Impacts of biomass harvesting on soil disturbance and surface soil erosion at Seller Creek in interior British Columbia

P.R. Commandeur and M.E. Walmsley

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Abstract

Numerous studies have documented the soil disturbance effects of ground-based harvesting systems. Biomass harvesting, in the form of the additional recovery of woody materials normally left on site, has the potential for increasing the levels of soil disturbance. The objective of this study was to document the impact of biomass harvesting by rubber-tired skidders on soils, namely soil disturbance and surface soil erosion. An increase in soil disturbance in the form of skid trails, skidroads, and deep and very deep gouges was observed on the biomass harvested plots compared to the conventionally harvested plots. Erosion bridges indicated more soil movement on the biomass than the conventional plots. Soil erosion volumes trapped behind sediment dams located at the base of the plots were greater on the biomass plots (average of 0.38 m^3 over 1.77 years) than on the conventional plots (average of 0.22 m^3). However, the unharvested plots also recorded accumulation of material where in fact no mineral soil erosion occurred (average of 0.15 m^3). This was the result of vegetation growth and decay and the accumulation of organic matter. Adjusted average erosion values of 0.78 m^3/ha/year for the biomass plots and 0.37 m^3/ha/year for the conventional plots are comparable to data obtained from studies conducted on clearcut and burned sites in the Oregon Cascades. These erosion figures are considered moderate and numerous site factors help explain this observed response. Rainfall simulation experiments conducted at the site indicated that infiltration rates on skidroads and fireguards are generally greater than 1.5 cm/hour. Rainfall intensities (15 minute duration) that exceed 1.5 cm/hour are expected to occur with a return period of about 1 year at the study site. Spring snow melt rates may exceed infiltration capacities especially along compacted, low infiltration areas such as skidroads. Some overland flow and surface soil erosion is expected to occur elsewhere under similar conditions as those found at the study site. Recommendations are given regarding the measurement techniques used in this study.

Résumé

De nombreuses études ont traité des effets perturbateurs sur le sol des méthodes terrestres d'exploitation forestière. La récolte de la biomasse, soit la récupération plus complète de matières ligneuses normalement laissées sur place, peut augmenter le niveau de perturbation du sol. La présente étude avait comme objectif d'étudier les effets sur les sols de la récolte de la biomasse au moyen de débusqueuses à pneus de caoutchouc, soit la perturbation du sol et l'érosion de la surface du sol. On a observé une plus grande perturbation du sol, qui se manifeste sous la forme de sentiers et de chemins de débardage et d'ornières plus ou moins profondes, dans les parcelles soumises à la récolte de la biomasse que dans celles exploitées selon les méthodes classiques. L'observation des ponts d'érosion a indiqué un mouvement plus important du sol sur les parcelles soumises à la récolte de la biomasse que sur celles exploitées par les méthodes classiques. Les volumes de sol emporté par l'érosion mesurés derrière les digues à sédiment placées à la base des parcelles étaient plus importants dans les parcelles soumises à la récolte de la biomasse (moyenne de 0,38 m^3 sur 1,77 an) que dans les parcelles exploitées selon les méthodes classiques (moyenne de 0,22 m^3). Toutefois, on a enregistré également une accumulation de matières dans les parcelles non exploitées là où l'on n'avait en fait observé aucune érosion du sol (moyenne de 0,15 m^3). La croissance végétale et la dégradation des matières organiques ainsi que l'accumulation de ces matières organiques étaient responsables de ce phénomène. Les valeurs moyennes pour l'érosion, après correction, s'élevaient à 0,78 m^3/ha/an pour les parcelles soumises à la récolte de la biomasse et à 0,37 m^3/ha/an pour les parcelles exploitées par les méthodes classiques, des données comparables à celles obtenues pour les coupes à blanc et les brûlis dans la chaîne des Cascades en Orégon. Ces données sur l'érosion sont considérées comme moyennes, et de nombreux facteurs liés à l'endroit etudié contribuent a expliquer les résultats obtenus. Les expériences de simulation de précipitations menées sur les lieux ont indiqué que la vitesse d'infiltration sur les chemins de débardage et les coupe-feu était en général supérieur à 1,5 cm/heure. Des précipitations (d'une durée de 15 minutes) dépassant 1,5 cm/heure sont susceptibles de se répéter à des intervalles d'environ 1 an à l'endroit étudié. Le taux de fonte des neiges au printemps peut dépasser la capacité d'infiltration dans le sol, notamment dans les zones où le sol est tassé et peu poreux, comme dans les chemins de débardage. On peut s'attendre à observer un certain degré de ruissellement et d'érosion de la surface du sol ailleurs dans des conditions semblables à celles rapportées dans la présente étude. On formule des recommandations sur les techniques de mesure utilisées.

Foreword

ENFOR is the acronym for Forestry Canada's ENergy from the FORest (ENergie de la FORêt) program. This program of research and development is aimed at securing the knowledge and technical competence to facilitate in the medium to long term a greatly increased contribution from forest biomass to our nation's primary energy production. It is part of the federal government's efforts to promote the development and use of renewable energy as a means of reducing dependence on petroleum and other non-renewable energy sources.

The ENFOR program is concerned with the assessment and production of forest biomass with potential for energy conversion and deals with such forest-oriented subjects as inventory, harvesting technology, silviculture, and environmental impacts. (Biomass Conversion, dealing with the technology of converting biomass to energy or fuels, is the responsibility of the Renewable Energy Division of the Department of Energy, Mines and Resources).

Most ENFOR projects, although developed by Forestry Canada scientists in light of program objectives, are carried out under contract by forestry consultants and research specialists. Contractors are selected in accordance with science procurement tendering procedures of the Department of Supply and Services. For further information on the ENFOR Biomass Production Program, contact:

ENFOR Secretariat
Forestry Canada
Government of Canada
Ottawa, Ontario, K1A 1G5

This report is based on ENFOR project P-366 which was carried out in large part under contract by Westland Resource Group, Victoria, B.C. (DSS File No. 13SB.01K51-8-0055).

Introduction

Timber harvesting in the British Columbia interior is largely conducted with ground-based systems which have historically caused high levels of soil disturbance. Recently, soil conservation guidelines have been implemented which limit allowable soil disturbance resulting from harvesting (B.C. Ministry of Forests 1992). Recovery of additional woody biomass beyond the conventional level to meet increasing demands for wood fibre for pulp, wood products and energy, is recognized as a real possibility in years to come. Recovery of additional biomass could be accomplished in many ways: the utilization of wood normally left in clearcuts, the greater utilization of wood normally yarded to the road, and whole tree harvesting (complete above-ground bole and branches) and utilization. Such additional recovery has the potential to result in greater soil disturbance and off-site impacts, and reductions in long-term site productivity (Standish *et al.* 1988). However, the exact nature and magnitude of the soil disturbance, erosion and site productivity response to biomass harvesting is not known.

This study was designed to address the soil disturbance and surface erosion concerns noted above. The specific objective was to determine the degree to which biomass harvesting, in the form of additional recovery of wood normally left on site, would lead to a reduction in the ability of soils to resist surface soil erosion, and to quantify this erosion.

Study area

The study area (lat. 51°41' long. 121°21') is located 80 km northeast of Williams Lake, British Columbia, on the south side of the Seller Creek valley at an elevation of 1200 m (Fig. 1). The site is located in the Cariboo River variant (ICHh2) of the Interior Cedar Hemlock biogeoclimatic zone, Wet Central subzone (B.C. Ministry of Forests and Lands 1987). The area is primarily forested with Engelmann spruce (*Picea engelmannii* Parry), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and scattered lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). Soils are predominantly Brunisolic and Luvisolic (Agriculture Canada Expert Committee on Soil Survey 1987) loams and silt loams, are moderately well to imperfectly drained, and have coarse fragment contents (> 2 mm) ranging from 25 to 40% by weight. According to a Surface Erosion Hazard Key developed by Lewis *et al.* (1989), the site is rated as having a moderate to high surface erosion hazard, which depends on whether a moderate or high rainfall factor is assumed. Soil parent materials are characteristically glacial till and weathered colluvium. Bedrock is dominantly shales and siltstones. The aspect is north to northeast with slope gradients ranging from 20 to 50%.

Harvest and site preparation history

The area was clearcut during the fall and winter of 1987/88 by Weldwood of Canada Ltd. with small tractors and rubber-tired skidders. The remaining

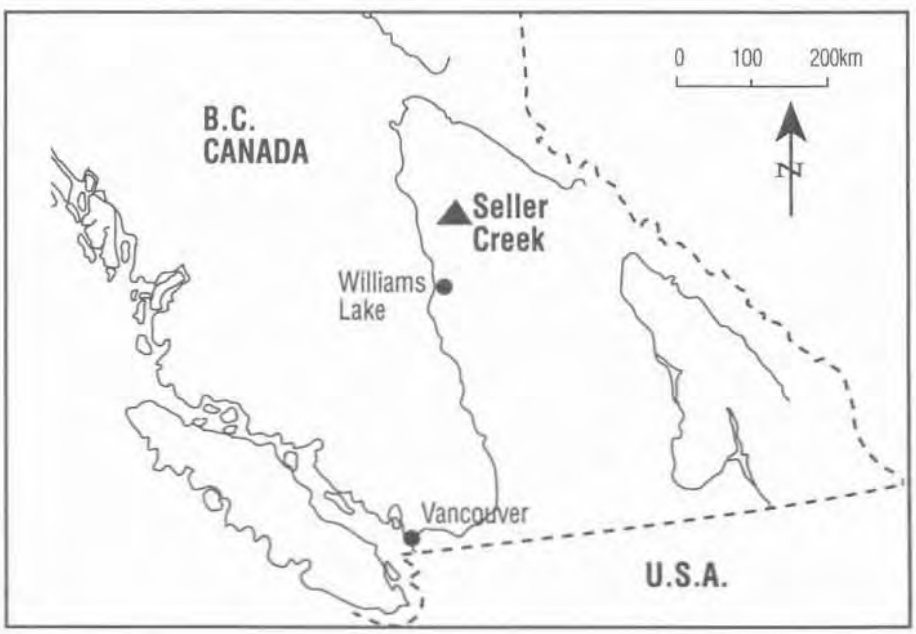

Figure 1. Study site location.

standing non-merchantable trees were felled during the summer of 1988. Site preparation in the form of prescribed fire took place in June 1989.

Methods

For the purposes of the study, three types of treatments were established: conventional harvest, biomass harvest and unharvested control. Three plots were established for each treatment, for a total of nine plots. The plots consisted of small drainage basins defined by natural topographic breaks and ridges, and ranged in size from 0.05 to 0.2 ha for the conventional and biomass plots (Table 1). The control plots were not surveyed to determine overall dimensions. All of the plots were similar in terms of soil and site characteristics. On each plot, soil samples were collected from the 0-20 cm and the 25-40 cm mineral soil depths, and standard soil analytical procedures (McKeague 1978) were employed for particle size analysis.

For the biomass harvested plots, a rubber-tired skidder was used in August 1988 to harvest additional wood which had been felled and left on the plots (Table 1). This wood consisted of larger boles which were considered unmerchantable during the primary harvest. In order to harvest this additional wood, pre-existing skidroads were reactivated or new skidroads and skid trails were established.

Climate measurements

A climate station was installed between the conventional harvest and biomass harvest plots in September 1988. The parameters measured were precipitation (two Weathermeasure model # 6011-B tipping bucket rain gauges), solar radiation (Li-Cor pyronometer model LI-200SZ-05), wind speed (Met One model 013A), air temperature (CSI model 107), soil temperature (CSI model 107B), and relative humidity (General Eastern RH8). The station was maintained for two water years (October 1, 1988 to September 30, 1990). Snowpack water equivalent measurements were taken on April 12, 1989 and March 28, 1990. In 1989, five water equivalent samples were made on conventional plot 1, biomass plot 3 and in the leave strip located to the west of the clearcut. During 1990, five additional water equivalent samples were taken on each of the conventional and biomass plots, and on three plots located within the leave strip area.

Soil disturbance measurements

After the biomass plots were treated, soil disturbance on each of the biomass and conventional plots was determined by utilizing the point-intercept method designed by Smith and Wass (1976). Along each of two transects for each plot, soil disturbance and other parameters such as slope gradient, aspect, presence or absence and size of slash, and moisture regime were assessed every 3 m. A total of 118 points on the biomass plots and 104 points on the conventional plots were sampled. A soil disturbance survey was not conducted on the control plots because these plots were completely undisturbed. In addition, along each transect for the biomass and conventional plots, a nuclear densiometer (CPN model MC1) was used to determine soil density and moisture (with organic layers removed) at 20-m intervals. Readings were taken at depths of 5, 10, 15, and 20 cm. Similar data were collected at random locations within the control plots.

Depth-of-burn indicator pins were installed on the biomass and conventional plots to assess the impact of the prescribed burn on duff consumption and mineral soil exposure. Twenty-four pins were located in a transect/grid pattern in the central portion of each plot.

Soil infiltration measurements

A portable rainfall simulator was employed to obtain soil infiltration values, and to determine the potential surface erosion response on selected locations such as skidroad surfaces, fireguards, and harvested and slash burned sites. The simulator consists of an air-tight chamber having 324 drop-forming tubing tips (0.56 mm inside diameter), a reservoir tank and flow meter, and a supporting structure equipped with telescopic legs which are used to level the rainfall chamber (Fig. 2). The simulator can be used on slope gradients up to 50%, and, at a maximum height of 2.7 m above the ground, simulates approximately 75% of the terminal velocity of natural rainfall having the same drop diameter of 3 mm (Epema and Riezebos 1983). Overland flow was collected with a system of troughs which were sealed against the soil with fast drying plaster (Fig. 3). A graph of infiltration rate versus time was plotted from which an infiltration capacity value, defined as the equilibrium infiltration rate, was obtained. Infiltration measurements were taken on six plots located in or near the study area (Table 2).

Table 1. Plot characteristics

Plot[a]	Avg. Width[b] (m)	Avg. Slope Length (m)	Area (ha)	Avg. Slope Gradient[c] (%)	Soil Texture 0-20cm depth	Soil Texture 25-40cm depth	Additional Volume Harvested (m^3)	Additional Volume Harvested (m^3/ha)	Area Covered in[d] Slash 0-5cm (%)	Area Covered in[d] Slash >5cm (%)	Area Covered in[d] Logs (%)
BIO-1	21.0	81.0	0.170	20/47	L	L	29	170	47.8	45.7	10.9
BIO-2	23.5	58.0	0.136	25/44	SiL	SiL	15	110	52.6	29.0	2.7
BIO-3	35.0	55.0	0.193	27/42	SiL	SiL	45	230	79.4	5.9	0.0
Average	26.5	64.7	0.166	34			30	170	59.9	26.9	4.5
CON-1	10.5	42.0	0.044	55	SiL	L			50.0	30.0	6.6
CON-2	28.0	70.0	0.196	51/37	L	L			56.0	44.1	6.9
CON-3	19.0	42.0	0.080	52	SiL	SiL			60.0	33.3	6.6
Average	19.2	51.3	0.107	50					55.3	35.8	6.7
UN-1	12.5			47	SiL	L					
UN-2	7.7			44	SiL	SiL					
UN-3	11.0			44	SiL	SiL					
Average	10.4			45							

[a] BIO = biomass harvested
CON = conventionally harvested
UN = unharvested control

[b] Length of fabric dam for unharvested control plots.

[c] Upper portion of plot/lower portion of plot.

[d] Based on the point-intercept transect data.

Figure 2. Rainfall simulator.

Figure 3. Overland flow collection system.

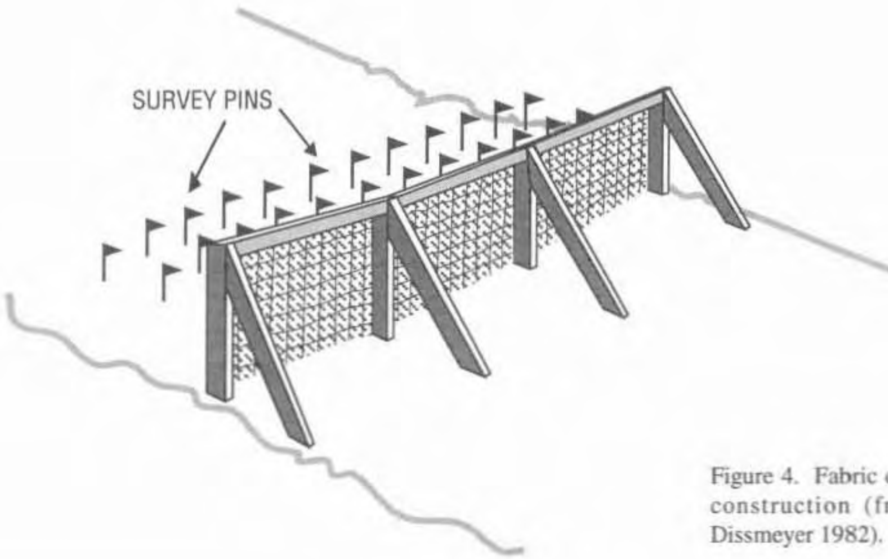

Figure 4. Fabric dam construction (from Dissmeyer 1982).

Figure 5. Photograph of dam on Biomass Plot 3.

Soil erosion measurements

A number of techniques were employed to assess the soil erosion response of each treatment. Geotextile fabric dams or sediment dams (Dissmeyer 1982) were constructed at the base of each plot and were located so that virtually all of the surface drainage within the plot "mini-basins" was fed into the dam. The dams consisted of layers of hog wire and rot-resistant and water permeable fabric (Exxon 150D needle punched geotextile) on a framework of treated wooden posts and cross pieces (Figs. 4 and 5). The dams were approximately 1 m in height and varied in length from 8 to 10 m. Erosion/deposition pins were installed in three rows (1 m by 1 m spacing) in front of the dams in early October 1988. The grid area for each dam more than covered the active deposition zone. Measurements were made the subsequent spring (May 1989), 2.5 weeks following the prescribed fire (July 1989) and the following summer (July 1990). The prescribed fire (June, 1989) destroyed five out of the six dams located within the conventional and biomass plots, and the dams had to be reconstructed and the measurement pins re-calibrated (July, 1989). The volume of eroded material trapped behind the fabric dams was calculated as follows:

$$EV = GRID\ AREA \times P \times D$$

where

EV = erosion volume in m^3;
$GRID\ AREA$ = total area occupied by grid points (m^2);
P = proportion of grid points with sediment deposits;
D = average depth of sediment on the grid points (m).

In order to obtain erosion/deposition measurements at other points within the study area, erosion bridges (Blaney and Warrington 1983) were installed at three locations within each of the nine plots. These consisted of three metal rods spaced 60 cm apart that were driven into the ground and leveled with a pre-drilled carpenter's level (Fig. 6). For each 60-cm section, measurements were made by inserting a metal rod in holes located every 5 cm along the level (total of 24 points per erosion bridge location) and measuring the distance it protruded above the bridge. The points were periodically remeasured to obtain aggradation/ degradation values over time. The erosion bridges were located to represent typical slope, soil and moisture conditions found within each plot.

Statistical analyses

Statistical comparisons were made using ANOVA and, when more than two means could be compared, the Student-Newman-Keuls multiple comparison test (Peterson 1985; SAS Institute Inc. 1985).

Results

Climate characterization

The most important climatic parameter in this study is precipitation. The total daily, monthly and water-year precipitation values for the 2-year period October 1988 to September 1990 are presented in Appendix I. The average annual precipitation for the 2-year period is estimated at 792 mm. For the 2-year period, the snowpack represented on average almost 50% of the total precipitation, which accumulated over approximately 4 ½ months (mid-November to end of March). The snowpack water equivalent was greater during the winter of 1989/90 (446 mm) than during the winter of 1988/89 (318 mm). Rainfall was fairly evenly distributed over the remaining 7 ½ months, except for April/89 and September/90 when only 12 and 10 mm were recorded, respectively. The wet rainfall season coincides with the summer thunderstorm period (June through August), and the wettest month recorded was August/89 when over 100 mm of rainfall occurred (Appendix I). Rainfall intensities are generally low: intensities greater than 5 mm/hour occurred only in 2.5% of all rainfall events. A rainfall intensity greater than 20 mm/hour occurred only once during the 2-year period. Maximum rainfall intensities and the estimated return interval for these events are presented in Table 3. The largest rainstorm (9.7 mm in 30 minutes or 19.4 mm/hour) had an estimated return period of 2.3 years. A 30-minute rainfall intensity of 30 mm/hour for a return period of 5 years, and 40 mm/hour for a return period of 10 years is estimated for Seller Creek; this is based on the nearest long-term climate station (British Columbia Forest Service, Horsefly).

Soil disturbance

The area in skidroads was significantly greater (α=0.05) on the biomass plots (12%) than on the conventional plots (0%) (Table 4). The area in skid trails was also greater on the biomass plots (43 versus 35%), but with less statistical significance (α=0.1). The biomass plots also had a significantly higher percentage in deep (5 to 25 cm) and very deep (> 25 cm) gouges than did the conventional plots (19 versus 2%). Bulk densities on the plots varied between 0.5

Table 2. Infiltration plot characteristics

Plot[a]	Surface character	Slope gradient (%)	Soil bulk density (Mg/m^3)	Rainfall intensity (cm/hour)	Infiltration capacity (cm/hour)
SR-1	min. soil	27	1.56	4.20	1.60
SR-2	min. soil	26	1.38	4.20	3.00
FG-1	min. soil	10	1.73	4.20	1.30
FG-2	min. soil	25	1.70	4.20	2.20
SB-1	min. soil & humus	45	1.38	4.20	2.75
SB-2	humus	25	1.23	7.75	>7.75

[a] SR = Skidroad running surface
FG = Fireguard surface
SB = Conventionally harvested and slash-burned site

Table 3. Maximum rainfall intensities observed during the period October 1988 to September 1990

Date (D-M-Y)	Time	Duration[a] (minutes)	Precipitation (mm)	Hourly equivalent (mm/hour)	Return[b] interval (years)
13-10-88	16:15	15	5.15	20.6	< 2[c]
20-04-89	16:30	30	4.8	9.6	≤ 1[d]
30-06-89	19:15	30	5.4	10.8	≤ 1
09-07-89	14:30	30	5.8	11.6	< 2
10-07-89	15:00	30	9.7	19.4	2.3
15-07-89	19:00	15	3.55	14.2	≤ 1
23-07-89	15:45	15	4.25	17.0	< 2
18-08-89	5:30	30	6.55	13.1	< 2
08-07-90	18:45	15	3.1	12.3	≤ 1

[a] 15 versus 30 minutes duration events have different return interval intensities which explains why, for example, the 20.6 mm/hour event is a <2 year event, whereas the 19.4 mm/hour event has an estimated return interval of 2.3 years.

[b] Return interval is based on the Environment Canada, Atmospheric Environment Service rainfall intensity and duration frequency data for the British Columbia Forest Service Horsefly station (nearest long-term climate station).

[c] indicates return interval probably greater than 1 year but less than 2 years.

[d] indicates a return interval of 1 year or less.

and 1.4 Mg/m^3; the higher values occurred on the skidroads and skid trails. The lower bulk density values probably reflect areas where organic matter was incorporated into the soil profile.

The average percentage area burned as a result of the prescribed fire was significantly lower (α=0.05) on the biomass plots (44%) than on the conventional plots (83%) (Table 5). The additional recovery of wood on the biomass plots reduced the amount of combustible materials in comparison to the conventional plots, especially for slash greater than 5 cm in size (27 versus 36% coverage) and logs (5 versus 7% coverage). This helps explain the smaller burn area on the biomass plots. Where duff consumption occurred, the average depth of burn for the two levels of harvest was comparable. Mineral soil exposure due to the fire (i.e., complete duff consumption) averaged 3 and 7% on the biomass and conventional plots, respectively.

Soil infiltration

The infiltration capacities were less than or equal to 3 cm/hour when exposed mineral soil was present (Table 2). Infiltration capacities were as slow as 1.3 to 1.6 cm/hour on the skidroad and fireguard. The plots located on the harvested and slash-burned sites gave variable results depending on the amount of the humus layer which remained after the fire. The plot with an intact humus layer maintained a high infiltration capacity (> 7.75 cm/hour).

Soil erosion

Prior to the prescribed fire in June 1989, the erosion volumes trapped by the erosion dams were relatively small, and there was no significant difference in erosion volumes between the treatments (Table 6). Comparisons between the pre-fire and the post-fire data are considered somewhat questionable because of the destruction of most of the dams during the prescribed fire treatment. For the post-fire period of July 1989 to July 1990, the erosion volumes trapped behind the biomass dams (average erosion increment, ΔEV, of 0.26 m^3) were, on average, greater (α=0.1) than the erosion volumes trapped behind the conventional and unharvested dams ($\Delta EV = 0.11\ m^3$). The deposition behind the dams in the unharvested plots was made up of litter and decomposing vegetation whereas on the conventional and biomass harvest plots it was a mixture of sediment and litter. If we assume that the average erosion volume behind the unharvested dams represents the background rate of deposition (i.e., non-soil material), then the erosion volumes over the post-fire period (July 1989 to July 1990) for the biomass and conventional treatments are 0.13 m^3 and 0.0 m^3, respectively. Over the entire study period (October 1988 to July 1990), the control plots accumulated on average 0.15 m^3 of material, and the adjusted erosion volumes for the biomass and conventional treatments are 0.23 m^3 and 0.07 m^3, respectively.

The biomass and conventional plot erosion volumes were converted into erosion volumes per area (m^3/ha). These biomass and conventional values are not significantly different for any of the time periods indicated in Table 6. Based on general field observations, the proportion of the plot areas which eroded and contributed to the erosion volumes was evidently smaller than the surveyed plot areas. Thus, the per area erosion values do not reflect the actual (but unmeasured) area over which the erosional processes took place, which could explain why the erosion volumes (m^3) and the area based values

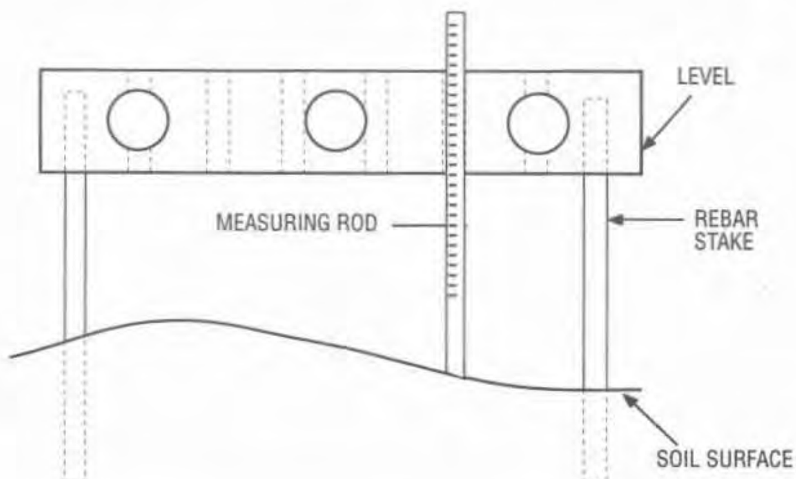

Figure 6. Schematic representation of erosion bridge (from Blaney and Warrington 1983).

Table 4. Soil disturbance survey results

Plot	Transect	% Cover					% Area of Plot[a]	
		Skidroads	Skidtrails	Landings	Undisturbed	Other[b]	Deep gouge	Very deep gouge
BIO-1[c]	1	0.0	43.5	0.0	47.8	8.7	13.0	13.0
	2	0.0	43.5	0.0	43.5	13.0	17.4	8.7
Average		0.0	43.5	0.0	45.6	10.9	15.2	10.9
BIO-2	1	21.1	36.8	0.0	42.1	0.0	10.5	10.5
	2	10.6	52.6	0.0	36.8	0.0	0.0	5.3
Average		15.8	44.7	0.0	39.5	0.0	5.3	7.9
BIO-3	1	17.6	41.2	0.0	29.4	11.8	0.0	11.8
	2	23.5	41.2	0.0	29.4	5.9	11.8	11.8
Average		20.6	41.2	0.0	29.4	8.9	5.9	11.8
Average for all biomass plots		12.1 **[e]	43.1 *	0.0 NS	38.2 **	6.6 NS	8.8 *	10.2 ***
CON-1[d]	1	0.0	20.0	0.0	46.7	33.3	0.0	0.0
	2	0.0	33.3	0.0	60.0	6.7	0.0	0.0
Average		0.0	26.6	0.0	53.4	20.0	0.0	0.0
CON-2	1	0.0	27.3	0.0	72.7	0.0	0.0	0.0
	2	0.0	40.9	0.0	59.1	0.0	0.0	0.0
Average		0.0	34.1	0.0	65.9	0.0	0.0	0.0
CON-3	1	0.0	46.7	0.0	40.0	13.3	6.7	0.0
	2	0.0	40.0	0.0	40.0	20.0	6.7	0.0
Average		0.0	43.3	0.0	40.0	16.7	6.7	0.0
Average for all conventional plots		0.0 **	34.7 *	0.0 NS	53.1 **	12.2 NS	2.2 *	0.0 ***

[a] Deep gouge = 5 to 25 cm depth
Very deep gouge = over 25 cm depth

[b] "Other" category includes yarding disturbances and windthrow

[c] BIO = biomass harvested

[d] CON = conventionally harvested

[e] * indicates that the average values for the biomass and conventional plots are significantly different at the α=0.1 level; ** indicates significance at the α=0.05 level and *** indicates significance at the α=0.001 level. NS indicates that the average values are not significantly different.

(m^3/ha) show different results with respect to treatment effects. For this reason, the erosion volumes are considered more reliable estimates of erosion than are the erosion per area values.

The erosion bridge results indicated that deposition occurred on all of the plots except biomass plot 1 where erosion was observed (Table 7). Irrespective of whether deposition or erosion occurred, soil movement was greater (α=0.1) on the biomass plots in comparison to the conventional and unharvested plots. The unharvested plots showed deposition when in fact no soil movement was observed. This apparent deposition was the result of vegetation growth, and litter and organic matter accumulation. Another source of error is associated with the instrument itself which is accurate to within 0.5 cm of the true value. The erosion bridge data are considered too few to fully substantiate the magnitude of erosion or deposition within any of the plots. However, the data suggest that the greatest amount of erosion and deposition occurred on the biomass plots.

Discussion

The biomass harvested plots had a greater extent and degree of soil disturbance than did the conventionally harvested plots. Since a soil disturbance survey was not conducted before biomass harvesting occurred, the exact proportion of the soil disturbance on the biomass plots that was due to the additional harvesting is unknown. However, we can say that the percentage area in skidroads and skid trails, and in deep and very deep gouges was greater on the biomass plots than in the conventional plots. In addition, a greater proportion of the biomass plots was compacted. This would lead to an increase in overland flow and associated surface erosion on the biomass harvest areas.

Soil movement, as determined by the erosion bridge and sediment dam measurements, was greatest on the biomass plots. In general, the erosion bridges recorded deposition which indicates that not all of the material eroded within the plots reached the fabric dams. However, the erosion bridge data are not considered very reliable because of the small number of bridges per plot, and because of problems associated with litter accumulation and the stability of the instrument itself.

Table 5. Summary of depth-of-burn pin transects

Plot[a]	Area burned (%)	Average depth of burn[b] (cm)	(%)	Mineral soil exposure resulting from fire (%)
BIO-1	67	2.8	38	8.0
BIO-2	26	2.8	19	0.0
BIO-3	39	3.2	27	0.0
Average	44 **[c]	2.9 NS	28 NS	2.7 NS
CON-1	75	2.3	38	4.0
CON-2	95	3.2	48	17.0
CON-3	80	1.9	28	0.0
Average	83 **	2.5 NS	38 NS	7.0 NS

[a] BIO = biomass harvested
CON = conventionally harvested

[b] Average depth of burn is calculated using burned locations only, and is the proportion of the total litter and duff that was consumed in the fire.

[c] ** indicates that the average values for the biomass and conventional plots are significantly different at the α=0.05 level; NS indicates that the average values are not significantly different.

The unharvested plots showed deposition in front of the fabric dams where in fact no soil erosion occurred. The effect of vegetation growth and decay, and the accumulation of organic matter is the reason for this observation. If we assume that this represents the background rate of deposition (although rates of vegetation growth and decay are expected to be different under clearcut conditions than under closed canopy conditions) then the erosion volumes for the biomass and conventional treatments are inflated. Over the entire duration of the study (1.77 years), the adjusted erosion volumes are 0.07 m^3 (0.22 m^3 - 0.15 m^3) for the conventional treatment and 0.23 m^3 (0.38 m^3 - 0.15 m^3) for the biomass treatment. The average plot area for the biomass and conventional treatments was used to obtain an average erosion rate of 0.37 m^3/ha/year and 0.78 m^3/ha/year for the conventional and biomass plots, respectively. These erosion rates compare favorably with surface erosion data obtained for clearcut and burned sites in Oregon's Willamette National Forest (Swanson *et al.* 1989), where surface erosion averaged 0.57 m^3/ha/year for slope gradients 31-60%, 2 years after treatment. However, these rates of erosion are low compared to surface erosion rates in areas where soil ravel occurs. For example, Bennett (1982) measured surface erosion at 22 m^3/ha/year on burned clearcuts with slopes less than 60% in certain areas of the Oregon Coast Range.

The Seller Creek site is rated as having a moderate to high surface erosion hazard. Based on general observations made in the field, it appears that the nature of the coarse fragments precluded much erosion. The coarse fragments, derived largely from shale parent material, were flat and extremely stable once exposed. They were observed to form an effective erosion pavement following initial erosion of the surface fines.

The rainfall simulation results indicate that overland flow on exposed mineral soil at Seller Creek (excluding main haul roads) will generally occur if

Table 6. Erosion volumes trapped behind fabric dams

Fabric dam[a]	Pre-fire (May/89) Δt = 0.62 years		Post-fire (July/89) 0.77 years		Final measure (July/90) 1.77 years		ΔEV (July/89—July/90) 1.0 years	
	(m^3)	(m^3/ha)	(m^3)	(m^3/ha)	(m^3)	(m^3/ha)	(m^3)	(m^3/ha)
BIO-1	0.11	0.65	0.08	0.47	0.45	2.65	0.37	2.18
BIO-2	0.21	1.54	0.16	1.18	0.36	2.65	0.20	1.47
BIO-3	0.07	0.36	0.11	0.57	0.33	1.71	0.22	1.14
Average	0.13 A[b]	0.85 A	0.12 A	0.74 A	0.38 A	2.34 A	0.26 A	1.60 A
CON-1	0.15	3.41	0.21	4.77	0.34	7.73	0.13	2.95
CON-2	0.09	0.46	0.09	0.46	0.24	1.22	0.15	0.77
CON-3	0.05	0.63	0.04	0.50	0.09	1.13	0.05	0.63
Average	0.10 A	1.50 A	0.11 A	1.91 A	0.22 B	3.36 A	0.11 B	1.45 A
UN-1	0.02		0.02		0.17		0.15	
UN-2	0.04		0.03		0.07		0.04	
UN-3	0.06		0.06		0.21		0.15	
Average	0.04 A		0.04 A		0.15 B		0.11 B	

[a] BIO = biomass harvested
CON = conventionally harvested
UN = unharvested control

[b] Means followed by the same letter are not significantly different at the α=0.10 level (Student-Newman-Keuls multiple comparison test).

the rainfall intensity or snow melt rate exceeds about 1.5 cm/hour. Where machine travel has not occurred, the infiltration capacity remains high, especially if the humus layer is still intact. Infiltration rates tend to vary both in time (e.g., seasonal variation (Johnson and Beschta 1981)) and space (e.g., due to heterogeneity in soil properties such as bulk density, coarse fragment content and macropores); therefore, this result only provides an estimate of the expected site response. In general, little evidence of overland flow and surface soil erosion was observed at Seller Creek. The exception was along compacted sections of skidroads (oriented in a downhill direction) where evidence of overland flow in the form of rills and small channels was observed following spring snow-melt.

Rainfall intensities greater than those expected to cause overland flow (1.5 cm/hour) occurred three times during the study period (thunderstorms in summer and early fall). The largest rainfall event had a return period of about 2.3 years, and storms with greater return intervals would eventually occur which could result in more serious surface erosion. Spring snow melt, especially if associated with rain-on-snow events, could result in higher rates of water delivery to soil (Harr and Coffin 1992) and significant overland flow and surface erosion. Snow melt was not measured in this study and the erosion bridge and fabric dam measurements were too infrequent to determine the specific effect of snow melt runoff on erosion.

Table 7. Erosion bridge results

	Average of three bridges for each plot[b]		
Plot[a]	pre-fire	post-fire	final measure
BIO-1	-4.52	-5.68	-5.29
BIO-2	0.57	1.94	2.99
BIO-3	5.49	6.13	6.72
Average	3.53 A[c]	4.58 A	5.00 A
CON-1	1.48	2.64	3.28
CON-2	1.57	0.49	2.21
CON-3	0.87	0.14	1.00
Average	1.31 A	1.09 B	2.16 B
UN-1	1.12	1.41	1.91
UN-2	1.50	1.71	2.92
UN-3	1.12	1.65	2.86
Average	1.25 A	1.59 B	2.56 B

[a] BIO = biomass harvested
CON = conventionally harvested
UN = unharvested control

[b] Change in surface elevation in centimetres. Biomass plot 1 is the only plot for which a decrease in surface elevation (erosion) was observed; all other plots recorded an increase in surface elevation (deposition).
The average values were calculated without reference to whether aggradation of degradation occurred, i.e., deposition and 'erosion' are both viewed as active forms of overall erosion.
The time periods are the same as for Table 6.

[c] Means followed by the same letter are not significantly different at the α=0.10 level (Student-Newman-Keuls multiple comparison test).

Conclusions

Biomass harvesting at Seller Creek resulted in a greater extent and degree of soil disturbance and a greater amount of surface soil erosion than did the conventional harvest treatment. In absolute terms, the biomass harvest plots accumulated nearly twice the erosion volume (0.38 m^3) than the conventional harvest plots (0.22 m^3) over the course of the study, and this volume included some organic matter. The relatively low erosion rates are attributed to site factors such as a soil texture having a high infiltration rate, and a relatively high percentage of flat, coarse fragments derived from a shale parent material that was conducive to the formation of an erosion pavement. The type of coarse fragments present at a site should be recognized as an important factor in surface erosion hazard keys. Climatic parameters such as low rainfall intensities and a relatively low total annual precipitation also contributed to the observed response.

A number of recommendations regarding the use of similar measurement techniques in future studies can be made:

(1) Sediment dams are a useful technique for comparing the gross erosional response of different treatments. However, they cannot be expected to provide an accurate measure of soil erosion, especially when small erosion volumes are involved. Because the unharvested plots indicated that accumulation of material was taking place (where in fact no mineral soil erosion occurred), the nature of the eroded material trapped by the fabric dams must be determined. On a practical level, the pins used to measure the erosion volumes should be made of sufficiently large diameter and be installed to an adequate depth to minimize movement. This is especially the case in areas characterized by heavy snowfall.

(2) The exact accuracy of the erosion bridge measurements is unknown due to a number of complicating factors such as vegetation growth and decay, the potential influence of freeze-thaw cycles on soil density, and the possible movement of the metal rods. The number of erosion bridge measurements in relation to the plot size will determine to a large degree the usefulness of this technique. In this study, too few erosion bridges were installed to fully define the erosional response within the plots.

(3) The rainfall simulator employed in this study was designed for use on small areas. A site's response to a rainfall or snow melt event is dependent on the interaction between site factors (e.g., antecedent soil moisture, slope gradient, topography) and climatic parameters (e.g., rainfall intensity and duration). A small-scale portable rainfall simulator cannot fully simulate all of the conditions under which rainfall and infiltration normally occur. However, rainfall simulation is still very useful in determining point measurements of soil infiltration capacity under defined conditions.

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APPENDIX Precipitation data for 1988/89 and 1989/90 water years

1988/89 WATER YEAR (Oct/88 to Sept/89) (mm)

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Oct. (45)	0	0	0	0	0	0	0	0	0	0	0	.1	11	9	4	7	.1	.1	.6	0	3	1	3	0	.7	.1	0	0	.3	0	5
Nov. (31)	12	2	7	0	10	0	0	0	0	.6	0	.1	.1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
November 15 to April 11/89 - average snowpack water equivalent = 318 mm																															
April (12)	-	-	-	-	-	-	-	-	-	-	-	0	0	1	0	0	0	0	2	8	0	9	0	0	0	0	0	0	0	0	
May (81)	0	0	0	0	.6	.8	0	0	5	10	7	.7	0	0	.3	4	8	14	.9	0	0	0	3	2	5	21	0	0	0	0	0
June* (44)	0	0	0	0	0	<---------------- 18.0 ---------------->								2	0	0	0	0	1	9	1	2	11								
July (78)	15	.6	.1	4	2	2	.7	2	11	13	2	1	2	0	15	0	.5	0	0	0	2	.4	6	0	0	.4	0	0	0	0	0
Aug. (103)	.1	24	.7	0	0	0	0	.3	1	0	0	0	3	.5	18	.2	0	11	.8	15	13	7	.5	1	0	0	0	0	0	6	1
Sept. (39)	11	0	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	.1	0	0	0	0	0	7	0	0	5	.5	

Estimated Total Precipitation for 1988/89 Water Year (October 1/88 - September 30/89) = 751 mm.
Precipitation in the form of snow accounted for 42% of the total precipitation.

1989/90 WATER YEAR (Oct/89 to Sept/90) (mm)

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Oct. (52)	.1	0	0	.6	1	0	0	0	.1	16	1	2	0	2	2	.6	2	4	0	1	.1	3	4	7	1	4	0	.1	0	0	.1
Nov. (35)	0	0	0	.9	.1	0	0	3	31	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
November 16/89 to March 28/90 - average snowpack water equivalent = 446 mm																															
March	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
April (55)	0	0	0	0	0	0	0	0	0	0	4	.1	2	3	0	0	5	0	9	0	.5	4	11	4	0	6	5	1	0	0	
May (48)	2	0	0	0	0	.1	2	0	0	0	.3	0	0	0	0	2	2	.1	.5	2	.5	3	3	2	5	.3	0	1	11	3	8
June (85)	0	1	15	3	3	0	6	1	1	11	16	2	0	0	0	0	2	2	2	2	0	0	0	.1	1	2	3	7	.5	4	
July (36)	1	6	4	.1	3	.2	1	8	0	0	.3	.3	0	0	0	0	0	1	0	0	0	0	3	8	0	0	0	0	0	.1	.1
Aug. (66)	0	.2	0	0	0	0	0	0	0	0	0	0	4	0	0	0	6	0	0	0	5	5	3	.1	3	7	0	0	2	19	12
Sept. (10)	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	.1	0	0	0	0	0	0	0	0	0	0	0	0	

Estimated Total Precipitation for 1989/90 Water Year (October 1/89 - September 30/90) = 833 mm.
Precipitation in the form of snow accounted for 54% of the total precipitation.

Note: The rainfall values are averages of 2 tipping bucket rain gauges.
Monthly totals are indicated in parentheses beside each month.
Snowpack water equivalent (WE):

- November 15/88 to April 11/89 - measured April 12; average WE was 338 mm for the conventional plots, 298 mm for the biomass plots, and 232 mm for the unharvested control plots.
- November 16/89 to March 28/90 - measured March 28; average WE was 471 mm for the conventional plots, 420 mm for the biomass plots, and 377 mm for the unharvested control plots.

* Missing data for the period June 6-20/89. Estimate based on nearest station - Likely Ranger Station.