Harvest Systems and Strategies to Reduce Soil and Regeneration Impacts (and Costs)[1]

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SUMMARY

The British Columbia Ministry of Forests (BCMOF) has established soil conservation as a priority for forestry operations throughout the province. On steeper and very sensitive sites, this normally means cable or aerial harvesting methods. On gentler and less sensitive sites, ground-based harvesting is still the dominant method, particularly in the lower volume stands of the BC Interior. Surveys done throughout the BC Interior from 1990 to 1993 demonstrated that soil disturbance guidelines, under development and debate since the 1970's, had been successful. The majority of "well planned and harvested" blocks were below 13% disturbance for summer, ground-based harvesting, using criteria similar to those in the Forest Practice Code. However, since the advent of the Forest Practices Code of BC in 1995, both the forest industry and the BCMOF have been hesitant to propose or employ harvesting practices that may temporarily exceed the 10 % soil disturbance levels, even though these cost efficiencies were provided for under the FPC. As a result, harvesting costs went up; direct costs have increased due to less efficient layouts such as wider trail spacing, and indirect costs due to increased voluntary shutdowns because of concerns about harvesting under wetter soil conditions.

Through cooperative efforts with the forest industry and BCMOF operational staff over the last few years, we have been working on a number of harvesting strategies that industry feels have been saving up to \$3 to 4 / m^3 when compared to more conservative layouts. Four key strategies have been tried and tested to ensure that they still protect the soil and related resources; these include: closer spaced temporary trails on gentle or moderately steep ground, closer spaced temporary spur roads on gentler ground, combined designated/random skidding, and hoe-chucking to wider spaced trails. Through careful planning, including accurate site descriptions and understanding of the site-specific soil disturbance hazards, the end result should be harvesting strategies that are less costly and more flexible because they depend less on climatic conditions. Some of these strategies can also save silviculture costs by providing a reasonable amount of "site preparation" type disturbance during the dispersed skidding component of the harvesting operation, thereby dealing with growth-limiting factors during stand establishment. Interpretive tools are being developed to match sites (soil sensitivity) to appropriate strategies, and to provide simple tests for adequate frost or excessive soil wetness; these are also summarized in this paper.

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[1] Paper presented at FERIC Conference and published in their Special Report for their members: Pp. 75-111 In: Impact of machine traffic on soil and regeneration. Proceedings of FERIC's Machine Traffic / Soil Interaction Workshop, held at Edmonton Alberta, Feb. 1999. FERIC Special Report No. SR-133. CONTACT INFO UPDATED BUT NOT CONTENT, WHICH IS STILL CORRECT UNDER FRPA.

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PREFACE

The intent of this document is to introduce the policy and environmental framework affecting ground-based harvesting in BC and demonstrate how, through careful site description and harvest planning, and full use of provisions contained in the FPC, ground based harvesting costs can be reduced while still limiting detrimental soil disturbance. Inadequate pre-harvest site description and/or misapplication of these provisions can result in inordinate soil disturbance and penalty provisions under the FPC. Some issues discussed in this paper are controversial and the science and policy supporting the FPC is evolving; the author's intent is to present objective information to support adequate conservation of the soil and related resources while still providing opportunities for economically viable forest harvesting.

ACKNOWLEDGEMENTS

A number of co-authors have been key in various studies and discussions on harvesting disturbance impacts on soil properties and tree growth, they are listed in the literature cited. BCMOF operational personnel in the Nelson Forest Region, and personnel at Atco Lumber Ltd., Crestbrook Forest Industries Ltd. (all divisions), Slocan Group (Radium and Slocan Divisions), Meadow Creek Cedar Ltd., and Pope and Talbot Ltd. (all divisions) have been key in cooperating on operational trials and discussions on issues related to harvesting impacts; their comments during the recent District workshops given by the author on this topic, and the comments of the students in the recent Institute of Forest Engineering of BC, Module 5 (Forest Soils and Hydrology), were appreciated during finalization of this manuscript. More detailed reviews by Dr. Bill Chapman, Simon Brookes, and Darrell Regimbald were greatly appreciated, as were english edit comments by Kathi Hagan. Funding for this work has been provided by the BCMOF and more recently by Forest Renewal BC through the Invermere Enhanced Forest Management Pilot Project and the research program administered by the Science Council of BC.

1 INTRODUCTION

The British Columbia Ministry of Forests (BCMOF) has established soil conservation as a priority for forestry operations throughout the province. Since the 1970s, the BCMOF's objectives, in cooperation with the forest industry, have been to limit ground-based forest harvesting to gentler and less sensitive sites, and to reduce the amount of potentially disturbance during forest harvesting.

The BCMOF and Canadian Forest Service have commissioned a number of reviews on soil degradation and potential impacts on forest productivity (e.g. Utzig and Walmsley 1988; Lousier, 1990; and more recently, Hunt & Associates, 1998). Previous discussion of harvesting strategies to manage soil disturbance appeared in the Land Management Report and Field Guide Insert by Lewis et al. (Lewis et al. 1989; Lewis et al. 1991), and the FERIC training materials assembled by Araki (1990).

The intent of this paper is to update the harvesting strategies aspects of the former publications. For more thorough discussion on soil disturbance effects on soils and tree growth., the reader is referred to the previous BC reviews and/or Greacen and Sands (1980), and Froehlich and McNabb (1984). For guidance on individual equipment configurations and compatibility with site conditions, the reader should consult the new FERIC handbook on *"Harvesting systems and equipment in British Columbia"* (MacDonald 1999).

The Forest Practices Code of BC (FPC) contains policy and regulation controlling soil disturbance levels; this document provides further background on the underlying rationale for these requirements, and general guidance on their implementation, particularly the new FPC General Bulletin 19 on *"The use of temporary access structures to reduce logging costs."*

Objectives and intended audience:

The main objective of this document is to describe how harvesting prescriptions can be developed to maximize independence of climatic conditions while remaining responsive to industry costs and resulting soil disturbance levels.

Specific objectives are to:

- describe the policy and environmental framework affecting forest harvesting in BC,
- describe key considerations that go into developing a forest harvesting prescription, and
- detail four harvesting strategies that can accomplish the main objective.

The section describing the policy and environmental framework is critical background to understanding the soil disturbance hazard rating system that we use in BC to help govern and guide soil disturbance during forest harvesting.

The intended audience for this paper is all levels of the forest industry and government in Alberta and related provinces, and the operational forest planning and harvesting level of forest industry and government in BC.

2 BACKGROUND

In the 1970's and early 1980's soil disturbance of concern was primarily excavated and bladed trails (skid roads). During this period, skid road soil disturbance levels of over 20% were common (Krag et al. 1986). Concerns about erosion, off site impacts, and site productivity lead to the development of soil disturbance and steep slope guidelines, which were the topic of many workshops, committees, and draft policies during the 1970's and 1980's. In the latter stages of these initiatives, we had gone from soil disturbance concerns being focused on displacement of fertile topsoil and creation of erosion channels, to also including compaction. The corresponding disturbance categories of concern evolved from skid roads with 25 cm cutbank height to inclusion of non-bladed skid trails and ruts deeper than 5 cm into the mineral soil.

In 1989, the Interim Harvesting Guidelines were released, which allowed, on less sensitive sites, 15% soil disturbance including landings (about 13% skidding disturbance). Surveys done in 1990 and 1991 demonstrated that the soil disturbance guidelines had been very successful, and even using the new disturbance criteria, many blocks surveyed were below 13% for ground-based harvesting (Thompson and Osberg, 1992; following the methods outlined in Curran and Thompson (1991).

In 1993 the Harvesting Guidelines were finalized and had a guideline maximum of 13%, but also included provisions for rehabilitation of excavated and bladed trails. Building further on the rehabilitation provision, the FPC included a requirement to rehabilitate excavated and bladed trails, and a soil disturbance guideline limit of 10% to reflect rehabilitation of excavated and bladed trails exceeding the 10 % number. In the Nelson Forest Region, the rule of thumb we have used for summer harvesting on less sensitive sites, was "10 + 3"[3] based on the 1990-1993 survey results; many sites have come in under these numbers.

Since the advent of the Forest Practices Code in 1995, both industry and BCMOF staff have been hesitant to propose or employ harvesting practices that may temporarily exceed soil disturbance levels, or ensure that harvesting can occur under wetter soil conditions. As a result, logging costs went up, in terms of direct costs because of less efficient layouts such as wider trail spacing, and in terms of indirect costs due to increased voluntary shutdowns. With the recent slump in the forest industry, these costs became an issue. Through cooperative efforts with industry and BCMOF staff over the last few years, we have been working on a number of harvesting strategies that industry feels have been saving them up to three or four dollars per cubic meter, while still protecting the soil and related resources.

[3] That is, 13 % maximum during the harvesting operation with a maximum of 10 % net disturbance following rehabilitation plus a maximum of 3 % over this amount during the harvesting operation.

The FPC targets disturbance types that are considered closely linked to hydrologic (drainage diversion, erosion, stability), and soil productivity impacts. The Forest Practices Code has specific definitions for these types of "soil disturbance", but recognizes that foresters commonly create purposeful disturbance that is considered beneficial as site preparation for seedling regeneration or planting and establishment; these disturbance types are not targeted by the FPC.

3 ENVIRONMENTAL AND POLICY FRAMEWORKS FOR FOREST SOIL CONSERVATION IN BC

BC is a province of complex diversity in terms of the physical and biological landscape. One way that this diversity can be classified is by the biogeoclimatic ecosystem classification system (e.g. Braumandl and Curran 1992). This system identifies regional forest ecology based on regional climate which is expressed on "zonal" sites. At the forest site level, "site series" are identified based on diagnostic, moisture, and nutrient indicating plants, or soil moisture and nutrient regime. This classification is required for all Silviculture Prescriptions (SPs) and provides a framework for determining the suitable species for restocking, making silvicultural interpretations, and making some general interpretations regarding seasonal soil conditions. The ecological classification is also used in coming up with general precipitation and runoff classes for use in the soil disturbance hazard keys, described below.

Slope stability is a concern on steeper and wetter sites. To identify and mitigate the potential for landslides, terrain mapping and/or terrain stability field assessments are required on sites that exceed certain slope gradients or have indicators of potential slope instability. Prescriptions that propose ground-based harvesting must also consider soil disturbance hazards by reporting and interpreting the compaction, displacement, and erosion hazards on the site. In addition, the potential for minor cut and fill failures (mass wasting hazard) should be determined whenever excavation is anticipated; this is also recommended for the less sensitive sites where stump removal is permitted for root rot control. Forest floor displacement hazard should be determined whenever dispersed (random) skidding on steeper slopes or if stump removal is being considered.

SOIL DISTURBANCE HAZARDS

Determining the soil disturbance hazards on a given site provides a framework for developing harvesting strategies by alerting the prescription developer to the specific soil disturbance concerns on that site. In practice, soil disturbance guidelines in the FPC permit up to 5 or 10 % net disturbance within a cutblock area (excluding permanent access). The trigger for 5 % is when one of the key hazards is Very High. A High rating for any hazard is primarily intended to alert the prescription developer, and the operational staff, of a hazard that may require special treatment to prevent problems (manage and mitigate the hazard). High compaction hazard also results in more equipment traffic disturbance types being counted under FPC criteria. The soil disturbance hazards also help identify site conditions that are suitable for construction of excavated and bladed trails (skid roads or backspar trails), and/or temporarily exceeding

soil disturbance levels and rehabilitating slope hydrology and forest site productivity. The hazards are defined below, including brief discussions of why they are of concern.[4]

Soil Compaction Hazard

Soil compaction is the increase in soil bulk density that results from the rearrangement of soil particles in response to applied external forces. "Soil puddling" is the destruction of soil structure and the associated loss of macroporosity that results from working the soil when wet. (Organic matter is often incorporated during puddling, because organic matter is lighter than mineral particles, soil bulk density may not increase, but the other properties described below are still negatively affected.) The science and rationale for the compaction hazard key were laid out in Carr et al. (1991). Concerns that coarse fragments do not typically provide "bridging" support for equipment until they are 70 % by volume resulted in modifications to the final key currently in use by the FPC.

As described by Dr. McNabb at the workshop, moisture content is probably the best determinant of compaction hazard at any given time. In BC, the soil compaction hazard key ranks the potential compaction hazard by grouping soil textures that are most susceptible to structural degradation from compaction and puddling, and are most likely to hold moisture and remain wet for longer periods. The soil compaction hazard key is a tool to help with planning of an operation, while careful monitoring of equipment effects on the soil, and hand tests for soil moisture content are the tools that help guide the operation (described under "Weather and climate considerations" in Section 3).

Soil compaction and puddling are of concern in timber harvesting operations because of effects on roots and site water relations. Compacted soils have higher penetration resistance that can impede root growth. Compacted and puddled soils both have lower aeration porosity and lower hydraulic conductivity and infiltration rates; however, in some coarser textured soils, compaction may actually increase water holding capacity (these soils typically have lower compaction hazard ratings) [5].

Lower aeration porosity results in reduced gas exchange that can adversely affect oxygen levels in the soil air; this reduces physiologic function of roots which in turn can lead to root die off under wetter conditions. Lower hydraulic conductivity and infiltration rates of the compacted or puddled soil can result in increased runoff during rainfall and snowmelt events. This can lead to increased net export of water from a cutblock, which can affect downslope sites, natural drainage features, and other resource values due to erosion and

[4] Soil degradation hazard rating keys for soil compaction, displacement, and erosion are found in the *Forest Practices Code of British Columbia, Hazard Assessment Keys for Evaluating Site Sensitivity to Soil Degrading Processes Guidebook*. The forest floor displacement hazard and the mass wasting hazard are described in Forest Practices Branch field guide SIL411, and all hazard keys and data required for them appear on the BCMOF field forms FS39. **The general BCMOF web site where these and other FPC information can be located is: http://www.for.gov.bc.ca/**

[5] The reader should recognize that the net effect on forest productivity will be which affected property becomes most limiting to growth, if aeration decreases to growth-limiting levels, increased water holding capacity becomes an academic issue. In the case of the site studied by Utzig and Thompson (1992), described below, the available water holding capacity increased slightly on some disturbances on some sites, but "are so small that they are probably inconsequential, and probably are within measurement error."

sedimentation. Increased water export also means less water may be stored on site to support tree growth during summer drought[6]. Compacted soils can also remain wetter longer, thereby further affecting seedlings because the soil may be colder and has poorer aeration.

From monitoring of traditional spring harvesting in the southern Rocky Mountain Trench near Cranbrook, we know that significant declines in aeration porosity can occur as soon as evidence of equipment traffic is visible on the ground (e.g. wheel lugmarks on the soil or slight impressions with track grouser marks; Utzig et al. 1992). Three sites were studied that had typical Trench soils: low coarse fragment silt loam to silty clay loam textured surface soils, underlain by denser subsoils with more coarse fragments. The undisturbed soils had aeration porosity values at or above one threshold recommended by the United States Forest Service (USFS) in some of its policy for the Pacific Northwest (i.e. 15 % at 10 J/kg water tension referred to in Boyer 1979).

On "light disturbance", (<5 cm ruts; often only about 2 to 3 cm deep), the resulting aeration porosity was between 10 and 16 %, while counted ruts (5 cm deep) had 7 to 12% aeration, main trails were less (Figure 1). Effects on water infiltration, as reflected by saturated hydraulic conductivity, were similar (Figure 2). Bulk density increased in a similar but opposite trend to the aeration porosity and saturated conductivity, as would be expected. The concern about these effects is how extensive the machine traffic disturbance is on this type of harvesting. On the three sites studied, the combined total of the light ruts, 5 cm ruts, and main trail disturbance ranged from 51.6 to 64.3 % of the entire cutblock area, with light disturbance covering from about 30 to over 45 % (Figure 3).

The above results are consistent with monitoring studies of nearby sites in northern Washington, Idaho and Montana (Laing and Howes 1988, Svalberg 1979, Kuennen et al. 1979). In the Washington study, Laing and Howes (1988) predicted a "*conservative estimate of 35 % volume reductions over the next rotation*" for detrimentally compacted areas (42 % of the cutblock area in their study). On similar sites in Northern Idaho and Montana, Kuennen et al (1979) suggested that changes in soil physical properties resulting from compaction can decrease the ability of trees to compete with pine grass. Whether or not such effects would be realized on our sites is not clear, but in the absence of hard data to the contrary, we need to be careful (we are cooperating with industry on evaluating tree growth on the sites studied by Utzig and Thompson (1992). One major installation where we are studying light compaction is our USFS designed, cooperative "Long-term Soil Productivity Study" sites (one is in the Invermere Enhanced Forest Management Pilot Project area).

[6] These hydrologic effects are recognized by hydrologists for concentrated disturbance like main skid trails; however, the jury is still out on the effects on more dispersed traffic, which are difficult to study because they are influenced by many factors (D.Toews, pers.comm. Research Hydrologist, BCMOF, Nelson).

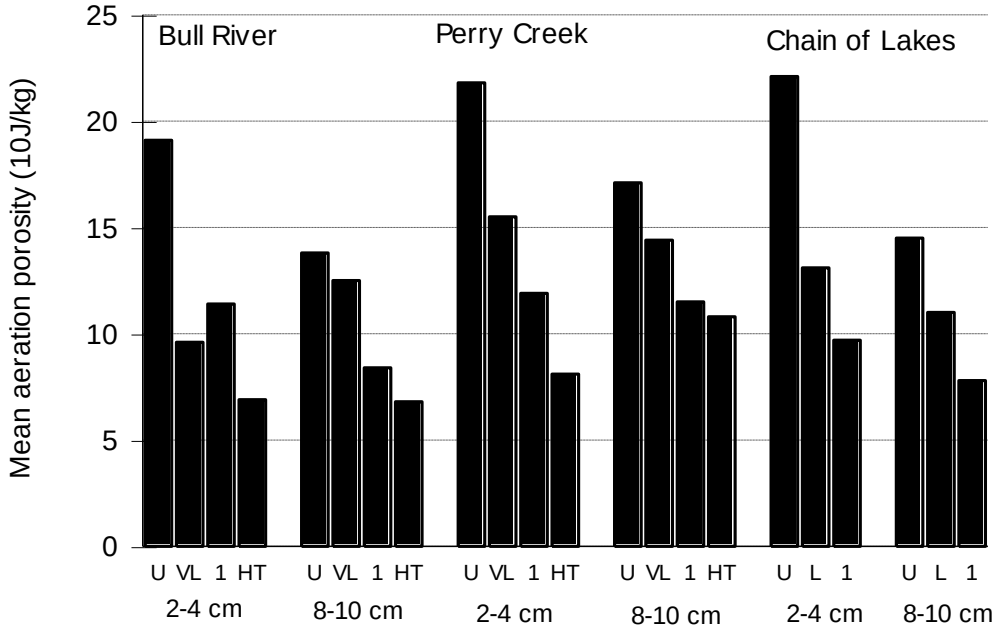

Figure 1. Aeration porosity at 10 J/kg tension for two sample depths on the three sites studied by Utzig et al. (1992). Data order U (undisturbed), VL (very light ruts, <5 cm deep), 1 (ruts 5 cm or deeper), HT ("heavy [main] trails). One threshold value in USFS policy is 15 % (Boyer, 1979); as demonstrated by the graph, most of the disturbance sampled in our study was below this 15 % value.

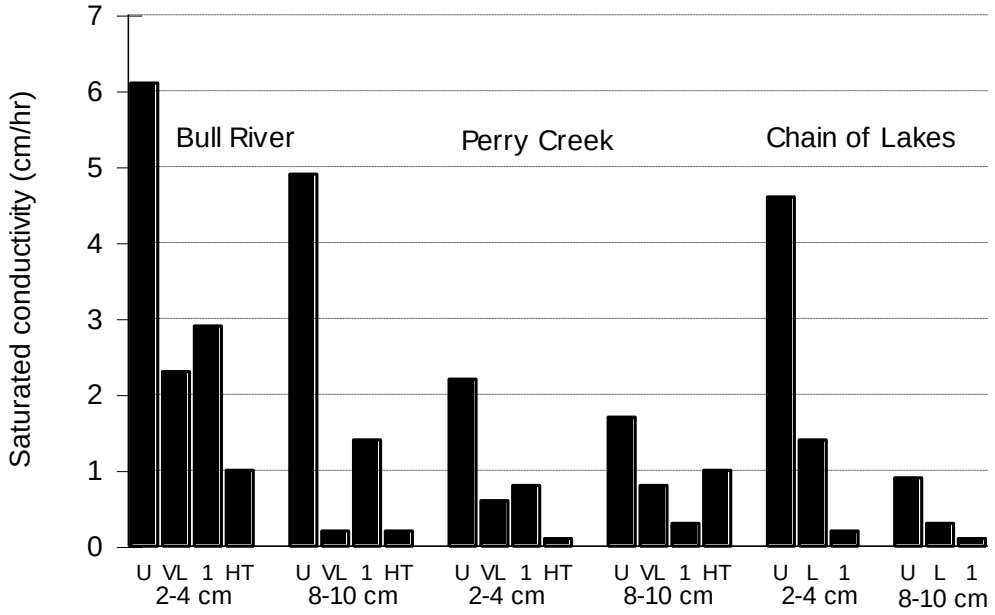

Figure 2. Saturated hydraulic conductivity for two sample depths on the three sites studied by Utzig et al. (1992). Data order U (undisturbed), VL (very light ruts, <5 cm deep), 1 (ruts 5 cm or deeper), HT ("heavy [main] trails).

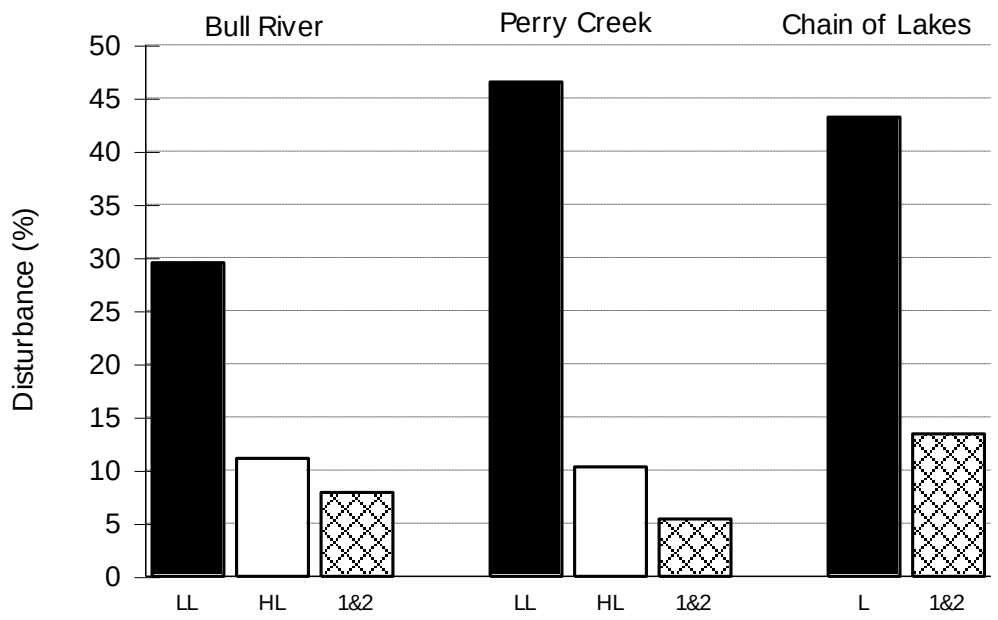

Figure 3. Soil disturbance levels on the three sites studied by Utzig et al. (1992). Data symbols: LL (very light ruts, <5 cm deep), HL ("heavy [main] trails), 1&2 (ruts 5 cm or deeper), and L (very light and heavy, combined).

In summary, the implications for site water storage, runoff, and tree growth are of concern when random skidding causes these types of disturbance. It is therefore inferred that, *under certain soil conditions (eg, harvesting under wetter than optimum soil conditions)*, detrimental compaction can occur before guideline soil disturbance limits are reached.[7] Harvesting strategies recommending dispersed skidding traffic need to recognize this risk and "tread lightly." Compaction is a long-lived phenomenon, natural freeze-thaw and wet-dry cycles have not been observed to ameliorate machine-induced compaction at depth. In the southern BC Interior and Alberta locations, where summer drought is one of the factors most limiting to tree growth, and in the absence of hard data to the contrary, prevention of widespread "below the FPC depth limit" compaction is probably the best bet and can be achieved economically.

Tire size?

One soil conservation strategy used in Alberta is to equip harvesting machinery with very wide, high-floatation tires run at low pressure. Caution is appropriate when considering this strategy for application in BC where soil and site conditions can be quite different than in Alberta. During wetter harvesting conditions, BC soils do not behave in a "semi-liquid plastic state" as described for Alberta soils at the workshop. Based on the author's soil survey and reclamation planning experience in Alberta, BC subsoils are often much stonier, compact glacial tills or much gravellier, dense glacial fluvial deposits or colluvium; they typically are not soft when wet like some of the low coarse fragment Alberta subsoils. Consequently, the compressing, shearing, and vibrating forces that cause compaction are concentrated on the upper layers of these soils; this causes marked rutting and impressions under conditions of poor soil strength.

With the use of wider tires on skidders, main skid trails would become wider, and regeneration and residual damage in partial cutting would increase[8]. Recognition of areas where damage has occurred would become problematic during or after operations, because ruts would not be clearly definable. Also, it is not clear what the traction limitations of wide high-floatation tires would be on grassy or slashy slopes. While it is important to encourage innovation, proceeding with caution is advised; the BCMOF is available to collaborate on any new trials.

Another option is to use tire chains that increase flotation, some of these are quite similar to grousers on cats. If the grousers are not too long (i.e. if they do not chop up the surface soil and recompress and shear it with each pass), then the use of these appears to extend the operating season of the equipment. (Use of standard chains under drier

[7] On a study of compaction from winter pushover harvesting, Redfern (1998), found on one site near Golden, soil disturbance survey criteria closely matched actual compaction, but on another site south of Fairmont they did not. However, because these sites were harvested under winter conditions when we would encourage dispersed traffic and not be concerned about compaction, this important study has little bearing on the strategies in this paper, *except that we need to study the survey criteria more to ensure that good winter harvesting is not discouraged*.

[8] One way of offsetting residual damage would be to limb and top in the bush; cost implications of this practice will depend on whether it's economical to process at the stump, which is beyond the scope of this paper. However, limbing and topping in the bush is environmentally desirably because of the increased foliar nutrients and woody debris left on the site after harvest.

conditions can reduce soil disturbance levels by increasing traction, thereby reducing wheel slippage disturbance during normal operating conditions - these are not expected to help increase operating season under wet conditions unless such traffic is confined to designated trails.)

Soil Displacement Hazard

Soil displacement is the mechanical movement of soil materials by equipment and movement of logs. It involves excavation, scalping, exposure of underlying materials, and burial of fertile surface soils. Three aspects of displacement can produce soil degradation:

- exposure of unfavourable subsoils, such as dense parent material, gravelly subsoil, and calcareous (high pH) soils,
- redistribution and loss of nutrients, and
- alteration of slope hydrology, which can lead to hydrologic effects (discussed under compaction, above).

Throughout the BC Interior, soil development is often shallow and many of the nutrients that are limiting to tree growth are often "biocycled" and concentrated in the upper soil horizons. As demonstrated in the table below, the top 20 cm of mineral soil and the forest floor are often where most of the nutrients are concentrated. Therefore, we don't want to displace this fertile topsoil away from seedlings, or reduce the rooting volume of these vital topsoil layers.

Table of typical nutrient distribution in BC Interior soils (BCMOF training mtls)

Soil layer	*Nutrients in kilograms per hectare (% of total)*		
	Nitrogen	Phosphorus	Potassium
Forest floor	1450 (44%)	112 (82%)	224 (73%)
0-20 cm	1050	13	56
20-40 cm	820	8	25
Total	3320	133	305

Calcareous Soils

Calcareous soils have high pH and fizz with 10% hydrochloric (muriatic) acid because free lime (calcium carbonate) is present in the soil. As mentioned above, most forest soils in the BC Interior are shallowly developed, often only to about 30 cm. Below this is less weathered parent material, which in the Rocky Mountains and adjacent areas, is commonly calcareous, being derived from marine materials such as limestone. In several other locations in BC there are also limestone derived soil parent materials and/or drier climates where soil development has not yet leached salts from the soils - these soils are often calcareous, sometimes very close to the surface (eg, Ponderosa Pine and drier Interior Douglas-fir biogeoclimatic zones). In Alberta, calcareous soils are common on the eastern slopes and foothills of the Rocky Mountains; although similar to BC, the

depth to the calcareous subsoil appears to become deeper as you go further north from the drier, southern ranges.

As part of the Invermere Forest District Enhanced Forest Management Pilot Project, a major study is being undertaken on soil disturbance, root rot, rehabilitation, nutrients, and the effects of calcareous soils on tree growth (Curran 1999). Results to date have indicated that, on some sites there may be some relationships between slower lodgepole pine growth and depth to calcareous soils < 40 cm (Kishchuk et al. 1999). This is consistent with Dumanski et al. (1972), who in the soil survey of the Hinton map sheet in Alberta, had reported that, based on forest productivity plots, pine growth was lower on soils that were shallower to calcareous subsoil. In studying tree growth on rehabilitated skid roads, Dykstra and Curran (1999) found poorer growth on the rehabilitated portions of the skid road on the most calcareous, Lussier River site (Figure 4).

Some treatments can bring large amounts of calcareous subsoils to the surface as deposits. For example, in a pushover logged site near Golden, BC, up to 29% of treatment units were calcareous at the surface Quesnel and Curran (1999; Figure 5; our new studies on this practice near Invermere have demonstrated that less calcareous material is left on the surface, but it still amounts to up to 100 % of local areas like group selection harvested areas). Calcareous deposits can raise the pH of underlying forest floor (Hall and Curran 1999; Figure 6). This is cause for concern because a number of essential nutrients are considered to be mainly available under acidic soil conditions, which in these soils primarily occurs in the forest floor. For example, Figure 7 demonstrates the low levels of soil iron on the Lussier River site studied by Dykstra and Curran (1999). However, the foliar iron levels do not reflect this level (Figure 8); probably because of mycorrhizal fungi providing the trees with the required iron. It is likely that there is a physiological cost of extra photosynthate in exchange for this iron and that may explain why the trees on the calcareous soil are not growing as well, further study is underway.

Calcareous soils are often finer textured (e.g. silty and clayey texture classes), which also makes them of more concern for soil compaction and puddling.

Forest Floor Displacement Hazard

Forest floor displacement is the mechanical movement of the upper organic materials by equipment and movement of logs. It involves excavation, scalping, mineral soil exposure, and burial of the forest floor. The effects of forest floor displacement range from beneficial to detrimental, depending on site factors (e.g. mineral soil characteristics) and how far the forest floor is displaced from the seedlings.

Forest floors typically represent a major component of the nutrient capital on a forest site. In the BC Interior, it is not uncommon for the forest floor to contain over 50% of the soil nitrogen and 80 % of the phosphorus (recall the table in the Displacement hazard section above). Given that many Interior sites are considered nitrogen deficient, conservation of the forest floor is important.

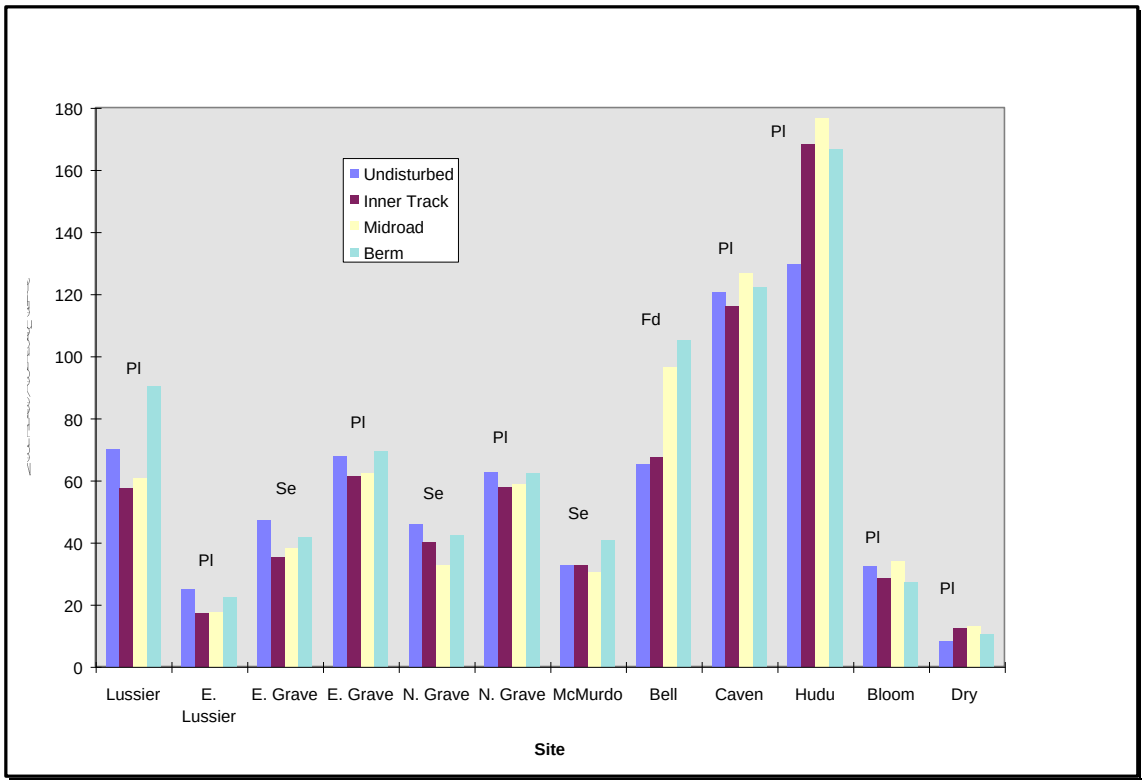

Figure 4. Three-year height increment on rehabilitated skidorads at 1996 block height, all blocks and species studied (Pl - lodgepole pine; Se = Engelmann spruce; from Dykstra and Curran, 1999). Lussier block is calcareous at 12 cm; data order is U (undisturbed), I (inner track), M (midroad), and B (berm).

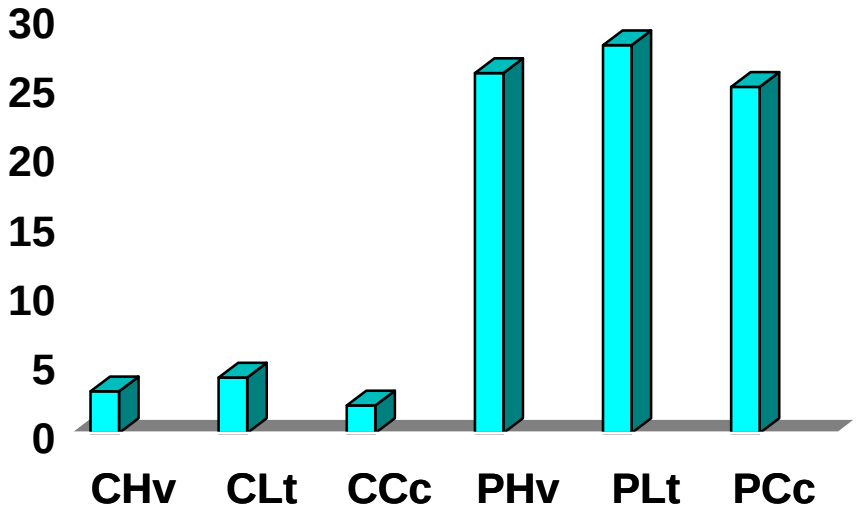

Figure 5. Percent of harvested area calcareous at Mount Seven, near Golden, after various harvesting and retention treatments (CHv = conventional harvest, heavy retention; CLt = conv., light retention; CCc = conv., clear cut; PHv = pushover harvest, heavy retention; PLt = push., light ret.; PCc = push., clear cut.; from Quesnel and Curran 1999).

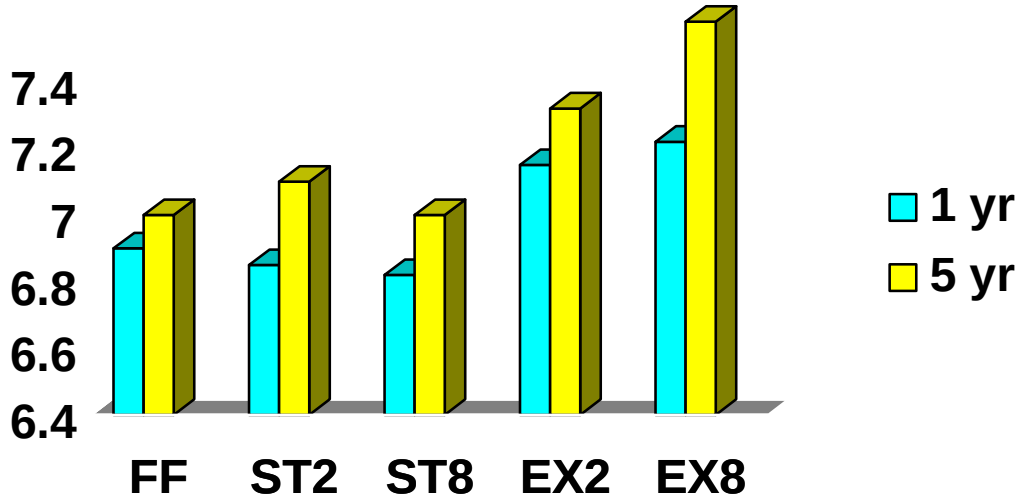

Figure 6. Forest floor pH after leaching in laboratory, equivalent to one or five years in the field (FF = forest floor alone; ST2 = under 2 cm strongly calcareous deposit; ST8 = 8 cm; EX2 = 2 cm extremely calcareous deposit; EX8 = 8 cm; from Hall and Curran, 1999).

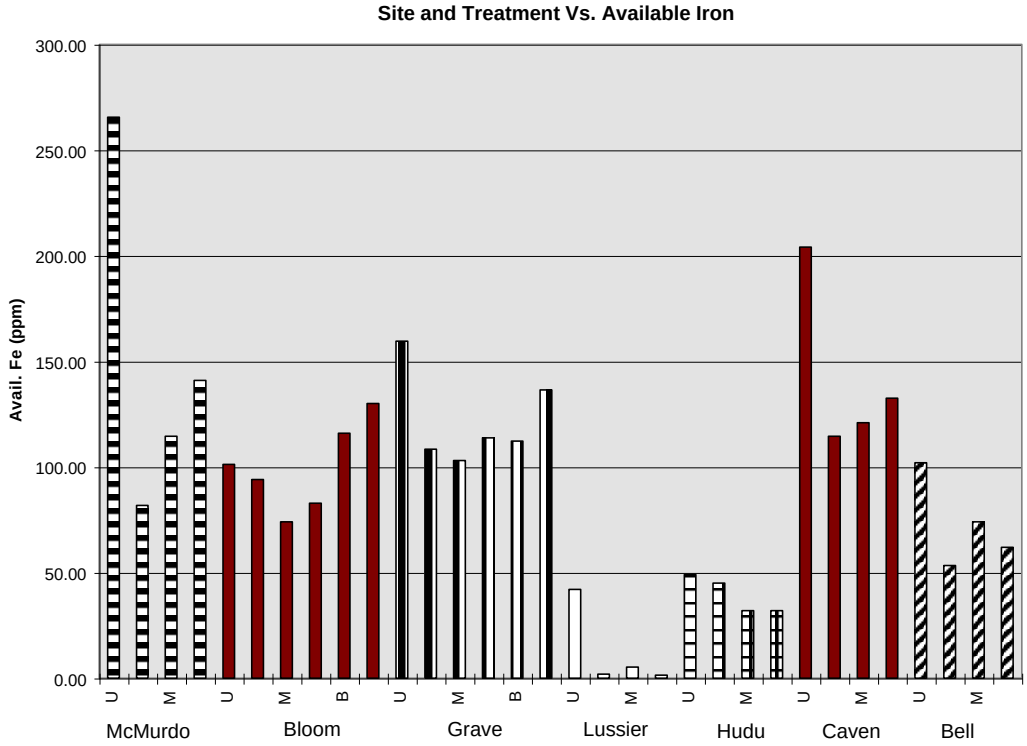

Figure 7. Available iron in soil samples from rehabilitated skidroads. Data order is U (undisturbed), Inner Track, M (midroad), Outer track (unlabelled bar) on Bloom and Grave, B (berm), and lower undisturbed (unlabelled bar) on Bloom and Grave.

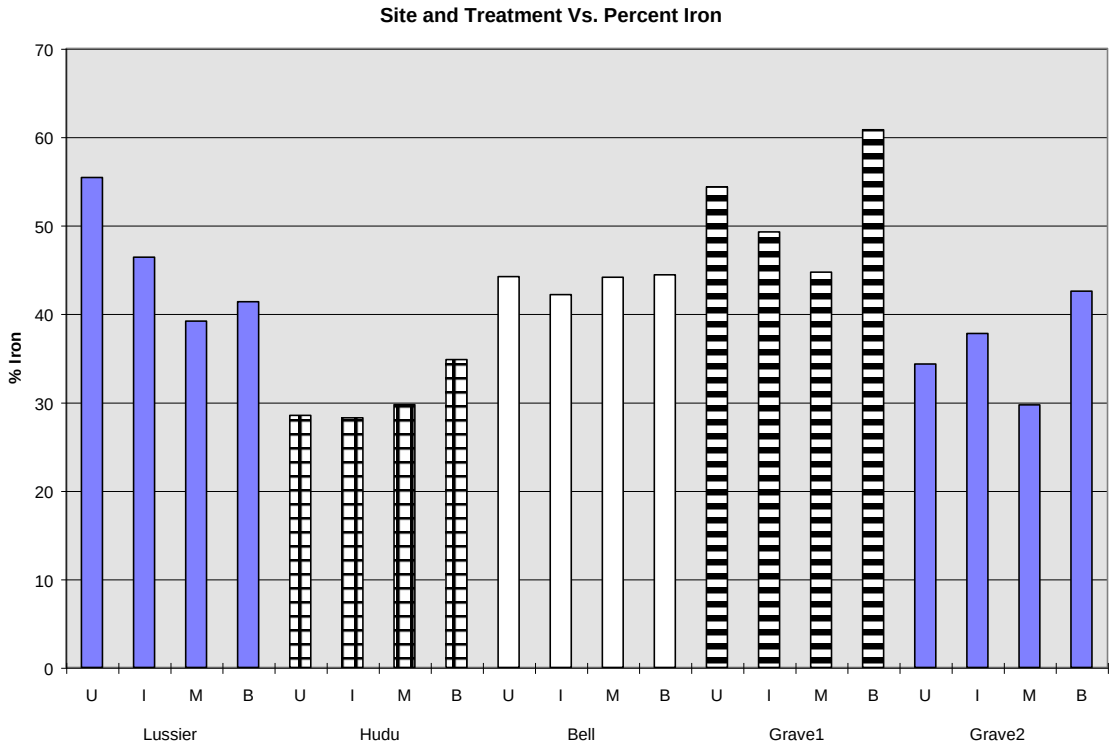

Figure 8. Foliar iron in trees growing on rehabilitated skidroads. Note how the trees on the calcareous Lussier block do not reflect the soil levels, presumably because of mycorhizal fungi on the tree roots. Other nutrients, like manganese, appear affected, data analysis is in progress. Data order is U (undisturbed), I (inner track), M (midroad), and B (berm).

Two aspects of forest floor displacement can produce soil degradation:

- redistribution and loss of nutrients (e.g. chemically bound and unavailable in the mineral soil, and accelerated decomposition of organic matter)
- exposure of unfavourable rooting medium

A review of forest floor displacement and implications for tree growth was done in one of our southern Districts by Hickling (1997), who found that while there were a few trends in soil nutrient levels, it was difficult to relate displacement to any negative effects on tree growth. Because of the difficulty in retrospectively assessing actual forest floor displacement 5 to 20 years after harvest, we had Hickling install long-term monitoring plots on various disturbance types (Hickling 1998). we are monitoring these plots in cooperation with Pope and Talbot Ltd.; some of these plots were associated with stumping. Most forest operations were well below the forest floor displacement limits originally set in the FPC, so determining the forest floor displacement hazard is no longer officially required for harvest planning and permitting. However, use of this hazard interpretation is supported and recommended for planning dispersed skidding on slopes, rehabilitation of soil disturbance, and root rot treatments. Forest floor displacement is more of a concern on calcareous soils.

Surface Soil Erosion Hazard

Surface soil erosion is the wearing away of the earth's surface by water and includes splash, rill, and gully erosion. It has **on-site** impacts (soil loss, nutrient loss, lower productivity) and **off-site** impacts (water quality, sedimentation, habitat impacts). The surface soil erosion hazard key focuses on on-site erosion and conservation of the fertile topsoil layers near developing seedlings. The science and rationale for the key were laid out in Carr et al. (1991), and tested in the Nelson Forest Region by Commandeur (1994), resulting in modifications to the final key currently in use by the FPC. One use of the key is to require rehabilitation of excavated and bladed trails (30 cm cutbank height) on sites with High Erosion hazard to reflect the potential for both increased channelling and redirection of water, and erosion under these site conditions. On moderate slopes, this hazard is normally mitigated through careful layout and prompt waterbarring and/or rehabilitation of skid trails.

Under the FPC, other assessments are used for haul road erosion and sediment delivery to streams. Haul roads and landings are of concern because erosion and drainage diversions can lead to sedimentation and stability problems. They require careful layout and attention to FPC requirements aimed at assessing erosion hazard on haul roads and minimizing erosion and sedimentation during construction and maintenance.

Mass Wasting Hazard

The mass wasting hazard assesses susceptibility to small, disturbance-related slope failures. ***It is not the same as landslide likelihood.*** Landslide likelihood is determined through terrain stability mapping and detailed terrain stability field assessments, described in the *Forest Practice Code of British Columbia, Managing and Assessing Terrain Stability Guidebook.*

Mass wasting hazard refers primarily to small-scale failures which mainly cause on-site degradation, while landslide hazard primarily refers to larger events. The small scale mass wasting is of concern because it impacts tree growing site and may have off-site effects. The two hazards are correlated: a Very High mass wasting hazard may indicate a possible landslide hazard, and such sites should be checked by a qualified slope stability specialist. In addition, small, disturbance-related slope failures can lead to larger landslides through drainage diversion or failure of "stacked" excavations up a hillside, such as in switchbacks or contour skid roads.

For a number of reasons not clear to the author, mass wasting hazard is no longer officially required for harvesting planning and permitting under the FPC; however, determination of indicators of slope instability is still required. Determination of mass wasting hazard is important in planning for any excavation, or root rot treatments, and is supported and encouraged for these uses.

The mass wasting hazard assessment should be done during cutblock or road alignment data collection, similar to indicators of potential slope instability. Both these tools help to identify areas of concern for on-site mass wasting and bring attention to areas that require further checking for possible landslide hazard. (Because of mapping scales, small areas of landslide hazard may be missed during terrain hazard mapping; therefore, it is important that data collectors carefully review sites for indicators of potential slope instability and assess the mass wasting hazard to help identify areas that might have been missed during mapping.)

Gully systems > 5 m deep should be mapped out and assessed separately for soil disturbance hazard assessment during data collection in the Interior. On the Coast, gullies are subject to the separate FPC *Gully Assessment Procedure*.

OTHER CONSIDERATIONS

Other considerations that are important when developing a forest harvesting prescription include drainage control (and protection of downslope values), the definition of detrimental soil disturbance for the site in question, and ensuring the prescription is based on accurate field data. These are each discussed below:

Drainage control (priority one)

As discussed for the various soil disturbance hazards above, alteration or diversion of natural slope drainage is a common concern with all soil disturbance, and particularly with any excavation or rutting. Drainage problems can lead to erosion, sedimentation, and in the worst case scenario, landslides. In the BC Interior, the most common cause of these problems are forest roads, landings, and excavated and bladed trails. The FPC contains a number of provisions regarding protection of natural streams and wetlands, and maintaining adequate drainage control at all times.

In practice, due diligence is needed regarding waterbarring and cross-ditching for seasonal deactivation. Care is also required in cases of seepage areas that may be too small to be recognized during ecosystem site mapping for the Silviculture Prescription. In some regions, the regional ecology guide contains general interpretations regarding “road

drainage control needs" for each ecological site series, to help remind data collectors and prescription developers that some sites are wetter during spring runoff than may be apparent during data collection in drier periods (e.g. Braumandl and Curran 1992).

Drainage control is the number one priority when planning any soil disturbance and needs to be planned for in layout and construction. Major runoff events can and do occur at any time of the year. In the case of excavated and bladed trails, the use of grade relief dips and outsloping sections is important in preventing drainage concentrating on landings or haul roads which can affect operations, stability, and downslope resource values. **Timely waterbarring, cross ditching and/or rehabilitation is important and drainage control must be in place before spring or other runoff events** (winter constructed trails and landings must be rehabilitated before spring thaw because these structures are often constructed with snow in addition to soil).

Defining soil disturbance:

It is important to recognize that, while the Forest Practices Code has a specific definition for "soil disturbance" (those categories of disturbance that are counted as being potentially detrimental to soil productivity or off-site values), not all soil disturbance in the general sense is bad. The true, technical definition of soil disturbance is any disturbance that changes the physical, chemical, or biological properties of the soil (Lewis et al. 1991). Foresters commonly prescribe purposeful soil disturbance as site preparation for seedling planting and establishment; these disturbance types are not counted in the FPC criteria briefly described below. By controlling how we harvest a site, we can create more "site prep" type disturbance and keep most of the potentially detrimental disturbance confined to travel corridors; these main trails may then be rehabilitated after harvesting, as appropriate. Whenever planning soil disturbance, the preservation and restoration of natural drainage patterns should be the primary goal (necessary repetition).

The strategies described in this document strike a balance between "favourable" and "detrimental" disturbance by limiting the amount of FPC counted soil disturbance. It is recognized in the FPC that some level of disturbance is necessary to permit access to timber. Counted disturbance includes main trails and ruts/impressions of certain dimensions, and wide (1.8 m x 1.8 m) or deep (30 cm) gouges into the soil. Those developing and implementing a harvesting strategy need to recognize that on more sensitive sites, more disturbance types are counted (e.g. 5 cm ruts and impressions on High and Very High Compaction hazard, as opposed to 15 cm on other soils; wide scalps [forest floor removal over a 1.8 x 1.8 m area] when Erosion, Displacement, or Compaciton hazards are Very High). On sites with more favourable soils, less disturbance categories are counted.

The actual affect of a given soil disturbance on tree growth will depend on which factors are the most growth-limiting on a given site and how these factors change over the course of a rotation. In the BC Interior, common growth-limiting factors include: competing vegetation, soil moisture (drought or excess), soil temperature, summer frost, rooting substrate (volume), soil nutritional problems (e.g. calcareous soils), and root rot. The net effect on growth will also depend on whether soil disturbance has introduced a new limitation, such as reduced soil aeration from compaction. Long-term effects could

include increased susceptibility to blowdown because of poor rooting in detrimentally disturbed soil.

Regional ecology guides often summarize common growth-limiting factors for various ecosystems (e.g. Braumandl and Curran, 1992), and a model has been developed for comparing disturbance effects on growth-limiting factors when deciding on site preparation prescriptions (Curran and Johnston, 1992). An example of tree growth on a rehabilitated haul road is shown in Figure 9 for a site where competing vegetation is quite severe for the undisturbed trees, but not the disturbed sites. Despite the confounded comparision, growth on the rehabilitated disturbance shows good promise and we feel productivity will be restored with the use of good pre-harvest planning combined with good construction and rehabilitation technique; (Sacenieks et al. in prep.)

Regardless of the actual tree growth effects, a number of soil disturbance types are also of concern because of potential for effects on site and slope hydrology and potential for downslope impacts. On-site changes in site hydrology are difficult to study but we need to err on the conservative side considering that much of BC is not flat and summer drought is often one of the most growth-limiting factors on many sites (effects on hydrology may confound tree growth on apparently "undisturbed" microsites in tree growth studies). Similar hydrologic concerns have been voiced by other researchers in the local area, like Kuennen et al. (1979).

"High Quality" Data Collection:

In order to meet the permitting and operating requirements of the FPC, detailed ecosystem-level site data is collected. It is important that this data be as accurate as possible because it directly influences the economic and environmental success of a chosen harvesting strategy. For example, not recognizing a Very High compaction hazard can be very troublesome and lead to costly, unplanned shutdowns or penalties. Conversely, calling a site Very High compaction hazard when it in fact is not will lead to selection of a much costlier and more restrictive harvesting strategy. In summary, when it comes to data collection, you can pay up front for high quality, or will likely pay more later for extra plan reviews and revisions, and problems on the ground. Below is a partial list of important supporting documents:

SIL 411, Data collection handbook for Silviculture Prescriptions (and field forms FS 39), available from Forest Practices Branch in Victoria.

Regional ecoguides, which often include anecdotal comments on seasonal soil conditions, available from Crown Publications in Victoria,

Regional guidelines for various practices (e.g. Armillaria Guidelines for the Nelson Forest Region by Norris et al. 1998), available from BCMOF regional offices, and

FPC Guidebooks for Silviculture Prescriptions, Soil Conservation, Rehabilitation and Soil Disturbance Hazards, Soil Disturbance Survey available from BCMOF Victoria.

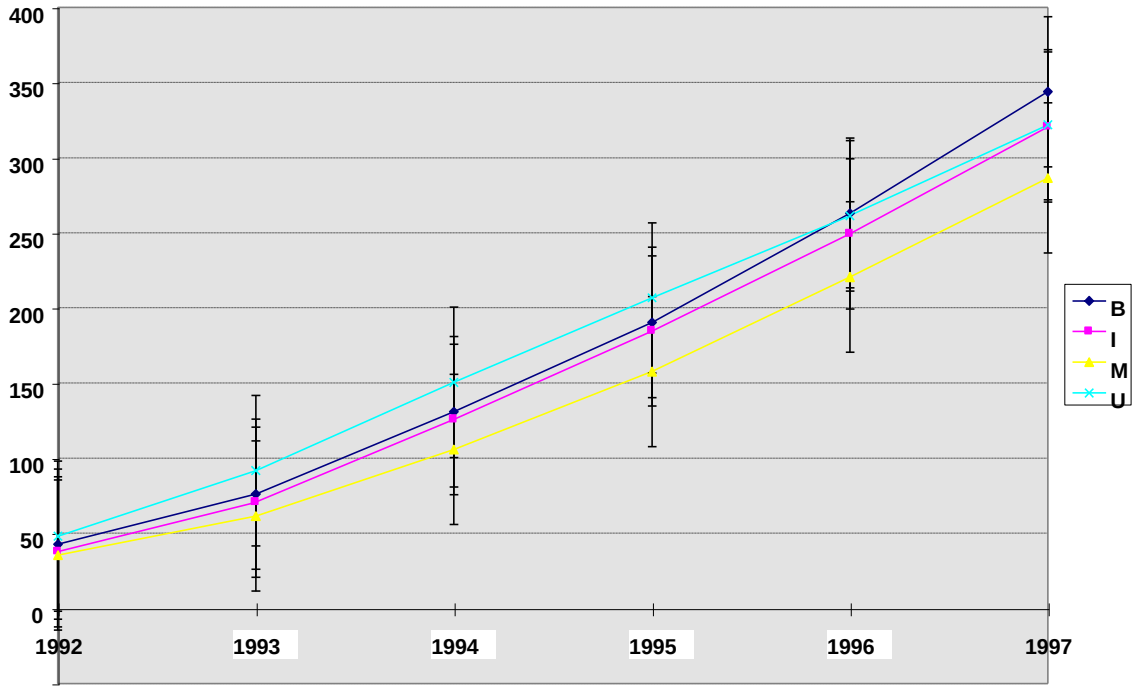

Figure 9. Tree growth on a rehabilitated haul road near Hudu Creek in the West Kootenay, on noncalcareous soils in wetter climate (based on data analyzed by Sacenieks et al., in review). Data symbols are U (undisturbed), I (inner track), M (midroad), and B (berm).

3 DEVELOPING A HARVESTING STRATEGY

Based on the environmental and policy framework described in the preceding section, a given harvesting strategy should meet the following four requirements:

1. it must be site specific and responsive to the soil sensitivities on site (and downslope),
2. it needs to offer a reasonable amount of independence from climatic interruptions,
3. it must incorporate rehabilitation, if necessary, to lower disturbance below guidelines,
4. and, it must instill enough confidence at all levels of approval and operations.

Over the last few years we have been working on a number of trials with Industry and District staff, to address concerns about managing harvesting soil disturbance. Trials have addressed tree growth on rehabilitated skid roads (Dykstra and Curran 1999), haul roads (Sacenieks et al. in prep.), and landings (Bulmer and Curran 1999a). Memos have summarized simple field tests developed during operational trials of seasonal harvesting constraints (i.e. "how wet is too wet?" and “how much frost is enough frost?”). Other research trials have been successful in demonstrating the feasibility of rehabilitating soil disturbance (Bulmer and Curran 1999b). Combined, these trials were designed to test tree growth on rehabilitated disturbance and develop strategies to reduce the dependency on weather conditions and reduce shutdown of operations during wetter conditions. Research and practical innovation are still ongoing, and further field guides will be produced as warranted (e.g. we are developing a simpler soil texture key at this time).

Based on industry innovation, practical experience, and research trials, we have identified four key strategies that we feel meet the above criteria:

a) close trail spacing with rehabilitation,

b) closely spaced temporary spur (haul) roads with rehabilitation,

c) combination designated and dispersed (random) skidding, and

d) hoe-chucking, Interior style (i.e., forwarding to wider spaced trails).

These strategies may or may not include fully mechanized harvesting with feller-bunchers and grapple skidders and may offer the opportunity to reduce site preparation costs by creating disturbance during the harvesting or rehabilitation phases. Each strategy is described in the next section (Section 4), after the following discussion of issues common to all of them (slope considerations, temporary access structures, rehabilitation technique, and weather and climate conditions).

Slope considerations

Assessment requirements for slope stability are outlined in the FPC and described in the *Mapping and Assessing Terrain Stability Guidebook*. On steep slopes, and on moderate slopes in wetter climatic zones, cable harvesting is almost exclusively used. On other sites, slope gradient, configuration, and downslope concerns must be compatible with the

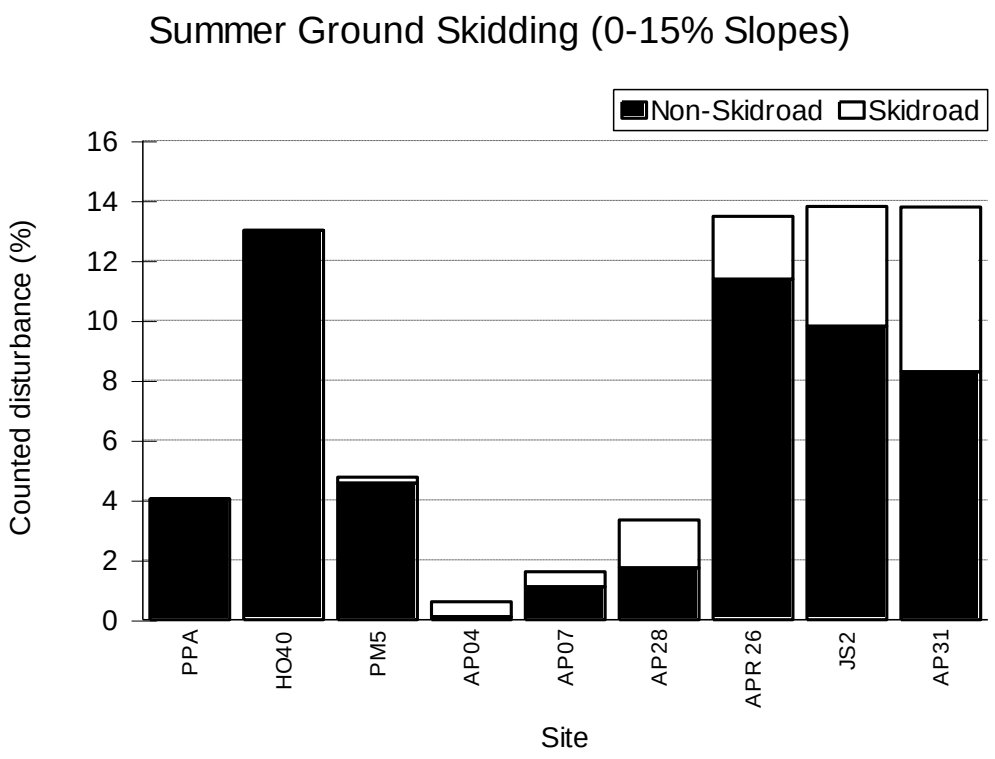

Figure 10. Benchmark soil disturbance data from Nelson Forest Region on summer blocks on 0 to 15 % slopes, from 1990-1993 surveys, using criteria similar to or more constraining than the FPC. Dark bar is dispersed skidding and non-bladed trails; light bar is bladed trails components (cutbanks would be less than 30 cm, so not excavated and bladed under FPC definition).

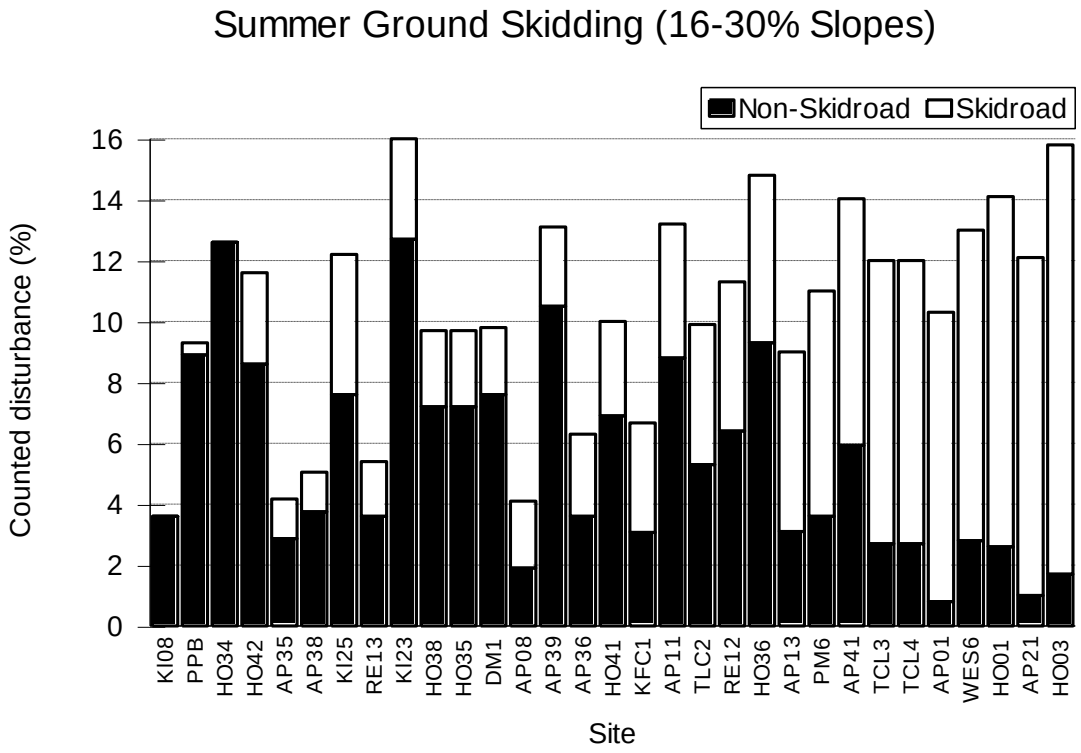

Figure 11. Benchmark soil disturbance data from Nelson Forest Region on summer blocks on 16 to 30 % slopes, from 1990-1993 surveys, using criteria similar to or more constraining than the FPC. Dark bar is dispersed skidding and non-bladed trails; light bar is bladed trails components (at this slope, most cutbanks would be less than 30 cm, so generally not excavated and bladed under FPC definition).

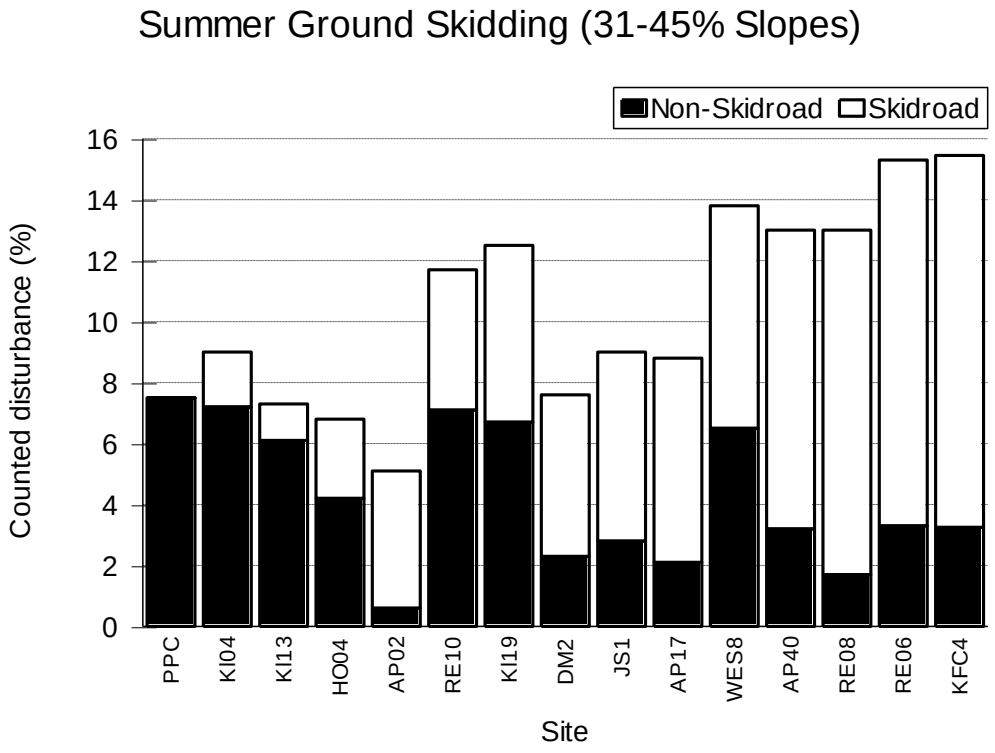

Figure 12. Benchmark soil disturbance data from Nelson Forest Region on summer harvesting on 31 to 45 % slopes, from 1990-1993 surveys, using criteria similar to or more constraining than the FPC. Dark bar is dispersed skidding and non-bladed trails; light bar is bladed trails components (at this slope, most cutbanks would be 30 cm or more and they would count as excavated and bladed under FPC definition). The graph demonstrates how harvesting strategies can range from no to almost entirely excavated and bladed trails, and how all sites would come in under 8 % after rehab of the trails; and how 13 % or less is often all that is needed during harvesting.

harvesting system proposed. It is recommended that the Mass Wasting Hazard and slope instability indicators be used in the field whenever excavation and blading is anticipated. Specific slope comments appear in the sections on individual strategies.

Temporary Access Structures

The recent FPC General Bulletin 19 clarifies the intent of the FPC with regard to temporarily exceeding soil disturbance guideline limits, and then rehabilitating below these limits following harvesting. This provision has been provided based on results from research and practical innovation. Bulletin 19 states that FPC Soil Conservation Guidebook guideline maximum *may* be exceeded **provided the following requirements are met:**

1. the maximum extra disturbance is specified in the Silviculture Prescription (SP),
2. the Temporary Access Structures are approved in the SP, and
3. and the SP provides for timely rehabilitation of the structures.

On appropriate sites, this effectively allows for up to "10 + 5" [9] percent soil disturbance during harvesting, under approved prescription conditions. Implicit in this approval is an assumption that soil productivity will be restored to the satisfaction of the District Manager. In approving prescriptions, the manager will be considering that the SP (harvesting strategy). Nelson Forest Region "benchmark" soil disturbance surveys from 1990 to 1993 demonstrate that, using survey criteria that were similar to or more constraining than the FPC, 13 % is often all that is needed for well planned, summer ground-based harvesting (Figures 10 to 12). Therefore, the 15 % should be viewed as an upper limit that should not always be needed on the ground, even for summer harvesting.

Bulletin 19 also notes that we must provide:

- **adequate soil conservation, and**
- **adequate environmental protection.**

while not presenting:

a) conflict with known management objectives, nor

b) unacceptable risks to resources.

where soils are suitable for rehabilitation to RESTORE SITE PRODUCTIVITY.

Implicit in Bulletin 19 is further guidance based on supporting research and extension from Ministry of Forests staff specialists, regarding specifics such as "appropriate sites." This document summarizes this guidance, further background for application in BC will be provided in a planned Land Management Handbook, following one more summer of field trials and feedback on the strategies in this document.

[9] That is, 15 % maximum during the harvesting operation with a maximum of 10 % net disturbance following rehabilitation plus a maximum of 5 % over this amount during the harvesting operation.

Soil rehabilitation

Soil conditions considered too sensitive or questionable for rehabilitation were previously defined in Regional Soil Conservation Standard Operating Procedures. Research results to date now suggest that rehabilitation success can be expected under a wider range of site conditions. However, a number of key hazards need to be avoided still:

- Avoid Very High hazard for Mass Wasting (often erosion as well),
- Avoid High Mass Wasting hazard if soil texture is clayey,
- Avoid seepage sites, and
- Avoid Very High Compaction hazard on calcareous soils.
- Other Very High Compaction hazard soils: Consult local soil scientists about the feasibility of rehabilitating clayey soils (recall that left unrehabilitated, compaction is expected to be a long-lived phenomenon and mechanical disturbance is required to accelerate the biological processes that ameliorate soil structure and aeration; the viability of rehabilitation on clayey soils is still under trial investigation).

Our research and practical experience has shown that use of Temporary Access Structures on other sites is okay provided adequate drainage control occurs and good construction and rehabilitation technique is used.

Drainage control. The primary objective in rehabilitation is to restore the natural hill slope drainage, thereby preventing erosion and/or drainage diversion. When subsurface drainage hits an excavated cut, such as a skid road, it will usually surface and run down the trail until it is directed off by a waterbar, dip, or outsloping section of trail. These are all important drainage control features to build into a trail and maintain until rehabilitation (remember that major runoff events can occur at any time, even during the harvesting operation). Not only do intact skid roads increase the risk for erosion, but even when waterbarred, they concentrate the snowmelt that should be stored on site for summer drought, downslope (off-site), away from hill slope seedlings.

To ensure subsurface drainage is restored, open waterbars are strongly recommended because the loose, rehabilitated soil may still pipe some water. Deep water bars are left open and run from the inner track, out through the sidecast. Spacing should be the same as normal deactivation and logs may be placed in the waterbars if visuals are of concern. (Cross ditches that run from an inner ditch through to the sidecast, are not normally required because temporary structures often do not require ditches, and are decompacted outsloping, typically resulting in no inner ditch line.)

Timely waterbarring, cross ditching and/or rehabilitation is important and drainage control must be in place before spring or other runoff events (winter constructed trails and landings must be rehabilitated before spring thaw because these structures are often constructed with snow in addition to soil; necessary repetition from an earlier section).

Rehabilitation technique. Soil productivity can be conserved by carefully handling the topsoil and minimizing mixing with unfavourable subsoils. Rehabilitation technique was previously described in a Canada Mine Reclamation conference paper (Curran and

Dykstra 1997) that was distributed to persons receiving the Skid Trail Rehabilitation Video[10] (Curran 1997), and is summarized in field cards (Nelson Forest Region, Research Program, 1997). The technique, briefly summarized below, applies to haul roads, some landings, and winter excavated trails as well. On coarser textured soils, some landings may be successfully rehabilitated with simple ripping (Bulmer and Curran, 1999a). Trails on gentler ground may just require simple ripping and drainage control.

Construction (excavated and bladed trails; excavator usually used):

- branches and woody debris are first removed and placed on the downhill side,
- forest floor and topsoil (to 30 cm) are stripped and placed on top of the branches, and
- running surface is constructed out of subsoil.

Use of small cats (crawler-tractors) to construct trails is viable under certain, restricted site conditions that include cutbank heights less than 35 cm AND less than 5 cm into unfavourable subsoil; avoid High Mass Wasting due to clayey textured soils. Use of small cats to construct trails under other conditions is discouraged because of risk of sidecast ravelling down the slope and because of mixing the unfavourable subsoil with the important topsoil.

Rehabilitation. (do under right soil moisture condition to avoid making clods of soil):

- woody debris is first removed from the running surface because this may act as a wooden culvert and pipe subsurface water,
- decompacted running surface in an outsloping manner (don't rip lengthwise),
- replace soil materials in reverse order, subsoil first,
- slash and other woody debris are placed back on top of the rehabilitated trail, to a similar level as the surrounding cutblock, and
- reforest the disturbance as per the surrounding cutblock.

Use of simple ripping as rehabilitation?

Use of simple ripping with small cats or an excavator is viable under certain, restricted site conditions that include cutbank heights less than 35 cm AND less than 5 cm into unfavourable subsoil, ***and on coarser textured, free draining soils***.

For non excavated trails: simple ripping may be viable under most soil conditions, on trail gradients less than about 5%(?), except High Erosion hazard and wetter sites where drainage diversion is a serious concern.

On all sites ensure adequate waterbarring is left in place after the ripping to avoid drainage diversion and erosion due to creating "mole drains" via ripping.

Use of ripping to rehabilitate trails under other conditions is discouraged because of risk of drainage diversion along the ripping, and because it is much harder (and becomes

[10] The Video and Field Cards are available through the author, (contact information on title page).

impossible as amount of cutbank increases) to restore of the soil profile to ensure productivity is restored.

Even when simply ripping, an excavator would probably be the desired machine because the operator could do a more effective job of waterbarring and placing slash similar to the surrounding cutblock (for visuals, soil restoration). In practice, cutbank height will vary greatly on many sites, so the operator can alternate from full rehabilitation to simple ripping and waterbarring as they crawl along the trail. The excavator can also carry out site preparation on surrounding areas during rehabilitation, in order to mitigate growth-limiting factors in the undisturbed areas.

Weather and climate considerations

Disclaimer: *the following section is merely interpretive advice to be used at your own risk and tempered with your local experience.*

Defining "wet", "dry", "frozen", and "snowpack" have been problematic. By definition, dry has typically meant powdery dry (soil squeezed in the hand will not form a cast); frozen has meant15 cm of hard frost in the soil; and snowpack has meant one meter of snow. However, more important have been defining the practical limits that operations can continue under. Our research over the last few years has helped to define approximate limits for operations.

Initial planning for climatic conditions is most important and can be assisted through use of practical experience, tempered with information from regional ecology guides. For example, on the climate description pages for biogeoclimatic subzones in the Nelson Region field guide (Braumandl and Curran 1992), we have provided our understanding of seasonal soil conditions, ranging from the driest to the wettest site series (e.g. "soils dry out for short to non-existent time periods"). The time periods and depths are defined in an appendix in the ecoguide. This interpretation is important because practical experience can be swayed by events like "El Nino" winters. One common misinterpretation is that soils remained frozen under snowpack. In the BC Southern Interior, and elsewhere, the soil is seldom frozen once a snowpack is over 30 cm; actual depth will vary with snow density, layering, and temperatures ***- once there is any snowcover, the soil begins to thaw because of heat stored in the ground***.

Once it has been determined at the Silviculture Prescription level that seasonal soil conditions are part of the harvesting strategy, operational staff need to determine when these conditions occur. In practice, it is often best to plan for designated trails and then take advantage of the weather when it is stable, and use the trails when it is not favourable (it is much easier to go from designated to dispersed, and make the decision about if it is dry enough, rather than to go day by day asking "is it too wet today?"). Combined designated and dispersed (random) skidding is discussed in one of the strategies in Section 4, below. Recall that the soil Compaction hazard key is a tool to help with planning of an operation, while careful monitoring of equipment effects on the soil, and hand tests for soil moisture content are the tools that help guide the operation.

Simple hand tests for seasonal site conditions are described below:

How wet is too wet? As demonstrated by Dr. McNabb at the workshop, soil moisture conditions near field capacity, or slightly drier, are the ones of concern. Hand tests appear to be the simplest criterion to apply and should not vary too much from person to person (e.g. stronger people typically have larger hands so pressure applied may not vary that much). The physical rationale for hand tests is that they mimic forces applied to the soil from machine traffic (the combined forces of compression, shearing, and some vibration).

In development of a hand test we tried a number of criteria during wet soil harvesting experiments. One possible criterion was whether the soil was wet enough to manipulate to the point of being able to roll a larger diameter worm (e.g. 8 mm). However, some textures are not conducive to any size of worm, and moisture thresholds are typically exceeded once you can manipulate the soil in this way. In fact, textural classes, as defined under the Canadian System of Soil Classification (e.g. Day 1983), are not very diagnostic for predicting how a soil will behave at a given moisture. The problem is that:

1. some categories have a very large range in clay content (e.g. 0 to 28% for silt loam),
2. if soils are sent to a lab for textural analysis, some of the soil minerals that influence their behavior are "cleansed" from the sample before determination (e.g. organic matter, calcareous material, and iron and aluminum oxides), and
3. different clay minerals behave differently to mechanical forces anyway, exhibiting different cohesive properties like plasticity and stickiness.

Therefore, we needed to define soil texture differently. Instead of reinventing the wheel, we looked at other existing classifications and decided that "soil consistence" as defined in the Canadian System of Soil Classification (Day 1983) was very similar to some of our simple interpretations. In a test of college students, we found that they more accurately and precisely determined consistence than textural classes. We also found that, as would be expected, "plastic" soils varied in actual clay content, presumably due to differing clay minerals. As sand decreased, the soil became plastic with less clay (e.g. as low as about 12% in some samples; Thorlakson and Curran 1998). Use of soil consistence classes will not alter the soil compaction hazard for a site, but helps alert the user to soil conditions that are more likely to lead to compaction and rutting[11].

The top 30 cm of the mineral soil needs to be evaluated because wetter soil near the bottom of this depth range will distort under equipment pressure and vibration, particularly if the soil behaves in a plastic manner. For example, in the Rocky Mountain Trench near Cranbrook we have observed rutting from single passes of skidders on powdery dry, sandy soils, because the underlying clay was too wet.

Hand test procedure: dig a small pit and sample the wettest soil in the top 30 cm of the mineral soil, squeeze this soil hard in your hand to form a cast that looks like a bicycle handle-grip. You should check about five pits in separate site locations to decide if and where site conditions are most favourable for mechanical operations on a particular day.

[11] Similar interpretations could be made for erosion and mass wasting. More cohesive (clayey) soils are less erodible, but more prone to minor cut and fill failures (e.g. silt loam textures with over 15 % clay).

(Hand tests have not been developed for sites dominated by forest floors or organic soils > 20 cm.)

Interpretation: Two interpretations are made, depending on soil consistence. In each case, the primary criterion is how much of the hand that contacted the squeezed cast is now moist, and provided the cast will easily break apart:

How wet is too wet hand test:

> If upon hard squeezing, the soil does not directly express water or glisten from free water on the newly formed surface (obviously too wet), use the following criteria:
>
> *Slightly Plastic*[12]*, Plastic and Very Plastic soils*: one to two passes[13] okay if < 25% of those parts of hand that contacted the cast are moist, AND the cast easily breaks apart when tapped with index finger.
>
> *Non-Plastic soils*: one to two passes okay if < 80% of those parts of hand that contacted the cast are moist, AND the cast easily breaks apart when tapped with index finger.

Another test, described by Dr. McNabb at the workshop, is to make a clod in your hand and throw it against the machine - if it sticks, it is obviously too wet. This interpretation needs further testing for BC soils, but if it falls off and doesn't break apart it is probably too wet; if it breaks apart and doesn't leave a completely moist mark, it might be okay. On clayier soils, a penetrometer can provide an estimation of soil strength (clays are soft when wet, hard when dry). Local experience and fine tuning will be required. These other tests will be evaluated in new trials.

How dry is too dry?

Note that sandy soils have low cohesive strength when dry and rutting can occur under these conditions - some moisture actually increases the trafficability of these soil types. Operating on sandy slopes under dry conditions is not recommended. Local experience is needed when considering operating on these soils under drier conditions on gentler ground.

How much frost is enough frost? As discussed by a number of us at the workshop**, soils are often not frozen, even under shallow snow packs**. Frozen soil primarily occurs in our drier, low snowfall areas; however, the soil may be too dry to create hard frost, local experience is needed in considering frozen ground during prescription development.

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[12] Slightly Plastic soil, the main cutoff in this table is defined as: "*a roll 4 cm long and 4 mm thick can be formed, but cannot support it's own weight"* (Day 1983). Some practice is required to ensure that the data collector has the optimum moisture content of the hand texture sample for this test, which should be performed in the field during pre-harvest data collection (slowly add more water and retest until it becomes too wet).

[13] In practice, once three or more passes are made, some compaction has occurred and some of the disturbance starts to get picked up on soil disturbance surveys; The actual amount varies with equipment, operator, texture, moisture content, slope, direction of travel, and other factors.

For the rare situations where soils are frozen, hammer deformation or penetrometer tests appear to be the simplest criterion to apply to frozen soils. Penetrometer pressure will vary from person to person, but it is still similar enough for our purposes. The physical rationale for these tests is that they mimic forces applied to the soil from machine traffic (the combined forces of compression, shearing, and some vibration). We tried a "timber mark" type hammer that would often be present at landings, and a soil penetrometer (simply a "T" of 3/8 inch [9.5 mm] metal rod with a 30 degree cone). Testing numerous sites and calibrating by digging through the frost, we have determined that once the frost is 7.5 cm (3 in.) in the mineral soil, it is next to impossible to get penetration with the penetrometer (i.e. < 1 cm); in harvesting trials, we didn't get any deformation of the soil under 7.5 cm of frost when the soil underneath was dry enough. If only the forest floor or a shallower layer in the mineral soil is frozen, more or total penetration is possible, but definite resistance is felt. Resistance typical of unfrozen soils indicates total lack of frost, in terms of potential to support equipment.

Below are the interpretations, all are based on the *assumption that the underlying, unfrozen soil is not wetter than the "how wet is too wet?" criteria* (you may need to check, if it's too wet the frost can simply act like a layer of "cardboard" and transfer compaction to a deeper, less detectable depth, through deformation). Determinations should be based on at least 10 different penetrometer probings; drip lines around larger trees and depressional areas often have different soil water content, and hence frost, during the winter:

How much frost is enough penetrometer test:

No penetration (< 1 cm):	3 passes probably okay
Frost resistance:	2 passes probably okay
No extra resistance:	use "how wet is too wet?"

One strategy that is used intermittently in BC is to blade snow off of main trails and let the soil freeze before operating. This is a good practice; these frozen trails often do not require rehabilitation, just waterbarring.

How much snow is enough snow? Snow condition is more transient than frost or wetness. A powdery dry snowpack can become wet and compressible in a few hours, under certain climatic conditions. In studying snow under harvest conditions, we decided that two possible criteria exist: simple snow depth and type, or a boot or jump compression test. The rationale for the boot or jump compression test is that it mimics the compression, shear, and vibration forces of machinery traffic; the criterion is the depth of snow left under a boot print. All depths should be average of at least five readings. Depth criteria are based on the *assumption that the underlying soil meets the how wet is too wet criteria*, (check it, it won't be frozen), **and snow is not bladed off by the machine;** further work is continuing**:**

Footprint and snow depth tests:

<u>Wet or near wet, compressible snow (makes snowball):</u>	
Boot compression test > 30 cm, OR snow pack > 60 cm	no limitations?

Boot compression test 15 - 30 cm, OR snow pack 30-60 cm	3 passes okay?
Boot compression test 8-15 cm, OR snow pack 15-30 cm	1 or 2 passes? Frost?[14]
Shallower?	Use how wet or frosty
<u>Dry, fresh or granular snow (can't make snowball):</u>	
Boot compression test > 30 cm, OR snow pack > 60 cm	3 passes okay?
Boot compression test 15 - 30 cm, OR snow pack 30-60 cm	2 passes okay?
Boot compression test 8-15 cm, OR snow pack 15-30 cm	1 pass? Frost?[14]
Shallower?	Use how wet or frosty
<u>Frozen, crusty snow (you can walk on top of it):</u>	
Jump compression test > 20 cm, OR snow pack > 40 cm	unlimited?
Jump compression test 10 - 20 cm, OR snow pack 20-40 cm	5 passes okay?
Jump compression test 8-15 cm, OR snow pack 10-20 cm	2 passes? Frost? [14]
Shallower?	Use how wet or frosty

Frozen, crusty snow is often created by doing a single pass over a new area at the end of the day; the next morning the snow has usually setup hard and will protect the soil better. In the rarer cases where frost is present below a shallow snowpack, presence of frost in above tests may be considered additive in terms of number of passes.

4 HARVESTING STRATEGIES

Based on the research trials on industry innovation, practical experience, and considerations presented above, four key strategies are presented below *for sites that are appropriate for ground-based harvesting.*

a) Close trail spacing with rehabilitation

b) Closely spaced temporary spur (haul) roads with rehabilitation

c) Combination designated and dispersed (random) skidding, and

d) Hoe-chucking, Interior style (i.e., forwarding to wider spaced trails).

Before the strategies are presented, further considerations for steeper sites, sensitive sites, and mechanical harvesting are discussed below.

Steeper Sites

Steeper and more sensitive sites are usually cable or aerial harvested. Where one of these sites is adjacent to a ground-based block, one strategy that may be considered is increasing the size of the ground-based block by the width of a steeper band of trees that can be fallen out of during harvest. Depending on the ability to directionally fall off the

[14] Recall that soils may not be frozen, even under shallow snowpacks, use penetrometer test for frost.

steep slope and the willingness to pull some line, (and considering operator safety), these "bands or slivers" could be over a tree length in width. This strategy would be compatible with each of the strategies discussed below. "Total chance" planning must be considered because we don't want to isolate wedges of operable land above these slivers, or affect the economic viability of a future cable harvest.

In addition to the above strategy, under some conditions, it may be also be possible to use feller-bunchers or hoe-chucking **on the less sensitive sections** of a cable harvest operation.

Sensitive sites

Under the soil disturbance hazard rating system, more sensitive sites, typically those with a Very High hazard rating for Compaction, Displacement, or Erosion, have a lower soil disturbance limit of 5 % after rehabilitation. On these more sensitive sites, it is often best not to exceed 8 % during harvesting because some of the disturbance not counted by the FPC may actually be of concern (e.g. the light disturbance in the compaction study by Utzig et al. 1992, in Figures 1 to 3).
On these sites, more constraints need to be placed on harvesting. In practice, most of these sites are either harvested under good winter conditions, using on-site processors and forwarders with low ground pressures and/or driving over limbs and tops, extensive hoe-chucking under the above conditions, or using cable harvesting.

Mechanized harvesting

The following strategies may or may not include fully mechanized harvesting with feller-bunchers and grapple skidders, and may offer the opportunity to reduce silviculture costs by creating site-preparation disturbance during the harvesting or rehabilitation phases.

For each strategy, some discussion is provided regarding:

- description
- environmental constraints/considerations (slope, soil sensitivities),
- weather and climate considerations, and
- operational overview; layout considerations; falling and yarding comments.

A. Close trail spacing with rehabilitation

Description:

On gentle ground, locating designated trails closer together and confining most skidder traffic to the trails provides better control over soil disturbance, higher equipment productivity, and less reliance on weather conditions. Feller-buncher, grapple skidder combinations are well suited to this strategy on gentler ground, and moderately steeper ground without High disturbance hazards. On more sensitive soils, but still just moderately steep ground, excavated and bladed trails may be an option, but caution is required during site data collection and interpretation to avoid seepage areas and more

sensitive, difficult sites. With the exception of the feller-buncher disturbance, less site preparation type disturbance occurs when using close trails; follow-up site preparation may be needed.

This strategy is applicable to a wide number of sites. Our research has demonstrated that soil disturbance can be controlled using this strategy on appropriate sites (provided the plan is followed correctly), and rehabilitation of the designated trails is likely to restore slope hydrology and soil productivity. Winter trails require less rehabilitation, particularly on flatter ground where waterbarring may be all that is required.

The **primary cautions** are that excess disturbance can result if the plan is not carefully followed and monitored, or if drainage problems arise.

Environmental constraints/considerations (slope, soil sensitivities),

This strategy can be considered under gentle to moderate slope gradients (up to 45%), on sites excluding Very High Compaction hazard or Very High Mass Wasting hazard (High if clayey texture).

weather and climate considerations,

This strategy is less dependent on weather conditions than the others. However, be aware that major runoff events can occur at any time during the harvest operation - drainage control must be built in during layout and construction, or landings may become too wet for operations, or erosion and/or off-site impacts may occur. Designated trails can often be used during wet conditions provided trail rutting does not become too deep (e.g. 15 cm into native soil *on the trails*) and drainage is controlled.

operational overview; layout considerations; falling and yarding comments;

Cost savings from three to four dollars per cubic meter are possible (over conventional, wider spacing). Layout needs to consider drainage, lay of land, lean of trees. If a feller-buncher is used, a front can be cut while driving between trails - most turning should occur on the trails to prevent extra disturbance (unless this is creating prescribed site preparation disturbance). On steeper ground, closer spaced trails usually means excavated and bladed trails, more slash, and lack of site preparation-type disturbance between trails - consider the combined designated and dispersed skidding strategy below (strategy C).

Clearcuts: Spacing BETWEEN TRAILS could be reduced to 25 m, provided proper rehabilitation measures are undertaken to lower disturbance levels below FPC guideline limits.

Partial cutting: Spacing BETWEEN TRAILS should be at least 30 m, with some backing off the trails, *under appropriate seasonal soil conditions*, to strike a balance between thinning thickets and creating some site preparation, while protecting a reasonable amount of advanced regeneration. (Some silviculture systems specialists feel that a certain amount of backing off trails to pick up logs is less damaging than extensive pulling of line and yarding to the trails.)

Suggested spacing table *(NOT Very High compaction*[15]**):**

Silv. system	**Min. trail spacing**[16] between center-center		**Max. pre-rehab. dist.**
Partial cutting[17]	30 m	34	13 (15) %
Clearcutting	25 m	29	15%

Use of trail spacing closer than the above table is a serious concern because of increased site disturbance and potential for hydrologic effects, particularly in partial cutting. The concern is that many partial cuts are preparatory cuts, with another entry possible as soon as 8 to 15 years. Follow this with the shelterwood removal, or another type of entry within 20 to 30 years and we essentially have harvesting corridors that we can right off in terms of contribution to long run sustained yield - we don't want up to 20% of the productive land base in this non-productive category (permanent trails). Use of random skidding under appropriate winter or dry soils conditions is more preferrable because of reduced permanent access - these need to be balanced with potential for compaction on light disturbance and damage to residual trees.

Notwithstanding the above paragraph, use of special low-ground pressure equipment, and forwarding systems can result in closer trail spacing with very little disturbance (similar to harvesting strategies on Sensitive sites, discussed at beginning of this section). Local experience and ongoing studies will help guide these innovations that are already in use in some areas.

B. Close temporary spur (haul) roads with rehabilitation

description

In order to reduce skidding distance and turn around time, some licensees have found it economical to construct closer spaced, lower grade, temporary haul roads and promptly rehabilitate these once the harvesting is completed. This strategy is applicable to a narrow range of sites described below.

Our experience is that soil disturbance can be controlled using this strategy (provided the plan is followed correctly), and our research has shown that rehabilitation is likely to

[15] Very High compaction hazard sites: treat as described in the paragraph at the beginning of this section on "Sensitive sites."

[16] On a given site, the protection of other resource values, or advanced regeneration, may require wider spacing; see notwithstanding paragraph below regarding tighter spacings.

[17] See text, below this table, about partial cutting and concerns regarding increased loss of forest landbase to permanent access network; take advantage of seasonal soil conditions as much as possible to limit main trails, the resulting disturbance during harvesting should usually be less than 13 % (if site preparation type disturbance is prescribed, pre-rehab. level of 15 % MAY be acceptable) PROVIDED the final number is under 10 %.

restore soil productivity. Winter roads on flatter ground might only need drainage control work.

The **primary cautions** are that excess disturbance and environmental risk can result if the plan is not carefully followed and monitored, or if drainage problems arise or are encountered.

In addition, the practice of rehabilitating spur roads and landings is encouraged on all site conditions and is good for restoring productive land base and reducing risk of future drainage or slope stability problems. In a review of a landing rehabilitation program in the BC Central Interior, Dr. Chapman[18] concluded that *"an investment in landing rehabilitation that is successful, is likely no worse and conceivably better than many other investments in silviculture, because it is directly responsible for the generation of all the wood in an area, as opposed to an incremental increase that results from most silvicultural interventions*." The same argument holds for haul road rehabilitation and some is occurring under Forest Renewal BC multi-year agreements; it would be great to see more of this practice as well.

Environmental constraints/considerations (slope, soil sensitivities),

The close temporary spur road spacing strategy can be considered under gentle to moderate slope gradients (35%), on sites excluding Very High Compaction hazard or Very High Mass Wasting hazard (High if clayey texture). Soil materials should be more deeply developed (e.g. B horizon to 45 cm, or over 60 cm to unfavourable subsoil), so that adequate topsoil and organic materials are available during soil rehabilitation.

Rehabilitation of other roads and landings is encouraged and can be employed under any soil and slope conditions where construction was permitted.

Weather and climate considerations,

Major runoff events can occur at any time during the harvest operation - drainage control must be built into the construction and layout. Temporary roads can often be used during wet conditions provided rutting does not become too deep (e.g. 15 cm into native soil) and drainage **and sediment production** are controlled.

Operational overview; layout considerations; falling and yarding comments;

Roadside harvesting is encouraged to reduce the size and number of landings required. Given due consideration to other resource values and issues, spur road density may be increased up to about twice what would normally be required. Cost savings are achieved by reducing skidding distances and turn around times. Long-term productivity and allowable annual cut benefits are possible by having less landbase in permanent access if all spur roads and single pass landings are rehabilitated. Environmental benefits accrue from having less road system in excavated state during a rotation (during which it is reasonable to expect a 100 year runoff event that would exceed the capacity of some road deactivation?). Layout needs to consider drainage and lay of land.

[18] Technical evaluation and recommendations for the Lignum Ltd. landing rehabilitation project. February, 1998. Dr. W.K. Chapman, Regional Soil Scientist, Cariboo Forest Region.

The detailed comments regarding construction and rehabilitation in the section on rehabilitation of skid trials apply.

C. Combination designated and dispersed skidding

Description

Under many site and climatic conditions, we cannot count on an ideal operating window for fully dispersed (random) skidding. In addition, some concentration of traffic is necessary in the areas around landings. The key is to layout trails that can be used under wetter conditions and save the harvest from these areas for these wetter soil conditions. At the ends of the trails and off to the "corners" of the block, dispersed traffic is planned. Conversely, a "go-back" and "speedtrail" layout may be used, as may wider spaced speedtrails (e.g. 60 to 80 meters). In practice, this strategy is often used already; however, it is not clear how *strategic* operators are in applying it.

This strategy is applicable to a wide number of sites. Industry has demonstrated that soil disturbance can be controlled using this strategy (provided the plan is followed correctly). Length of actual excavated and bladed trails can often be minimized, and rehabilitation is likely to restore soil productivity. Simple rehabilitation methods, like ripping behind a cat, can be used on main trails on less sensitive sites and with low trail and slope gradients, provided drainage will be controlled with waterbars, layout, etc..

Some contractors and supervisors do a good job of trying to avoid creating excavated and bladed trails, and this strategy is often used in their "pedo-righteous quest" for minimizing deep soil disturbance.

The **primary cautions** are that excess disturbance can result if the plan is not carefully followed and monitored, or if drainage problems arise or are encountered.

Environmental constraints/considerations (slope, soil sensitivities),

This strategy can be considered under gentle to moderate slope gradients (45%), on sites excluding Very High Compaction hazard or Very High Mass Wasting hazard (High if clayey texture).

Weather and climate considerations,

Major runoff events can occur at any time during the harvest operation - drainage control must be built into the construction and layout. Designated trails can often be used during wet conditions provided rutting on the trails does not become too deep (e.g. 15 cm into native soil *on the trails*) and drainage is controlled. **Dispersed skidding is only used during times of favourable soil conditions.**

Operational overview; layout considerations; falling and yarding comments;

Cost savings from three to four dollars per cubic meter are possible (over wide spaced designated trails without dispersed skidding). Site preparation costs can be saved if creating suitable disturbance during harvesting. Layout needs to consider drainage, lay of land, lean of trees. If a feller-buncher is used, a cutting front can be cut while driving

between trails - on slopes most of turning should occur on the trails to prevent extra disturbance unless this is creating desirable disturbance types for site preparation purposes. On steeper ground, bunches can be laid out to accommodate dispersed skidding and minimize length of concentrated trails.

If skidding between trails, care must be taken in choosing an optimum trail spacing to avoid ending up with areas of more than 2 or 3 passes over the ground (**that is when some disturbance often starts counting**, even under favourable conditions because of equipment turning, rocking, etc.). Factors affecting trail spacing include timber type (piece size and total pieces), equipment yarding capacity, presence of surface roughness (e.g. rock, old slash, old stumps), and microtopography.

Taking advantage of seasonal soil conditions can save time and money in terms of harvesting and creation of more favourable "site prep" type disturbance by random skidding. However, in practice, it is often best to plan for designated trails and then take advantage of the weather when it is stable, and use the trails when it is not (it is much easier to go from designated to random, and make the decision about if it is dry enough, rather than to go day by day asking "is it too wet today?"). **If soil conditions remain poor, simply fill in designated trails between the existing ones and harvest as per close trail spacing, with rehabilitation as required (Strategy A).**

D. Hoe-chucking, Interior style

Description

Under many site and climatic conditions, there are complex topographic conditions that preclude the use of cable harvesting with larger volume stands, or the use of continuous excavated and bladed trails with other timber types. Similar to the combined designated and dispersed trail strategy, hoe-chucking is typically used in the Interior to bring wood to speedtrails for grapple skidders. Hoe-chucking can also be used to feed logs to cable operations in areas of poor deflection AND PROVIDED the ground favourable to equipment operation.

This strategy is applicable to a wide number of sites. Our practical experience has demonstrated that soil disturbance can be controlled using this strategy (provided the plan is based on good field data and is followed correctly). Length of actual excavated and bladed trails can often be minimized, and rehabilitation is likely to restore soil productivity. Simple rehabilitation methods can be used on main trails on less sensitive sites and with low trail and slope gradients.

The **primary cautions** are that excess disturbance can result if the plan is not carefully followed and monitored, or if drainage problems arise or are encountered.

Environmental constraints/considerations (slope, soil sensitivities),

This strategy can be considered under gentle to moderate slope gradients (45%), on sites excluding Very High Compaction hazard or Very High Mass Wasting hazard (High if clayey texture).

Weather and climate considerations,

Major runoff events can occur at any time during the harvest operation - drainage control must be built into the construction and layout. Designated trails can often be used during wet conditions provided rutting does not become too deep (e.g. 15 cm into native soil) and drainage is controlled. **Dispersed skidding can be used during times of favourable seasonal soil conditions**. (Hoe-chucking can often occur under less favourable conditions; proceed with caution.)

Operational overview; layout considerations; falling and yarding comments;

Cost savings can range as high as for closer spaced designated trails, but may be less because of the cost of the excavator and depend highly on the skill of the operator. Site preparation costs can be saved if creating suitable disturbance during harvesting. Layout needs to consider drainage, lay of land, lean of trees. If a feller-buncher is used, a cutting front can be cut while driving between trails - on slopes most of turning should occur on the trails, or carefully on or adjacent to stumps, to prevent extra disturbance unless this is creating prescribed disturbance types for site preparation purposes. On the coast, hoe-chucking often involves multiple handling of each piece of wood; in the Interior, handling is minimized through layout of speedtrails, but some layouts may require some multiple handling, using a moving front of timber that is re-forwarded towards the speedtrail for the skidders. Factors affecting trail spacing include timber type (piece size and total pieces), equipment yarding capacity, presence of surface roughness (e.g. rock, old slash, old stumps), and microtopography.

4 CONCLUSIONS

Whenever we drive equipment on soil, the potential for negative effects is very real. The negative effects can impact on-site processes that regulate forest productivity, and can impact off-site values through processes such as erosion, increased runoff, landslides, or sedimentation. Some effects, like compaction and displacement of the fertile topsoil layers, can take decades, centuries, or even longer to be naturally ameliorated back into a similar, productive state (our soils have taken about 10,000 years to reach their shallow depth of development).

It is recognized in the Forest Practices Code that some disturbance is necessary for accessing and managing timber; it is also recognized that some disturbance types can be beneficial for establishing and producing future forests on a given site. In this paper, the policy and environmental framework affecting forest harvesting in BC was presented, along with the key considerations that go into developing a forest harvesting prescription. The four harvesting strategies presented were developed to maximize independence of

climatic conditions while remaining responsive to resulting soil disturbance levels (and industry costs).

The soil disturbance hazard rating system that we use in BC helps govern and guide soil disturbance during forest harvesting. This system, and the FPC, are not static, but will evolve as further scientific and practical information is generated on how our soils respond to various equipment forces and disturbances. Equally important is the effect of the various disturbance types on long-term forest productivity and other resource values such as water. Some of this new information will be available shortly, some will take time to research and for tree growth data to provide the "bioassay." Some of the effects may not be as severe as thought, but others may be worse. As stewards of the forest land base, our collective responsibility is to proceed cautiously in issues involving soil productivity and other forest resources. The author's primary concerns are drainage control and extensive use of dispersed traffic under unfavourable soil conditions; fortunately we have proven that these can be managed without extra costs, by following the strategies presented.

One of the primary premises behind the strategies presented is to confine the heaviest machine traffic to designated trails, except when soil conditions are favourable. Another is that rehabilitation will successfully restore productivity, provided adequate planning, construction, and rehabilitation technique are used. The recent evolution of the FPC, including providing clarification on this use of temporary access structures, has been possible and supported by the results of research trials and practical innovation. New information regarding ground-based harvesting has been presented in this paper.

The success of a given strategy depends on a number of factors, ranging from operator skill and layout, to high quality Silviculture Prescription data collection. The value of high quality site data can not be understated when you consider the risk management decisions that are made in prescribing and implementing harvesting strategies.

The four strategies presented in this document need to be carefully considered for a given set of site and resource management conditions. They will not work on all sites, nor will they be compatible with all resource management objectives. Forest planning and management staff will have to make final decisions regarding risk management related to allowing extra soil disturbance during harvesting. These decisions need to be based on a good operational understanding of what is achievable on the ground. Not all strategies require extra soil disturbance.

As discussed with the strategies, partially cut and/or more sensitive sites should be harvested with alternative methods, or saved for harvesting under seasonal conditions conducive to lower disturbance levels, such as snowpack, or in the drier zones: dry or frozen ground.

In summary, the continuing evolution of the FPC is reflecting the results of a combination of advancing the science behind the FPC (research) and practical implementation of the provisions of the FPC (industry/BCMOF innovation). Results to date have demonstrated, that through careful site data collection and planning, we can achieve soil disturbance levels and restore soil productivity while still having lower harvesting costs than when the FPC was implemented in 1995.

Areas requiring further study

A number of key areas still require further study to support the science behind the Forest Practices Code, or evolution thereof. A number of these issues are being studied on our major installations where we are studying light compaction (the USFS designed, cooperative "Long-term Soil Productivity Study" sites; one is in the Invermere Enhanced Forest Management Pilot Project area). Below is a partial list of some of the areas requiring and/or receiving further study, under various site conditions:

Compaction: level of traffic and how wet is too wet in terms of detrimental compaction when using lower ground pressure equipment (e.g. wider tires); definition of detrimental compaction on our soils (long-term tree growth studies needed).

Displacement of fertile topsoil and forest floor away from seedling microsites; implications of whole tree harvesting; coarse woody debris requirements for long-term productivity.

Implications of various disturbance types for slope hydrology (difficult to study).

Rehabilitation: how much topsoil is enough topsoil?, under what site conditions is simple ripping adequate?, rehabilitation techniques and feasibility for clayey soils, landing rehabilitation techniques; economics of rehabilitation.

Tradeoff between using Erosion versus Mass Wasting interpretations in determining guideline soil disturbance levels and suitability of excavated and bladed trails (the author prefers the Mass Wasting hazard).

Root rot treatment options and implications for soil properties and long-term productivity.

Implications of soil disturbance types under partial cutting re-entries.

Properties and behavior of calcareous soils and implications for forest management.

Where is it feasible to use hoe-chucking or feller bunching on cable ground?

Other harvesting issues will be addressed as identified by industry and district staff.

Any one interested in helping investigate these issues on BC soils is encouraged to contact the author or other soil scientists at the BCMOF; we can help in identifying potential industrial collaborators, etc.

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