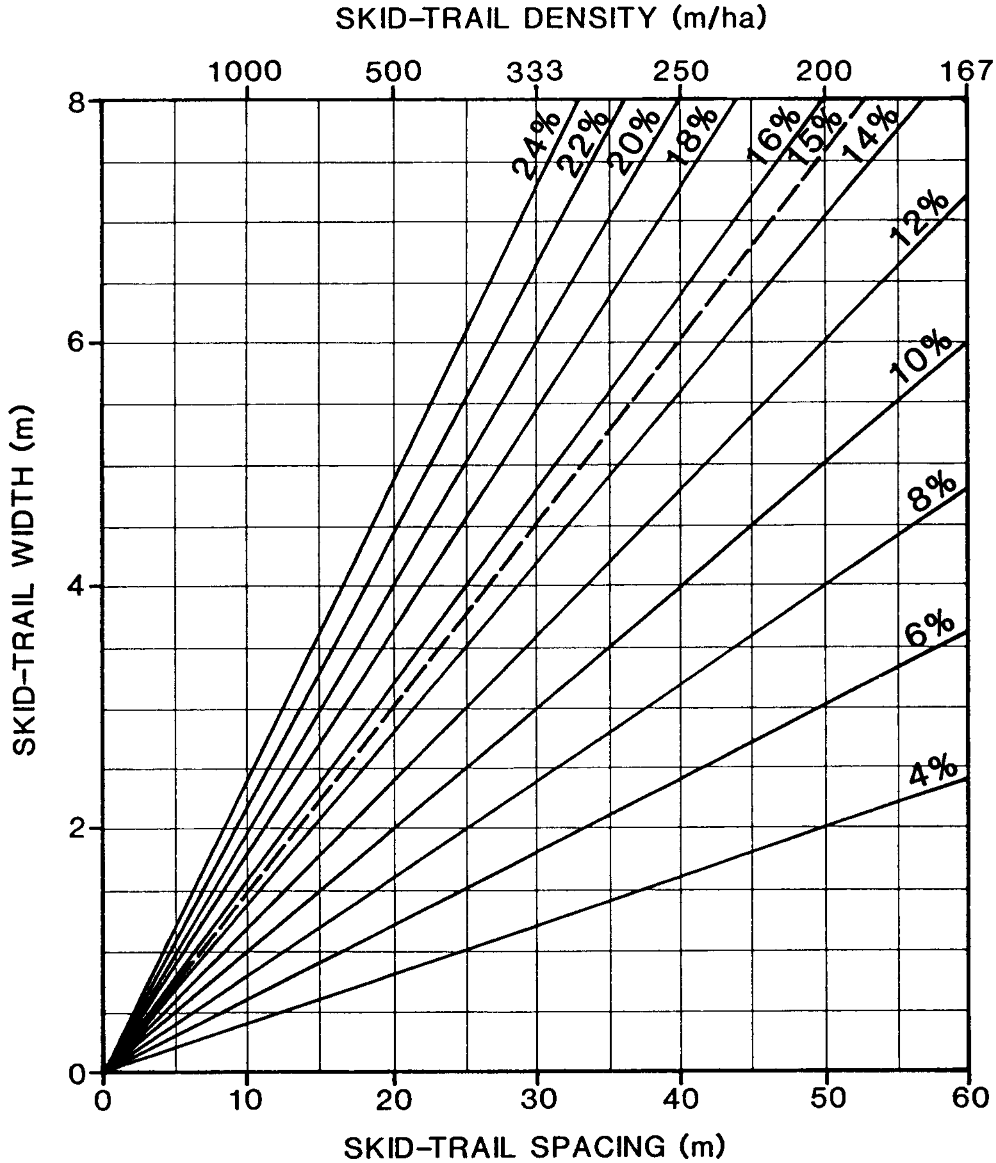


Figure 3. Soil disturbance versus skid-trail density and width.

allowable disturbance), trail width and/or spacing must be adjusted to arrive at a workable combination.

The *Interim Harvesting Guidelines* recognize that skid trails built on deep, firm snow may cause less severe disturbance than trails built on bare ground because cuts are shallower, sidecast is less compacted, and less soil is displaced. Therefore, it may be appropriate to use a narrower trail width for estimating disturbance. If winter harvesting is planned, assumptions concerning skid trails should be discussed with the BCMOF before the Logging Plan is finalized.

The above discussion assumes that mainly bladed skid roads will be built, but the estimation procedure can also be applied to heavily used (i.e. unbladed) skid trails with some modifications. Different trail-width estimates may be required. Also, it may be necessary to determine what proportion of the entire network of unbladed skid trails is impacted sufficiently to qualify as heavily used trails.

Backspar Trails. Disturbance due to backspar trails is the product of total horizontal length and width of backspar trails. Road locations and yarding breaks will indicate the probable locations and lengths of backspar trails. Identify and include the travel paths that link the haul road and backspar trail. Average widths can be determined by field measurements of existing backspar trails on similar sites, or by estimating the width of the type and size of machine that will build the trails.

Where they are required and deflection is favourable, perimeter fireguards should be used for backspar trails. The planner should consult with the local BCMOF to determine whether the fireguards are included in disturbance totals or not.

Develop Harvesting Prescriptions. By estimating soil disturbance in the above manner, the planner effectively determines which available harvesting options can satisfy the *Interim Harvesting Guidelines.*

Where ground skidding is the preferred harvesting method, the planner may have several options that will achieve a similar result. These include increasing trail spacings, using smaller skidders, harvesting in winter, using designated trails, or using alternative ground-skidding systems. The following comments may help in determining which of these strategies is appropriate.

- Increase average trail spacing. Increasing skid-trail spacing is the simplest way to reduce trail disturbance. If estimated trail disturbance exceeds the allowable disturbance by no more than 3 or 4%, average trail spacing would have to increase by about one-quarter to meet the *Interim Harvesting Guidelines* (assuming the sites are rated as Moderate). It should be possible to achieve such an increase without prelocating trails. For example, if estimated trail spacing and width is 33 m and 6 m respectively, expected trail disturbance would be about 18%. Assuming allowable trail disturbance is 15% (i.e., a Moderate site), trail spacing would have to increase by 7 m to 40 m, to reduce expected trail disturbance to the allowable limit.

  If the average trail-width and the soil-disturbance targets are known, the required skid-trail spacing in metres can be easily calculated by dividing the trail width in metres by the soil-disturbance target expressed as a decimal.

- Downsize trail builders and skidders. If candidate logging contractors own equipment in a range of sizes, it may be feasible to assign specific cutblocks (or portions of cutblocks) to specific contractors. In essence, this approach tries to match contractors' equipment profiles to site conditions. Downsizing by itself may reduce trail disturbance by about two or three percent. Downsizing in conjunction with increasing trail spacings can reduce skid-trail disturbance by one-quarter to one-third or more.

- Harvest in winter. If the original plan called for harvesting in snow-free conditions but winter harvesting is a feasible alternative, rescheduling the harvesting season may significantly reduce trail disturbance. However, trail building must be delayed until the snowpack is sufficient (at least one metre deep is usually stipulated), so it may be difficult to predict when operations will begin if weather is unreliable. Also, logging contractors usually prefer to reduce trail spacings in winter because of difficulties in hooking up turns and finding small trees in deep snow. The planner and BCMOF should agree on how soil disturbance will be defined and measured before accepting this option.

- Specify designated skid trails. Locating and marking skid trails prior to harvesting, and ensuring the contractor builds only those trails, is the surest way to control skid-trail disturbance. Marking trails can be time consuming, but it may not be necessary to locate all the trails. Locating just the main trails may be sufficient on many areas. On more difficult sites, however, it may be necessary to locate more of the skidding network to ensure that soil-disturbance goals are met. Where cutblocks contain areas of more sensitive soils, whether in large units or isolated patches, marking skidding patterns to avoid these units is advisable.

- Use a different harvesting system. If estimated skid-trail disturbance exceeds the allowable disturbance by more than about 10% (e.g. for a Moderate site, estimated skid-trail disturbance is 25% or more), the probability of meeting the *Interim Harvesting Guidelines* using conventional ground-skidding systems is relatively low even if some of the above techniques are adopted. Alternative harvesting systems, whether ground-based or some form of cable yarding, should be considered.

Finalize the Logging Plan. The Logging Plan is finalized only after the planner is satisfied that the estimation phase has produced a workable and practical harvesting strategy. The adopted harvesting strategy is finalized by documenting the details of the strategy, including specific instructions to the loggers, in the Logging Plan. The Logging Plan is distributed with the Cutting Permit application to the BCMOF and other agencies as required. It is important that the Logging Plan be as complete as possible at this stage so that agency personnel can make informed decisions. It may be modified further in response to agency comments. Once approved, the Logging Plan becomes part of the Cutting Permit document, and the licensee is required to adhere to the terms and conditions of the Cutting Permit.

Implement the Logging Plan. If the final Logging Plan prepared by the planner is basically sound, its success will depend upon how well it is implemented by the supervisor and the logging contractor. The goals of a Logging Plan are most easily realized when the planner, the supervisor, and the logger understand and agree on what the plan is designed to achieve and how to achieve it. Thus, after the planner has identified a practical harvesting strategy, he must perform two additional important tasks. First, he must communicate the details and requirements of the Logging Plan to the logging supervisor, and second, he must complete the field layout to ensure that the plan will work.

Ideally the planner should involve the logging supervisor in the preparation of the Logging Plan if the area is difficult to develop and special practices are prescribed. If this is not feasible, the planner and supervisor should review the Logging Plan together in the field. A joint field review serves several purposes. First, the supervisor becomes familiar with the site and aware of the site's sensitivity and soil disturbance targets. Secondly, the planner can explain his ideas about how the area should be developed. Finally, the supervisor can suggest changes or improvements to the plan while there is still time to consider them. The timing of a joint field review is flexible, but it is important to do it far enough in advance of harvesting so that changes, if needed, do not delay road-building or harvesting.

During the field inspection, the planner and supervisor should examine important control points affecting roads or skidding, in particular difficult or sensitive areas, and decide if the proposed harvesting strategies are appropriate. Areas that require special treatment should be marked or ribboned to ensure they are not overlooked during harvesting.

Changes as well as specific instructions for special sites should be agreed upon and noted on the Logging Plan and maps. Many other details of the layout, such as locations of spurs, landings, and important skid trails, can also be finalized during the field inspection.

If this inspection indicates that minor changes must be made to the Logging Plan, the changes should be discussed with the BCMOF to determine whether a Minor Amendment is needed. If the field inspection necessitates substantial changes to the Logging Plan, the revised plan must be resubmitted to the BCMOF. A final field inspection with the BCMOF and other agencies may be required.

Occasionally there may be a long time lag between the time the Logging Plan is finalized and the time operations begin. In such cases, the logging supervisor should refamiliarize himself with the Plan shortly before initiating either road-building or harvesting activities. If circumstances have changed in the interval and further changes to the plan are necessary, the supervisor should notify the planner and assist him with the modifications.

Finally, before operations begin, the supervisor must discuss the Logging Plan with the contractor who will work on the area. This can be done well in advance of harvesting or, more commonly, on startup day. The details of the Logging Plan should be reviewed carefully with the contractor, and copies of maps should be provided for each of the contractor's machine operators. It may be worthwhile to walk the area as well. If the area is difficult to harvest, the planner should also participate in this review. Road-building and harvesting should begin only when all parties understand and agree on the objectives and methods.

It is important to recognize that harvesting operations often deviate from the Logging Plan because circumstances change between planning and harvesting; and actual conditions at the time of harvesting may be very different from expected conditions. Also, supervisors, contractors, and machine operators should always be encouraged to look for ways to improve their operations. For these reasons harvesting operations will always require on-site judgement and decision-making to ensure that operations proceed smoothly and all objectives are met. Logging Plans must be flexible enough to accommodate change when circumstances dictate that changes are necessary. However, the supervisor and contractor must also bear in mind that any changes to the Logging Plan must still satisfy the *Interim Harvesting Guidelines* for that site.

Operational Strategies to Minimize Soil Disturbance

The final phase of a soil-disturbance reduction program, the operations phase, is when the Logging Plan is implemented. Soil disturbance is minimized in this phase by following the Logging Plan carefully and employing good road-building and harvesting techniques.

The following discussion describes a variety of techniques to reduce soil disturbance when building roads and harvesting on steep slopes. The list is not complete. Rather, it is intended only to demonstrate some of the options available to reduce disturbance, and to encourage the logger to look for the most practical methods that are compatible with his preferred work methods. Road-building and ground-skidding practices are emphasized, but the principles can easily be applied to any other harvesting system and any harvesting situation.

For convenience, the techniques are grouped into three sections: roads and landings, skid trails, and cleanup and post-harvesting activities. These components are not independent of each other; the methods used in one phase must be compatible with those used in other phases to ensure the entire harvesting operation is efficient. Supervisors and contractors must always consider the effect that changes to one phase may have on other activities.

Roads and Landings

The operations phase commences with road construction. Road building may be done concurrently with harvesting or the activities may be separated to allow roads to season and to avoid interference between the two activities. Landings may be built during either road building or harvesting.

Roads. Although the construction of approved haul roads is not counted as soil disturbance, a complete program should attempt to minimize all forms of soil disturbance. Minimizing road disturbance is especially important because the land taken up by roads usually will not contribute usefully to the next tree crop. The supervisor and logging contractor must ensure that roads occupy no more area than is absolutely necessary for conducting safe and efficient harvesting operations.

Eliminating unnecessary roads. The greatest reductions in road-related disturbance are made by minimizing the total length of road. The first step is to eliminate unnecessary roads and spurs. The supervisor and the logging contractor should reconsider the need for all located roads, especially spurs, when they review the Logging Plan and instructions. This practice will help eliminate unnecessary roads and guard against the possibility of having to build unapproved roads later.

If road building is contracted separately from harvesting, and the logging contractor has not yet been determined, doubtful spur roads should be left for later construction.

Scheduling road construction. Road builders are very aware of the importance of constructing roads at the right time of year, i.e. when site and weather conditions are most favourable. However, unpredictable weather may disrupt construction schedules and, at times, necessitate construction under less-than-optimal conditions. Wet-weather construction often requires gravel and surfacing material be brought in by truck, and it also causes more disturbance and erosion and sediment problems.

Scheduling construction on moist or wet sites is difficult because the optimal road-building window may be brief and difficult to predict from year to year. Under these circumstances the planner and supervisor should consider the possibility of scheduling road building one or even two years in advance of harvesting. Greater lead time will increase the likelihood of building the road in favourable conditions, but the construction costs must be carried and the road must be maintained for a longer period of time.

If harvesting is scheduled for winter, it may be worthwhile to defer construction of spur roads until the winter as well. Disturbance related to road construction may not be reduced significantly, but costs may be less if winter construction eliminates the need for surfacing.

Preparing the right-of-way. Right-of-way preparation consists of felling, skidding, and decking the right-of-way timber. A properly prepared and cleared right-of-way makes road-building easier, which in turn helps to reduce road-related disturbance.

The first step is to ensure the right-of-way is wide enough to contain the entire road prism (i.e. the road cross section) plus setbacks to standing timber. Rights-of-way should be wider on steep slopes because cuts and fills are larger and overall road width increases. When building a road through a narrow right-of-way, sidecast material often carries into the standing timber, cutslopes are too steep, and trees above the road are undermined. Sidecast debris in standing timber complicates falling, cutslopes ravel and collapse, and undermined trees above the road become safety hazards.

The planner or supervisor should indicate which road sections require a wider right-of-way on the Logging Plan given to the road-builder. Marking the boundaries of the right-of-way in the field is seldom necessary. A useful rule of thumb is to increase the right-of-way width by 3 m for every 10% increase in sideslope above 40%.

Depending on terrain and skidding distance, the right-of-way can be skidded with rubber-tired or flexible-tracked skidders, or with bulldozers. If sideslopes are steeper than 30% or so, normally a skid trail is built. Because this trail eventually becomes part of the finished road, it should be located and built with the final road grade and alignment in mind. Containing the trail within the finished road prism will simplify road building without creating additional soil disturbance.

Decking sites for right-of-way logs should be chosen carefully because right-of-way landings may be considered as soil disturbance under the *Interim Harvesting Guidelines*. Wherever possible, right-of-way logs should be decked on landings identified on the Logging Plan, or on planned truck pull-outs.

Building roads. If the total length of road has been minimized through careful planning and review, the task of the construction phase in reducing road-related disturbance is to minimize the overall width of the finished road. Road dimensions are influenced by the desired road standard, choice of road-building equipment, and construction techniques.

Forest roads should be built only to the standard that is required for safety and efficiency. The BCMOF has established a set of standards for grade, vertical and horizontal alignment, and dimensions for main, branch, and spur roads. A Cutting Permit application specifies the standards for each road within a development area, but, in practice, the standards are not rigidly enforced except for main roads. As a result, spur roads are sometimes built to higher standards than are necessary for safety. Therefore, the logging supervisor should ensure that the road-builder understands the purpose of each road and does not "overbuild" spurs.

Bulldozers and hydraulic excavators can employ a variety of specific construction techniques to control the finished dimensions of the road, but disturbance can best be minimized by properly matching the construction machine to the site conditions. The bulldozer is the conventional road-building machine in the Interior and is well suited for most construction applications. However, the hydraulic excavator is better suited to working on steep and wet ground, and should be considered for these situations where better control and placement of excavated material are important.

As a general rule, road-related disturbance can also be reduced by fitting the road to the terrain, avoiding construction on very steep slopes, and by not stripping overburden from beyond the limits of the road prism. This practice will minimize the volume of excavated soil and reduce the sizes of cuts and fills. Roads on very steep slopes require large excavations and are more prone to slope failures. A longer road that avoids steep, unstable areas may cause less disturbance overall, due to smaller cuts and fills, and may be less susceptible to landslide damage and erosion.

Building the road a year or two in advance of logging allows time for the road to settle and strengthen before log hauling begins. A stronger, stable surface requires less patching, cutting, and spreading of soil during the hauling season, all of which can widen the road surface.

Turnouts, fuelling pits, and borrow pits for rock or gravel also increase the area occupied by roads. Wherever possible, their locations should coincide. Turnouts should take priority because they are necessary to reduce interference of vehicles in the hauling phase, but they should be carefully located to minimize their number and size.

Minimizing road impacts. Forest roads not only remove forest land from timber production but can also reduce water quality through surface soil erosion and mass wasting. In most cases good basic construction technique will produce stable, useable roads, and minimize soil disturbance and erosion problems as well. Difficult construction situations which require drilling and blasting, endhauling, or other special techniques should be identified during area planning.

Good road drainage is especially important. Forest roads on steep slopes should be properly back-sloped, ditched, and cross drained at the time of construction. Timely maintenance of the drainage network is essential during active road use and immediately following harvesting. After harvesting, all temporary roads must be properly treated to prevent further deterioration, with culverts removed and cross drains installed where needed.

The following publications are recommended for information and methods for controlling erosion from forest roads:

- Rothwell, R.L. 1971. *Watershed Management Guidelines for Logging and Road Construction.*

Canadian Forest Service, Information Report A-X-42. Edmonton, Alberta.
- Carr, W.W. 1980. *Handbook for Forest Roadside Erosion Control in British Columbia.* British Columbia Ministry of Forests, Land Management Report No. 4. Victoria.

Landings. Landings, which are included as soil disturbance in the *Interim Harvesting Guidelines,* are also usually heavily impacted by machine traffic. In general, landings can be successfully restored to former productivity levels, but complete rehabilitation is very time-consuming and costly. Therefore, the goal of the *Guidelines* is to minimize the area allotted to landings.

The *Guidelines* favour the construction of fewer and smaller landings to reduce disturbance, but supervisors and contractors generally favour more and larger landings to optimize production and permit safe and efficient harvesting operations. Landings are busy sites and tend to be production bottlenecks because trucks, loaders, skidders, and workers usually interfere with each other. Achieving a satisfactory compromise between soil-disturbance, production, and safety goals on steep-slope cutblocks will require the planner, supervisor, and logging contractor to devote more effort to ensuring that landings are properly located and used.

Reviewing proposed landings. Before construction begins, the supervisor should review proposed roads and landings to ensure that they are in the right locations. If possible, landing locations should be finalized with the contractor who will harvest the block because his preferred work methods may influence landing location, size, and orientation.

As with roads, the best way to minimize landing-related disturbance is to avoid building unnecessary landings in the first place. If the Logging Plan has been prepared and reviewed carefully it is unlikely any of the landings will be unnecessary. However, if the need for any of the landings is doubtful their construction should be deferred until it is certain they are needed.

Another possibility is to explore whether cuts and fills can be reduced with minor shifts in road and landing locations. Even if overall landing disturbance is not reduced, minimizing cuts and fills may increase the working size of each landing without increasing total landing area.

Landings on short spurs or stubs extending from main or branch roads should be closely examined. If the only purpose of a stub is to isolate the landing so that harvesting operations will not interfere with traffic on the main road, it should be determined if access beyond the landing is needed during the planned harvesting period. If not, eliminate the stub and use part of the main road surface for the landing.

Given the importance of the landing to the contractor's productivity, it is easy to understand why landing size is often a contentious issue between companies and logging contractors. No firm rules exist to help planners determine optimum landing size. Among the many operational factors which influence this decision are the number and type of skidders working a landing at a given time, the type of log loader, tree length, number of sorts required, landing orientation with respect to skidding direction, and preferred working methods. The landing dimensions proposed in the Logging Plan should be compared to the contractor's operational requirements. If the indicated sizes are not sufficient, the supervisor and contractor should agree on the desired sizes, note the changes on the Plan, and discuss them with the planner. If the landing dimensions shown on the Logging Plan are already compromises between ideal landing size and allowable soil-disturbance limits, increasing the size of some landings will require that other landings be reduced in size or eliminated.

Landings cannot always be built to optimize log production. On steep or difficult terrain there may be no choice but to specify small landings. In these situations the contractor must adapt his working methods to suit the landing, and the company may have to find alternate locations for sorting logs. If small landings are necessary, congestion and interference can be reduced by working two or more adjacent landings concurrently and alternating loading and skidding activities.

Building and using landings. Methods for preparing and building landings are basically the same as for roads. Because landing size usually increases during harvesting because of debris accumulation, an allowance for some expansion of landing area should be made at the time of construction. The supervisor and contractor should agree on how to handle debris to minimize expansion of the landing.

Special landing configurations may be necessary in some instances; these should be determined on a site-specific basis. For example, cable yarders pulling tree-length logs uphill on steep slopes may encounter difficulty because of insufficient clearance at the outer edge of the landing. Stepped landings, in which the yarder is positioned on a bench above the level of the main landing, may alleviate such clearance problems. Alternatively, swing yarders or special rigging configurations that permit logs to be decked alongside the yarder may reduce landing widths.

Skid Trails

The principal opportunities for minimizing skid-trail disturbance include methods of locating and building skid trails, falling patterns and techniques, and skidding operations. These activities are highly interdependent, and must be carefully coordinated to minimize disturbance and maintain productive harvesting operations.

The following discussion assumes that: (1) harvesting is done with rubber-tired skidders or bulldozers and slopes are generally steep enough to dictate blading of most skid trails; (2) trail-builders take full advantage of benches and ridges when locating and building skid trails; and (3) dispersed skidding (i.e., skidding without building trails) is not feasible on most of the cutblock.

Locating skid trails. The process of deciding on the location and spacing of skid trails largely determines how much of the cutblock will be disturbed by skid trails. On any site, the skidding network must be well planned to ensure that the *Interim Harvesting Guidelines* can be met, and difficult or sensitive sites require more careful planning than less sensitive sites.

The most effective way to minimize skid-trail disturbance is to minimize the total length of constructed trail, which in turn means that trails must be spaced as far apart as efficient harvesting will allow. The "designated-trail" method, in which the planner locates and marks *all* skid trails at predetermined spacings prior to harvesting, is probably the surest way to satisfy the *Interim Harvesting Guidelines.* This approach is best suited to uniform slopes. Trials in Oregon (Froehlich et al 1981; Olsen and Seifert 1984) have demonstrated that marking trails on gentle to moderate slopes substantially reduces the area occupied by skid trails with little or no increase in harvesting costs, even though more line-pulling is required. The average trail spacing required to meet a specified level of disturbance can be estimated from Figure 3 if the size of the trail-building machine is known.

A modified version of the designated-trail method was successfully used in the Cariboo Lake logging trials. On steep or broken terrain, this method appears to be more practical than using predetermined spacings. During the trials, the area supervisor located the main trails and key branch trails for each landing area. Prior to building the trails, the supervisor and trail-building contractor walked each area to review and finalize the skidding pattern. Once this was agreed upon, the trail-builder established the remainder of the trail network around the skeleton of main and branch trails. On uniform slopes the trail-builder determined approximate trail locations by falling the occasional tree or by measuring slope distances with a hip chain.

This system of locating trails, combined with the use of small crawler-tractors for skidding, resulted in an average soil disturbance level of 12.4% for skid trails on the summer-logged block. Skid trails built in winter were about 20% wider and spacings were about 10% less than skid trails built in summer, yielding an average disturbance level of 16.2% for winter skid trails. Site sensitivity on the tractor-logged areas was Moderate for the summer block and High for the winter block. Thus, summer ground-skidding operations met the current *Guidelines* but winter ground-skidding operations exceeded the *Guidelines.* However, if only the width of the excavated portion of winter skid trails is considered as disturbance (the definition used for the Cariboo Lake logging trials), skid-trail disturbance on the winter-logged block would have been reduced to 5% and the combined total disturbance due to skid trails and landings would have been 7.7%, which is less than the 9% limit for High sites.

Recent logging trials in the East Kootenays (G. Kockx, FERIC study in progress) using mid-sized tractors and rubber-tired skidders compared the practice of "contractor-choice," i.e. having logging contractors locate trails, to a modified designated-trail approach similar to that used in the Cariboo Lake logging trials. Disturbance related to skid trails averaged about 22% for the contractor-choice method and 17% for the modified designated-trail method. Although disturbance levels in both cases exceeded the limits of the *Guidelines,* preliminary results suggest that with modest improvement the modified designated-trail approach could be a viable technique for use with medium-sized skidding equipment.

Main or feeder trails must be located to permit logs to be skidded into the landing in the orientation that is most favourable to the loading phase. This is particularly important on small or "tight" landings that lack space for the loader to freely manoeuvre logs. Branch or spur trails, on the other hand, should be located to facilitate falling and skidding. If trees are top-skidded, the direction of skidding should be approximately the same as the direction of lean. If the skidding direction opposes the lean, trees must either be felled against the lean, skidded by the butts, or swung through large angles to orient them to the skidding direction. Production decreases in these situations, and swinging trees through large angles usually results in significantly more log breakage; soil displacement can also result.

Normally the planner considers the lean of the trees when selecting landing locations, but on steep or broken ground it is sometimes necessary to choose landings that require skidding against the lean. A carefully planned skid-trail network can often compensate for this difficulty. Where topography allows, branch or spur trails should be joined to the main trails with large gentle curves rather than sharp-angled junctions. If large-radius curves are not possible, stumps on the inside of the junction should be cut as close to ground level as possible to allow logs to swing to the inside of the curve. The density of skid trails will probably be higher than usual for such landings, but well-designed trail junctions that facilitate skidding will reduce a skidder operator's temptation to take shortcuts that create even more disturbance.

Building skid trails. A variety of options are available to reduce disturbance by reducing the overall width of skid trails. These include using a smaller trail-building machine or using excavators instead of bulldozers, minimizing cuts and fills by varying trail gradients and outslopes, and building winter trails on deep snowpacks.

For a given sideslope, overall trail width is strongly influenced by the size of bulldozer used to build the trail. The average depth of cut also increases as the size of trail-building machine increases. Most of the increase in trail width, however, occurs in the sidecast. Table 3 shows that for a given density of skid trails, downsizing the trail-building machine can reduce skid-trail width by 15% or more.

Given the importance of machine size to trail width, it is worthwhile to ensure that the contractor's trail-builder and skidders are properly matched. Many conventional contractors build skid trails with a general-purpose bulldozer that performs a range of duties, including road and landing construction, skid-trail construction, and skidding. A general-purpose bulldozer may not be well suited for building skid trails because its size is usually governed by the heavier-duty applications such as road-building. However, most logging contractors need a general-purpose machine and cannot afford to invest in a specialized trail-building machine. Therefore, some companies now employ separate contractors for trail-building. The trail-building contractors handle all trail-building duties within the operations, providing enough work to justify investing in special machines.

Several Interior operations are now using or experimenting with small hydraulic excavators for building skid trails. Users believe that excavators have better control when removing stumps and windfalls and placing excavated soil, resulting in shallower cuts and fills and narrower trails. Special attachments have been developed to facilitate trail construction with excavators (Bennett 1988).

Sloping trails require smaller cuts and fills and, therefore, tend to be narrower than contour skid trails. However, sloping skid trails must be adequately drained during harvesting and properly waterbarred afterward to control erosion. Cuts on summer trails can also be reduced slightly with gentle outsloping, which also facilitates drainage (outsloping is not recommended for winter trails). Evenly spaced high stumps should be left on the low side of outsloped trails to prevent skidded logs from rolling.

When building sloping trails with a bulldozer, it is easier to work downhill than uphill. The trails can be built in two passes. On the first pass, working uphill away from the landing, windfalls and some stumps are moved and the trail is roughed in. On the second pass, working downhill toward the landing, the trail is excavated to finished dimensions. This technique uses the machine's weight more effectively and carries excavated soil ahead of the bulldozer, rather than sidecasting it, thus reducing cut depth.

Sidecuts on winter skid trails can be greatly reduced by building trails on deep, dense snowpacks. Ideal snow conditions are difficult to forecast but most often occur shortly before breakup. If sensitive sites are scheduled for winter harvesting, consider reserving the most difficult or steepest areas of these cutblocks until snow conditions are favourable. However, there is some risk in depending on suitable snow conditions because they may not materialize. The supervisor must be prepared to make a timely decision about whether or not harvesting should proceed if favourable conditions do not develop.

Falling. Falling techniques must be compatible with skidding methods to ensure that harvesting operations are efficient. If falling and skidding techniques are well matched, and the quality of falling is high, skid-trail spacings can often be increased with little effect on overall production. If the quality of falling is poor, skidder operators must spend more time hooking up turns and they will be less inclined to widen trail spacings. Because most logging contractors prefer to top-skid trees, the faller's task is to place the tops as close as possible to the skid trail to minimize line-pulling by the skidder operator.

Where the skid-trail network has been prebuilt, and the trails are about one tree length apart, the falling task is relatively straightforward. With skid-trail spacing already established, the quality of falling may affect skidding productivity but will not affect soil disturbance. On many sites, however, skid trails will have to be spaced well over a tree length apart to meet the *Interim Harvesting Guidelines,* and not all trees will reach the skid trail when felled. Good falling practices are essential to minimize the negative effect of wide trail spacing on skidder productivity. The possibility of falling some of the trees to the next higher trail should be considered. If the skid trails climb at a steady gradient of 20 to 25% it may be feasible to fall a strip of trees approximately parallel to the contours so their tops are close to the upper trail.

If skid trails are built as harvesting progresses ("face logging"), the quality of falling can sometimes determine skid-trail spacing and, therefore, soil-disturbance levels. Again, good falling practices are essential for maximizing the width of the felled strip. Fallers must be aware of the desired trail spacing. During harvesting, the supervisor or contractor should check spacings regularly and consult with the fallers if desired spacings are not being met.

A falling technique that has been successfully employed to increase trail spacings in short lodgepole pine stands in the Kootenays may be suited to other uniform stands. In this method, the trees to be skidded to a trail are felled in three strips. Trees in the strip immediately above the skid trail are felled almost parallel to the trail. The second strip of trees is felled at an angle of about 45 to the trail so that the tops rest on and the branches interlock with the first strip. The final strip is felled directly downslope onto the second strip and approximately perpendicular to the trail. The skidder operator begins by skidding the trees in the first strip. As these are pulled out, the interlocked branches cause the trees in the second and third strips to be gradually pulled downhill and into lead with the skid trail. This practice minimizes the amount of line-pulling required to reach the trees that do not reach the trail during falling.

A similar method has been suggested for uneven stands with many short trees. In this approach, the taller trees are felled first and the shorter understory trees are felled on top of the tall trees. The short trees are drawn closer to the skid trail as the tall trees are skidded out. This practice can lessen the amount of time spent on cleanup operations afterward. Fallers who have tried this technique indicate that it decreases falling productivity but also reduces breakage of smaller trees.

Skidding. The level of skid-trail disturbance is determined largely by the activities of locating and building the skid trails. Provided these activities are carefully planned and executed, and skidder operators are aware of soil-disturbance concerns, skidding should not cause additional disturbance. Exceptions occur if skidder operators take shortcuts between trails or build extra trails to reach inaccessible trees. The supervisor and contractor can avoid these occurrences by giving clear instructions to operators before harvesting starts, and by providing adequate supervision during skidding.

Another practice that is being used more frequently to reduce skid-trail densities on steep slopes is for the skidder to travel empty along an upper skid trail, drop down the slope to hook up a turn, and skid the turn back to the landing along a lower trail. This technique is effective with flexible-tracked skidders with low centres of gravity. Before trying this method with rubber-tired skidders or crawler-tractors, however, supervisors and contractors should consult with the local Workers' Compensation Board Safety Officer.

Situations will occur where additional trails must be built, regardless of how carefully skidding has been planned. Ground conditions might be more difficult than expected and require trails to be relocated, or cutting boundaries may have to be extended to recover windthrow or small areas of merchantable trees that would otherwise be isolated. Workers must inform the contractor or supervisor before building unplanned trails. Extra trails should be built only after all feasible options and their effects on soil-disturbance targets have been considered.

Cleanup and Post-Harvesting

Usually the contractor is responsible for ensuring that the harvesting site is left in suitable condition for site-preparation activities. The contractor's cleanup duties typically include recovering merchantable trees missed during prime logging, waterbarring skid trails, cleaning ditches and culverts, draining landings, piling landing debris for disposal, and possibly building fireguards around either the landings or the perimeter of the cutblock. The goals at this stage are to avoid generating additional or unnecessary soil disturbance while completing the cleanup tasks.

With the exception of fireguard construction, these chores can be achieved without travelling on previously undisturbed ground. The usual type of avoidable disturbance during cleanup is caused by extending existing skid trails rather than pulling line to reach merchantable small trees along the fringes of the cutblock and between skid trails. The supervisor and contractor must instruct the crew not to build additional skid trails during cleanup.

If the cutblock is to be slashburned, the supervisor and contractor should try to incorporate fireguards into the skidding pattern wherever possible. In some situations it may be possible to eliminate some fireguards by conducting a thorough cleanup along the block margins. If only the landings are to be burned, each landing's fireguard requirements should be assessed individually and then only the necessary guards built. If debris accumulations are relatively light on some landings, it may be feasible to pile the debris back toward the centre and eliminate fireguards around these landings.

CONCLUSIONS

FERIC's study of harvesting systems operating in the Cariboo Lake area were initiated in 1984 in response to increasing concern about the effects of steep-slope harvesting on site productivity. The primary goal of the logging trials was to identify cost-effective alternatives for harvesting steep slopes and reducing soil disturbance. A second important goal was to learn how to plan and manage steep-slope harvesting operations to minimize soil disturbance for all steep-slope harvesting situations. This report addresses the second objective.

A review of research undertaken in British Columbia and the Pacific Northwest demonstrates that ground-based harvesting systems typically cause more soil disturbance and compaction than cable- or aerial-harvesting methods. Furthermore, tree growth on disturbed or compacted soils may be reduced, relative to trees growing in undisturbed conditions, for periods lasting up to several decades.

The *Interim Harvesting Guidelines for the Interior of British Columbia*, released in 1989 for a two-year trial period, attempt to minimize productivity losses by stipulating allowable levels of specific types of soil disturbance associated with harvesting operations. The *Guidelines* emphasize prevention of soil disturbance. Permissible disturbance levels are based on the sensitivity of forest sites to soil degradation.

Almost 30% of the Interior's supply of mature timber, and 21% of the Cariboo Forest Region's mature timber, is on steep slopes. Thus, steep-slope forests represent an important source of timber to the Interior forest industry, and the *Guidelines* can be expected to have a significant impact on steep-slope harvesting operations.

Based on historical performance, it is concluded that Interior steep-slope harvesting operations using ground-based machinery will face a challenge in consistently satisfying the *Interim Harvesting Guidelines*. To ensure the *Guidelines* are met, planners and logging managers must view the reduction of soil disturbance as an important goal when carrying out Logging Plans and operations. A strategy for controlling disturbance during harvesting, based on the *Handbook for Ground Skidding and Road Building in British Columbia*, is proposed. The strategy requires that thorough planning be undertaken to ensure the final Logging Plan has a realistic chance of meeting the *Guidelines;* the Logging Plan is carefully executed; the planner, supervisor, and logger maintain good communications at all stages to exploit opportunities and avoid mistakes; and consistent follow-up activities be carried out to identify ways in which performance can be improved.

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