Soil erosion studies using rainfall simulation on forest harvested areas in British Columbia

PAUL R. COMMANDEUR

Forestry Canada, Pacific Forestry Centre, 506 West Burnside Road, Victoria, BC, Canada V8Z 1M5

Abstract A field portable rainfall simulator was employed to determine the infiltration and soil erosion response of forest harvested areas (skidroads, fireguards and slash burned sites) in coastal and interior British Columbia. The results indicate that infiltration capacity decreases as total bulk density and coarse fragment content increase. The suspended sediment concentration of the overland flow was found to increase as the volume of the runoff increased. However, variability in suspended sediment concentrations was high for the highest runoff volumes which suggests that other factors such as soil texture, slope gradient and surface armouring also have important effects. Future work will investigate the role of soil texture on infiltration and soil erosion.

INTRODUCTION

Soil erosion on forested land in British Columbia is a serious concern that can have both on-site and off-site detrimental effects. The impacts of erosion on stream resources in the form of fisheries habitat and water quality degradation have received the most attention. Perhaps equally important are the on-site effects including forest road damage, and soil degradation and resulting reduction in site productivity. Surface erosion is mainly associated with bare mineral soil surfaces such as haul roads, skidroads and other bladed or otherwise exposed areas of mineral soil. Numerous studies have made use of artificial rainfall to study infiltration and surface soil erosion on both forest and agricultural land, both in the field and in the laboratory (Luk *et al.*, 1986; Meeuwig, 1971; Munn & Huntington, 1976, Roth *et al.*, 1985; Wilson & Rice, 1990). The major advantage of rainfall simulation research is that it is more rapid, efficient, controlled and adaptable than natural rainfall research (Meyer, 1988). In this study, a field portable rainfall simulator was employed to determine the infiltration capacity and potential surface erosion response of disturbed sites.

METHODS

During the summer of 1990, rainfall simulation experiments were conducted at

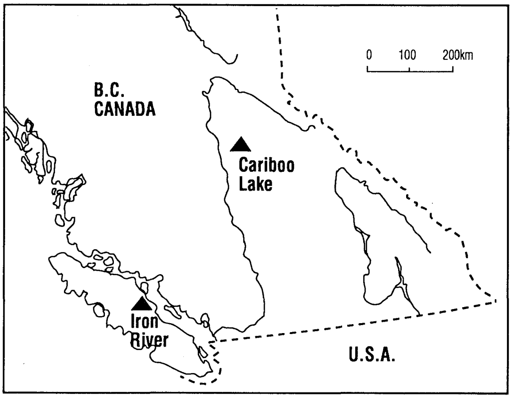

Fig. 1 Location of the field study sites.

a site in coastal British Columbia (Iron River) and at a location in the interior of the province (Cariboo Lake) (Fig. 1). The Iron River site is one of five sites chosen to study the effects of wide-tyre skidder traffic on forest soils (Rollerson 1989). On this site, which was treated during the spring of 1988, five plots each were located on the 5, 20 and 80 skidder pass trails (track and mid-track locations) for a total of 15 rainfall simulation experiments. The Cariboo Lake location consists of two sites: a winter skidder logged area (1987/1988) where experimental biomass harvesting (summer 1988), and prescribed fire (summer 1989) treatments were conducted (Cariboo-1); and a summer logged cutblock (summer 1988) where bladed skidroads were employed (Cariboo-2). At the Cariboo-1 site, two plots were located on skidroads, two on fireguard surfaces (bladed roads designed to contain prescribed fires), and one on an intensively prescribe-burned site (complete consumption of the forest floor). The five plots established at the Cariboo-2 site were located on bladed skidroads (track to mid-track locations). Table 1 lists the characteristics of the plots sampled at each site.

Soil bulk density for the 0-10 cm depth was measured at each plot using either the excavation method (sand cone) or a nuclear densiometer (Troxler model 4311). A sub-sample of 10 soils demonstrated that a high correlation exists between the two measures of soil bulk density at these sites (r = 0.97). Soil samples were collected from the 0-10 cm depth and analysed for coarse fragment content and soil texture. The pre-test soil moisture content was determined by collecting gravimetric samples from around the perimeter of the plot prior to the beginning of the test.

A number of simple linear regressions were performed on the combined Cariboo Lake and Iron River data, using infiltration capacity and the suspended sediment concentration of the runoff as dependent variables, and total bulk density, coarse fragment content, pre-test soil moisture content, volume of runoff, and silt content (%) as independent variables. A number of other variables were not significant in explaining variation in infiltration capacity or suspended sediment concentration i.e. fine ($<$2 mm) soil density, vegetation

Table 1 Site characteristics.

	Iron River	Cariboo-1	Cariboo-2
Biogeoclimatic zone/subzone[a]	CWH	ICHh2/ESSFh[c]	ICHh2
Elevation (m)	820	1200	900
Slope gradient (%)	15-35	10-60	25-30
Soil classification	Podzols	----------Brunisols/Luvisols----------	
Soil texture[b]	L	SL-SiL	SL-L
Coarse fragment content (% by volume > 2 mm)	7-25	32-44	18-45
Vegetation cover (%)	0-20	0-70	0-12

[a] CWH = Coastal Western Hemlock; ICHh2 = Interior Cedar-Hemlock (Cariboo River variant); ESSFh = Englemann Spruce-Subalpine Fir (h subzone).
[b] L = loam, SL = sandy loam, SiL = silty loam.
[c] BC Ministry of Forests (1987).

cover, slash cover, slope gradient, and clay content (%).

DESCRIPTION OF THE RAINFALL SIMULATOR

The rainfall simulator was designed and constructed at the Pacific Forestry Centre and field tested during the summer of 1989 (Fig. 2). It consists of an air-tight chamber constructed out of heavy gauge aluminum (76.5 × 76.5 × 5.5 cm) and equipped with 324 Teflon capillary tubes (0.56 mm inside diameter) arranged in a grid pattern. Adjustable telescopic legs are fastened to the chamber by means of U-shaped brackets. With the legs fully extended (2.7 m above the

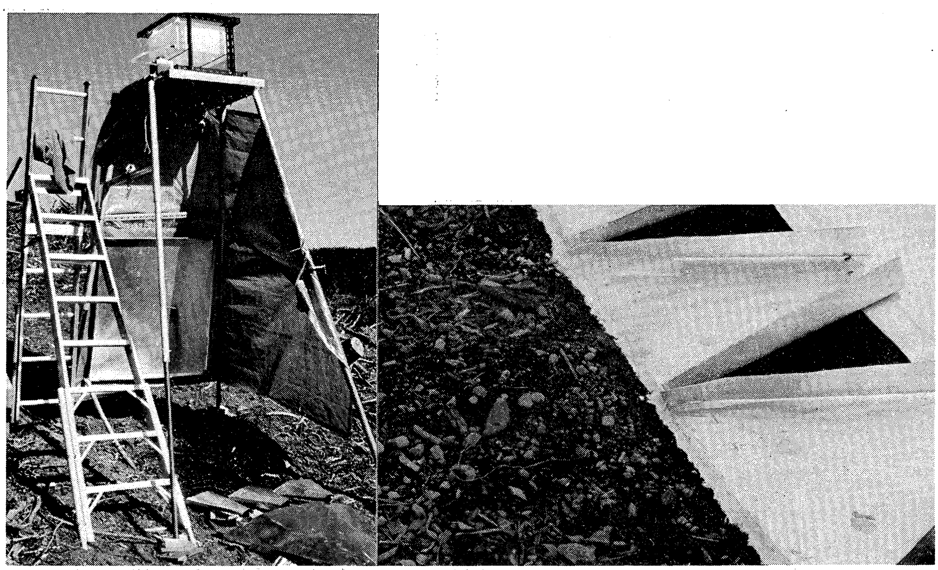

Fig. 2 Rainfall simulator and overland flow collection system.

ground), the rainfall produced attains 75% of the terminal velocity of similar sized (3 mm) raindrops (Epema & Riezebos, 1983). A 36-litre reservoir tank is held in place above the chamber by means of a frame constructed out of angle iron. Flexible PVC tubing connects the reservoir to an in-line flow meter (1 l min^{-1} capacity), and connects the flow meter to a valve which is attached to the rainfall chamber. The reservoir tank is fitted with a constant head device (a piece of rigid tubing inserted through the top of the tank and extending almost to the bottom) to maintain the pressure within the tank at a constant level. At a rainfall intensity of 4.5 cm h^{-1}, rain can be applied for up to 75 min.

A set of three overland flow collection troughs (30 cm across) are installed a few centimetres below the first row of drop formers (determined by means of a plumb bob), and placed perpendicular to the slope. Each trough, equipped with a bent lip, is pushed tightly against the soil, held in place with spikes and sealed against the soil with fast setting plaster. A larger trough collects the flow from the three smaller troughs and directs the flow to a collection can. A set of nine cans (12.5 cm diameter) arranged in a grid pattern is used to determine rainfall uniformity and to calibrate the flow meter. An average coefficient of variation (C_V = standard deviation/mean × 100%) of 8.9% was calculated for a sample of eight calibration runs.

During a test, the rainfall rate is kept constant and overland flow is collected and the volume measured every 2.5-5 min depending on the volume of runoff. The infiltration rate (cm h^{-1}) is derived using the difference between the amount applied and the amount collected with the overland flow troughs over the selected time period. These values are plotted as a function of time (Fig. 3). The infiltration capacity for a plot is defined as the equilibrium infiltration rate and is estimated from the graph by projecting the horizontal asymptotic value. Because the tests were designed to provide an index of the potential for soil erosion, the plots were not pre-wetted to attain the saturated soil conditions under which infiltration capacity is normally determined. The objective was to determine the typical soil response to high intensity rainfall events and therefore

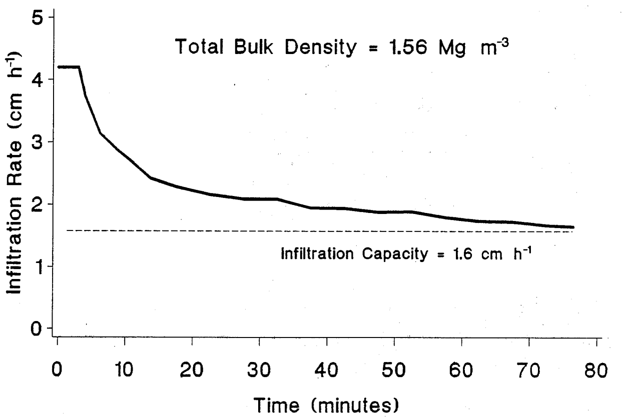

Fig. 3 Typical soil infiltration curve (Cariboo-1, skidroad surface).

the soils were tested "as is". Soil moisture contents (by weight) were found to range from 13 to 37% at the Cariboo Lake sites, and from 28 to 56% at Iron River.

RESULTS

The regression of infiltration capacity versus total bulk density is very significant ($p = 0.0001$) and bulk density alone explains 50% of the variability in infiltration capacity (Fig. 4). As expected, the relationship is one of decreasing infiltration with increasing density. However, the regression of infiltration capacity on coarse fragment content, significant at the $\alpha = 0.01$ level ($r^2 = 0.384$), is also one of decreasing infiltration capacity with increasing coarse fragment content. The reason for this unexpected result appears to be the high positive correlation between total bulk density and coarse fragment content ($r = 0.914$), which ensures that the two relationships behave in a similar way. The regression of infiltration capacity versus pre-test soil moisture content, significant at the $\alpha = 0.05$ level, indicates that infiltration capacity increases as moisture content increases. This may be an artifact of combining the data, because the Cariboo Lake plots were drier (late June) and generally denser, whereas the Iron River plots tended to be wetter (late May) and had lower soil densities (and therefore higher infiltration capacities).

Suspended sediment concentration was regressed against total bulk density, coarse fragment content, runoff volume, and vegetation cover. Only runoff volume ($p = 0.0063$, $r^2 = 0.282$) helped to explain the variation in the observed suspended sediment concentrations (Fig. 5). Not surprisingly, concentrations increase as runoff increases. It should be noted that the variability of the suspended sediment concentrations increases as the runoff volume increases.

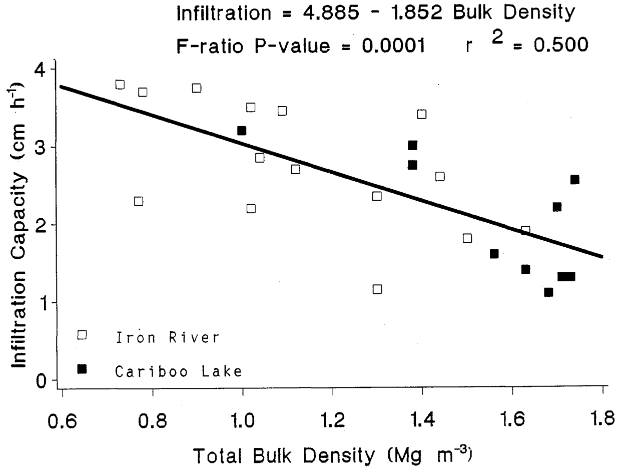

Fig. 4 Infiltration capacity regressed against total soil bulk density for the combined Cariboo Lake and Iron River data.

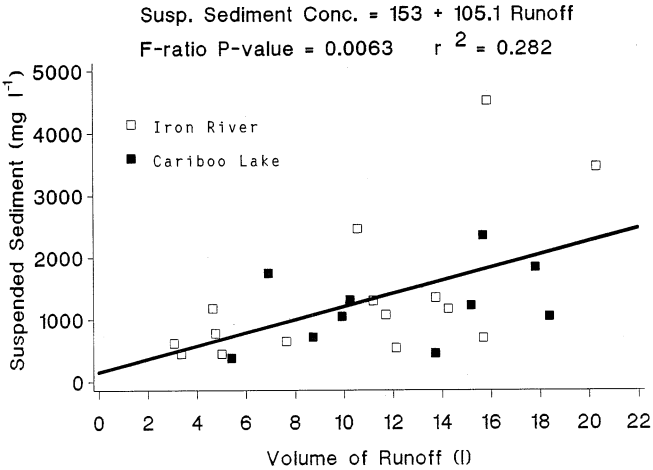

Fig. 5 Suspended sediment concentration regressed against volume of runoff for the combined Cariboo Lake and Iron River data.

Although not significant (p = 0.089), the regression of suspended sediment concentration versus vegetation cover suggests a trend of decreasing suspended sediment concentration with increasing vegetation cover which seems intuitively correct.

The Iron River data were analysed separately for suspended sediment concentrations. The regression against runoff volume is more significant than for the combined data (p = 0.0128): runoff volume explains 39% of the variability in the concentration of suspended sediment. To determine if soil texture affected the amount of soil eroded and transported by runoff, the suspended sediment concentrations were regressed against clay content and silt content. The regression versus silt content is significant (p = 0.0127) and explains 39% of the variability in concentration, whereas the regression versus clay content is not significant. The range in silt content for the soils at Iron River is relatively small (33-44%) and these results need to be confirmed for other sites and soil textures.

In addition to the rainfall experiments described above, a test was undertaken on a harvested and slash-burned, but otherwise undisturbed, location at Cariboo-1 (duff layer 6 cm deep, vegetation cover 20%). The results of this test confirmed expectations of high infiltration capacities on such sites (>7.5 cm h^{-1}).

DISCUSSION

The data clearly indicate a strong relationship between the infiltration capacity of exposed mineral soil surfaces and the total bulk density in the 0-10 cm surface layer. In addition, the almost equally strong relationship between infiltration capacity and coarse fragment content, and the high positive correlation between bulk density and coarse fragment content, suggest that coarse fragment content could be used as a reasonable surrogate property for determining the expected soil infiltration response. This would necessitate the development of site-specific infiltration/coarse fragment content predictive models. The variation in coarse fragment content for the soils in this study was between 5 and 45%. Soils with higher coarse fragment contents could very well behave differently.

The concentration of suspended sediment in the plot runoff was shown to be related to total runoff volume, and both the Iron River and Cariboo Lake sites appear to behave similarly in this respect. However, for the highest runoff volumes, the variability in suspended sediment concentration increases, which suggests that a simple linear model may not be the most appropriate. For the Iron River data, soil texture (in the form of silt content) explained almost 40% of the variation in suspended sediment concentration. Additional field experiments will be required to define the relationship between sediment production and soil texture for British Columbia conditions more fully. Numerous additional parameters would be expected to affect the suspended sediment concentration of runoff, such as slope gradient, surface armouring and organic matter content.

The statistical analyses conducted on the Iron River data alone (n = 15) demonstrated that variability within this site is lower than when the data are grouped with the Cariboo Lake data. This emphasizes that infiltration, runoff and surface soil erosion are processes that can be affected by site-specific factors, which must be clearly identified before predictive models can be developed.

The role of soil moisture content in influencing infiltration capacity is not well defined in this study because of the confounding effects of combining the data from two study locations. However, soil moisture content is expected to affect the infiltration response observed at a site. This is supported by Johnson & Beschta (1981) who reported on variation in infiltration capacities due to seasonal fluctuations in soil temperature and moisture levels.

FUTURE WORK

Additional skidroad impacted sites located in southeast British Columbia were examined during the summer of 1991, with the specific objective of sampling a range of soil textures. The experimental technique was changed to accommodate a second hour of rainfall to test the hypothesis that erosion slows down as surface fines are washed away. In addition, a micro-trench experiment was added at each plot to look at the effect of concentrated flow within a rill-sized feature. The data will be analysed and the results will be used to refine a surface erosion hazard key contained in a field handbook (Lewis & Carr, 1989), devised to assist forest managers in minimizing forest site degradation in the interior of British Columbia.

Acknowledgements The author would like to thank Brian Sieben and Ed Wass for their assistance with the field component of this study, and Steve Glover and Eugene Hetherington for their review comments.

REFERENCES

BC Ministry of Forests (1987) *A Field Guide for the Identification and Interpretation of Ecosystems of the Cariboo Forest Region* (revised edn). Research Section, Williams Lake, BC.

Johnson, M. G. & Beschta, R. L. (1981) Seasonal variation of infiltration capacities of soil in western Oregon. *USDA Forest Service, Research Note PNW-373.*

Epema, G. F. & Riezebos, H. Th. (1983) Fall velocity of waterdrops at different heights as a factor influencing erosivity of simulated rain. In: *Rainfall Simulation, Runoff and Soil Erosion* (ed. by J. de Ploey), 1-17. *Catena Supplement* **4**, Braunschweig.

Lewis, T. & Carr, W. W. (1989) Developing timber harvesting prescriptions to minimize site degradation- interior sites. *Land Management Handbook Field Guide Insert*, Timber Harvesting Subcommittee, Interpretation Working Group, BC Ministry of Forests.

Luk, S., Abrahams, A. D. & Parsons, A. J. (1986) A simple rainfall simulator and trickle system for hydro-geomorphological experiments. *Phys. Geogr.* **7**(4), 344-356.

Meeuwig, R. O. (1971) Infiltration and water repellency in granitic soils. *USDA, Forest Service, Research Paper INT-111.*

Meyer, L. D. (1988) Rainfall simulators for soil conservation research. In: *Soil Erosion Research Methods* (ed. by R. Lal), 75-95. Soil and Water Conservation Society, Ankeny, Iowa, USA.

Munn, J. R. & Huntington, G. L. (1976) A portable rainfall simulator for erodibility and infiltration measurements on rugged terrain. *Soil Sci. Soc. Am. J.* **40**, 622-624.

Rollerson, T. P. (1989) *Effects of Wide-tyre Skidder Traffic on Several Vancouver Island Soils.* MacMillan Bloedel Ltd, Woodland Services Division, Land Use Planning Advisory Team, Nanaimo, BC.

Roth, C. H., Meyer, B. & Frede, H.-G. (1985) A portable rainfall simulator for studying factors affecting runoff, infiltration and soil loss. *Catena* **12**, 79-85.

Wilson, B. N. & Rice, C. T. (1990) An indoor soil erosion research facility. *J. Soil & Water Cons.* **45**(6), 645-648.