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EFFECTS OF FOREST HARVESTING ON THE HYDROLOGIC REGIME OF CARNATION CREEK EXPERIMENTAL WATERSHED:

A PRELIMINARY ASSESSMENT

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ABSTRACT

Preliminary results are given for two small, west coast watersheds characterized by rugged terrain, an old growth coniferous forest, heavy rainfall and flashy runoff. Following successive clearcuts covering 40% and prescribed burning on 20% of Carnation Creek watershed, there was no clear evidence of changes in storm runoff but annual water yield and summer low flows apparently decreased in some years. Valley bottom groundwater levels were higher. In a smaller tributary watershed which was 90% clearcut and 35% burned, annual water yield, summer low flows, and peak flows increased, while the time-to-peak hydrograph characteristic decreased. On steep side slopes, peak groundwater levels changed after both road construction and harvesting.

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RESUME

Les résultats préliminaires sont presentés pour deux petits bassins de la côte ouest, caractérisés par un terrain montagneux, une forêt de conifères surannés, de fortes pluies et un ruisellement rapide. Suite à des coupes à blanc successives couvrant 40% et un brûlage controlé sur 20% de la superficie du bassin Carnation, les débits de crue ne semblent pas avoir changés, tandis que l'écoulement annuel et les débits d'étiage ont apparamment diminués durant quelques années. Les niveaux de l'eau souterraine dans la plaine alluviale furent plus élevés. Dans un petit bassin tributaire du premier, avec 90% de la superficie coupée à blanc et un brûlage controlé sur 35%, l'écoulement annuel, les débits d'étiage et les débits de pointe ont augmenté, tandis que les temps de montée des hydrogrammes de crue ont diminué. Sur les pentes fortes de ce bassin, les niveaux de pointe de l'eau souterraine ont changé suite à la construction des chemins et encore plus après la coupe.

INTRODUCTION

The Carnation Creek Experimental Watershed Project, initiated in 1970 by the federal Department of Fisheries and Oceans to study logging effects on a small west coast salmonid stream (Hartman 1981), included three periods: 5 years pre-logging calibration, 6 years logging and at least 3 years post-logging. Major emphasis was placed on investigating physical and biological processes of the aquatic system and the changes that follow clearcut harvesting. This paper describes the results of some preliminary analyses of logging effects on the hydrologic regime of the watershed: specifically, annual water yield, slope and valley bottom groundwater levels, storm hydrograph peak flow and time-to-peak characteristics, and summer low flows. The analyses focus on both the main creek and a small 12-ha tributary watershed.

The Carnation Creek project is the major of three longer-term watershed studies of logging effects on stream systems in coastal British Columbia (CNCIHD 1971, Cheng et al. 1975). Additional studies of logging impacts on coastal streams in Oregon (Rothacher 1973, Harr et al. 1975, Harr et al. 1979, Harr 1980) and California (Ziemer 1981) provide a context within which Carnation Creek results can be assessed.

STUDY AREA

Watershed characteristics

The Carnation Creek watershed is located on the west coast of Vancouver Island near Bamfield, British Columbia (Fig. 1). The basin area of 9.5 km^2 features rugged terrain from sea level to 880 m elevation with steep slopes, of 40 to over 80%, and a relatively wide valley bottom through which the main stream meanders. Slope soils, underlain by watertight bedrock of volcanic origin, are coarse colluvial materials of gravelly loam to loamy sand texture with a moderately thick organic layer and are classified as ferro-humic podzols (Oswald 1973). They are shallow, having an average depth of about 70 cm, remain moist year-round and are highly permeable. The valley bottom contains mostly alluvial sands and gravels. The forest is comprised of old growth western hemlock (Tsuga heterophylla (Raf.) Sarg.), amabilis fir (Abies amabilis (Dougl.) Forbes) and western red cedar (Thuja plicata Donn), with some Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) on drier sites, Sitka spruce (Picea sitchensis (Bong.) Carr.) in the valley bottom and red alder (Alnus rubra Bong.) along the stream margin (Oswald 1973).

Climate and streamflow

The climate of the watershed is influenced by the adjacent Pacific Ocean and features mild wet winters, characterized by frequent frontal storms, and mild summers. Annual precipitation is mostly rain and ranges from 210 to over 480 cm, over 75% falling in October-March (Fig. 2). Some snow occurs at higher elevations in most years but it usually disappears quickly. Annual

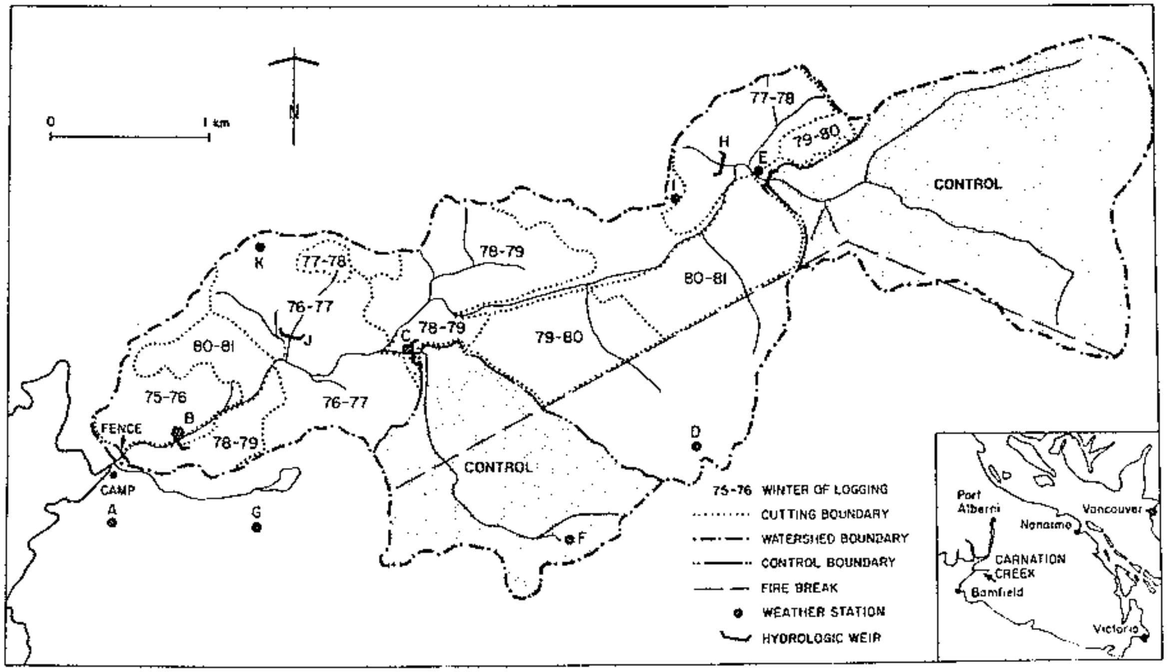

Figure 1. Carnation Creek watershed showing location of hydrometeorological stations and clearcut logging boundaries.

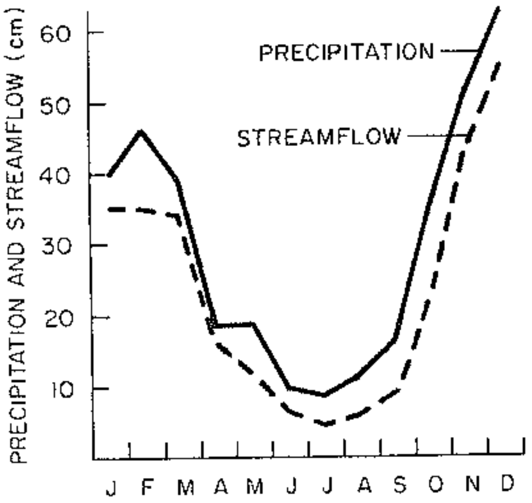

Figure 2. Average monthly precipitation at station F and streamflow at B weir expressed as a depth over the watershed (1973-1980).

water yields ranged from 210 to 400 cm and measured flows from less than 0.03 to 44.3 m^3/s. Streamflow closely followed the precipitation pattern (Fig. 2) and exhibited flashy storm runoff, although overland flow was rare in undisturbed areas. Precipitation was measured at 9 sites and streamflow at 5 weirs (Fig. 1). Characteristics of the gauged areas are given in Table 1. Watersheds C and E remained unlogged and served as controls for evaluating flow changes at the other weirs. Groundwater levels were also measured, using piezometers, in the main valley bottom southwest of J weir to monitor changes in summer recession characteristics, and on the slopes of H watershed to monitor changes in storm peaks (Symons 1978). To avoid damage, piezometers were cut to ground level and capped prior to logging.

Table 1. Characteristics of gauged watersheds in Carnation Creek basin.

Weir	Drainage Area (ha)	Elevation Range (m)
B	930	8-884
C	145	46-700
E	264	150-884
H	12	152-305
J	24	30-300

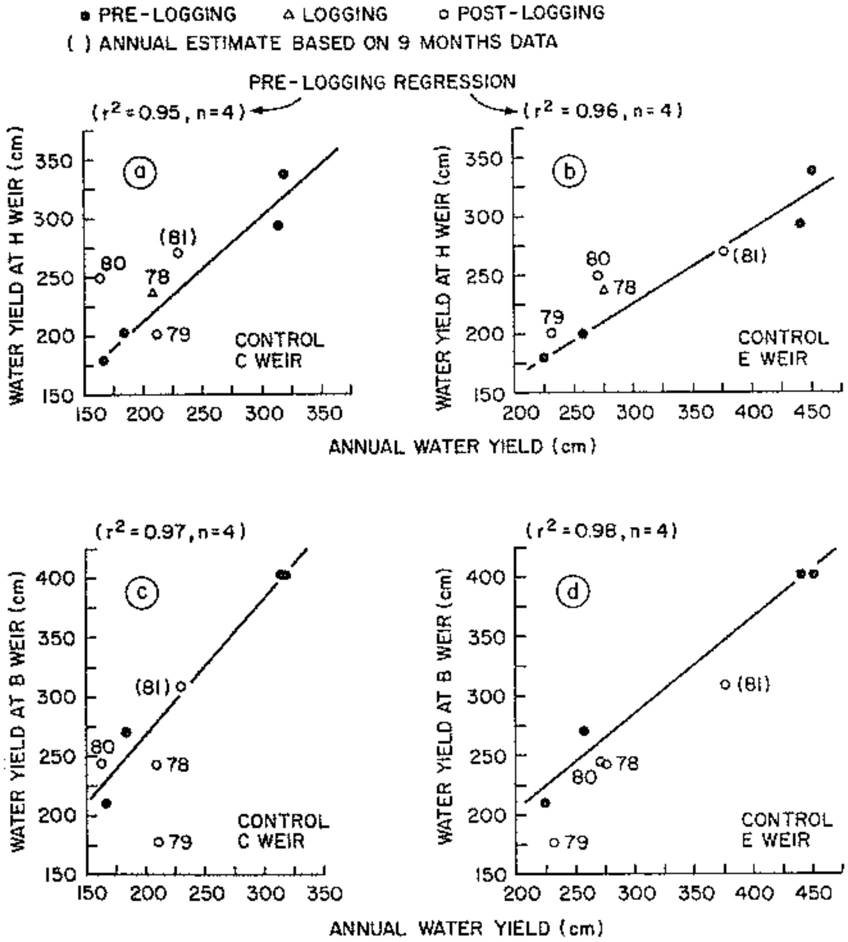

Figure 3. Relationships between annual water yields from the treated watersheds at H and B weirs and the controls at C and E weirs (based on water year).

Figures 3a, b and 4 are given in Table 3. These data suggest that annual water yield from H watershed increased by an average 36 cm or about 14% of total runoff in at least two of the three post-logging years.

For the logged watershed above B weir, most post-logging annual water yield values lie below the pre-logging regression lines (Fig. 3c, d). A comparison of B weir data with that from the other three weirs suggests that the 1978-79 value is about 40 cm too low. If this and the above-noted adjustments were made, only the 1980-81 points would not lie below the regression lines of Figure 3c, d. The data indicate an average decrease in annual water yield at B weir of at least 20 cm or about 8% of total runoff for three years, and a possible marginal increase in 1980-81, the last year of logging (Table 3).

Table 3. Estimated post-logging changes in annual water yield at H and B weirs and annual evapotranspiration for H watershed.

	Water Year			
Source	1977-78	1978-79	1979-80	1980-81
	cm			
H-weir				
Fig. 3(C)	17	-21(16)	71(41)	31
Fig. 3(E)	26	17	41	-3(31)
Fig. 4(ET)	20	38	36	-
B-weir				
Fig. 3(C)	-35	-103(-14)	21(-20)	5
Fig. 3(E)	-23	-53(-13)	-19	-39(6)

( ) adjusted value

All post-logging points fall within broad 95% confidence bands for all pre-logging regressions in Figures 3 and 4.

Storm runoff

Storm runoff is rapid in the Carnation Creek watershed. For example, streamflow increased from 2.5 to 44.3 m^3/s in only 7 hours in the maximum recorded storm at B weir. During another major mid-winter storm, streamflow in H watershed followed rainfall variations closely and quickflow was equivalent to over 90% of the precipitation (Fig. 5). Mid-slope groundwater levels also responded almost instantaneously to rainfall intensity fluctuations, with vertical soil-water flow rates exceeding 40 cm/hr (Fig. 5). From observations in soil pits and along road cut slopes, it appears that much of this rapid transmission of water from the surface to the groundwater table is through macro-channel networks which bypass the soil matrix. In this old growth coastal rain forest, these macro-channels are mainly decayed roots.

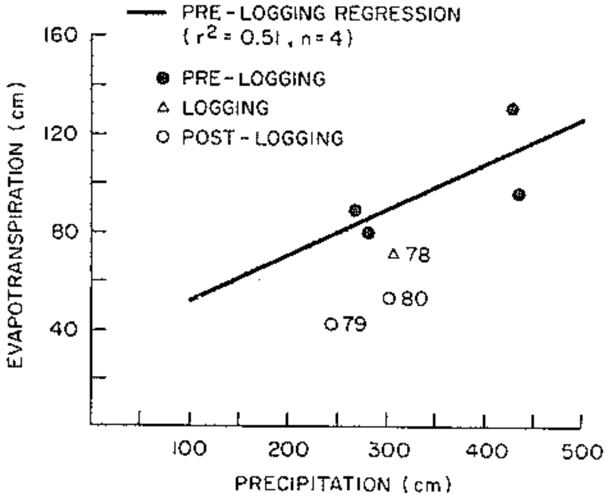

Figure 4. Relationship between annual precipitation and evapotranspiration for H watershed (based on water year).

Slope ground water levels

Peak groundwater levels at one site, located 30 m downslope from a road, decreased significantly after road construction and then increased after harvesting to near pre-logging values (Fig. 6). For example, a storm which produced a peak groundwater level of 40 cm at the below road site prior to logging activity, would have produced a peak level of only 21 cm after road construction (19 cm lower) but 37 cm after harvesting. A second site, located directly upslope 15 m above the road, showed no change after road construction but a significant increase after harvesting (Fig. 7), the increase being 24 cm for the same storm. These changes were some of the largest recorded in H watershed.

Peak Flows

In H watershed, peak flows increased significantly after road construction and harvesting (Fig. 8a, b), although the after-road regression with the control C was only significant at the 10% level. The average increase for both periods was 20%, being 11 and 30% after roads and 22 and 19% after logging in relation to controls C and E, respectively. At B weir, peak

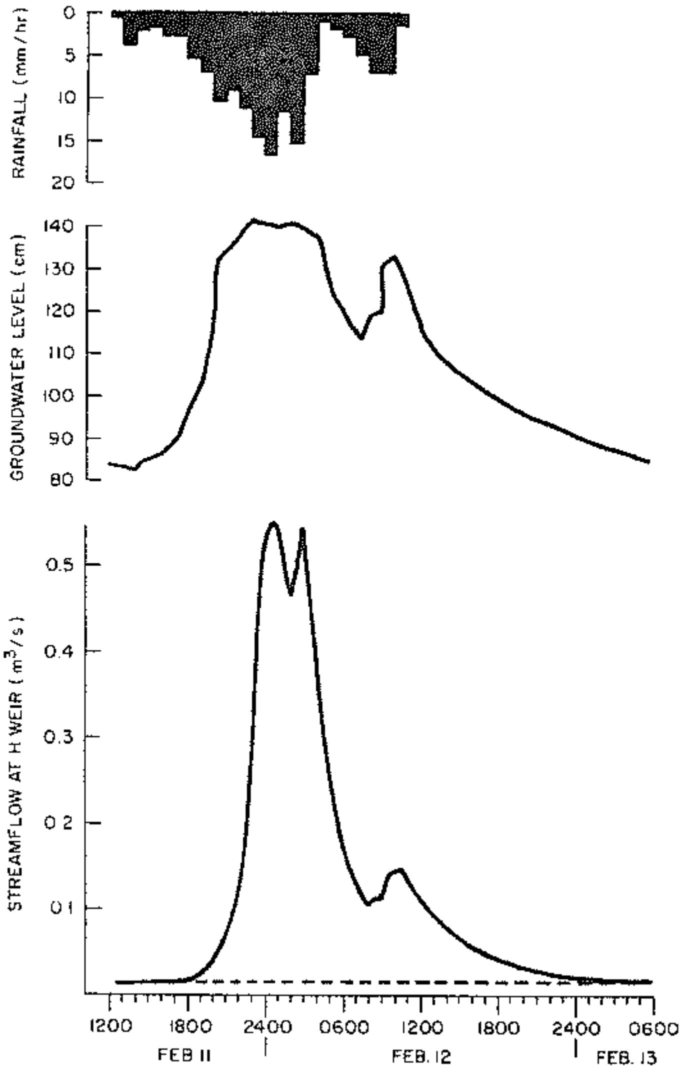

Figure 5. H-Creek streamflow hydrograph and mid-slope groundwater level response to rain storm of February 11-12, 1977.

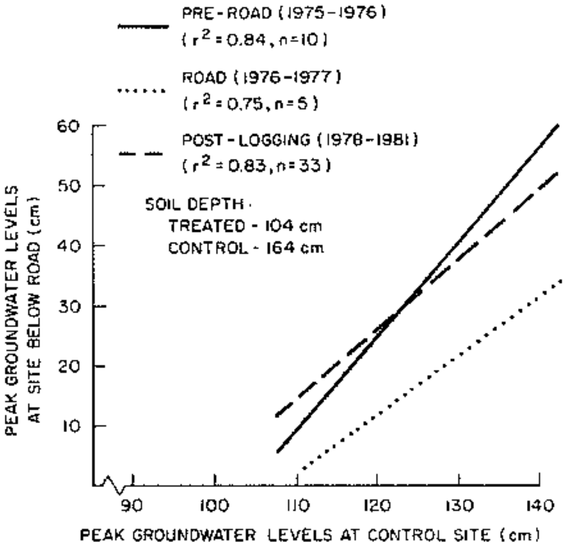

Figure 6. Relationships between peak slope groundwater levels in H watershed at a below road site and a nearby control site before roads, after road construction and after logging.

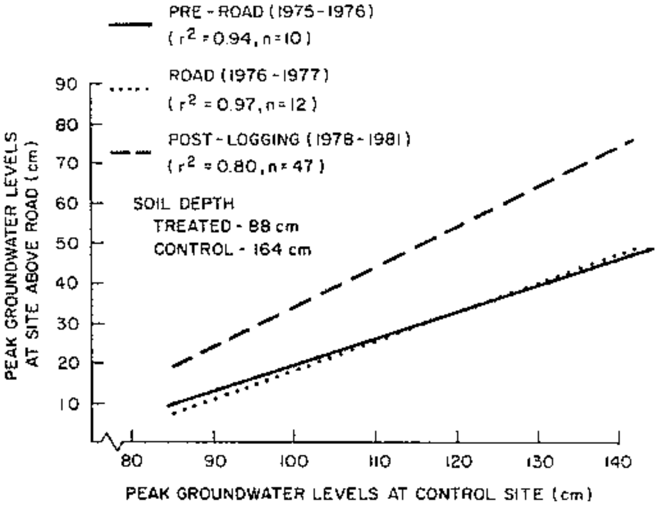

Figure 7. Relationships between peak slope groundwater levels in H watershed at an above road site and a nearby control site before roads, after road construction and after logging.

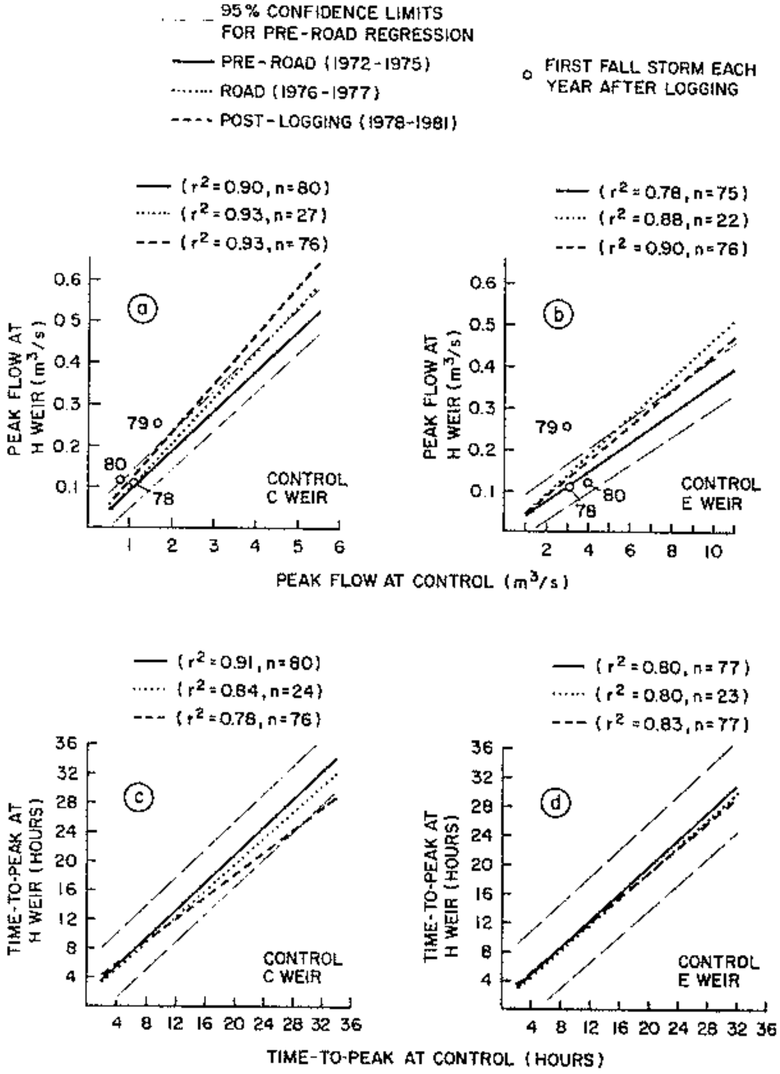

Figure 8. Relationships for peak flow and time-to-peak storm hydrograph characteristics between H watershed and control watersheds C and E (before logging, after roads and after logging).

flows showed no significant change overall (Fig. 9a, b), yearly post-logging regressions being nearly identical. Of the first major post-logging fall storm peaks in the logged watersheds, only the 1979 peaks were significantly different in relation to both controls, being an average 102% higher at H weir but 34% lower at B weir (Fig. 8 and 9).

Anomalies in annual water yield data for the two controls C and E have already been mentioned. To check for post-logging discrepancies in individual storm peaks, regressions linking control weir peaks in pre- and post-logging periods plus yearly post-logging regressions linking H weir peaks with those from both controls were fitted (not shown). Statistical tests revealed no significant differences among these regressions.

Time-to-peak

In H watershed, time-to-peak showed a progressive decrease after road construction and harvesting (Fig. 8c, d), although only the regressions on control C were significantly different for both mean and slope. For pre-logging time-to-peak durations of 5 to 30 hours, maximum decreases were 0.5 to 4.6 hours in relation to control C and 0.2 to 1.5 hours in relation to control E.

At B weir, time-to-peak both increased and decreased in relation to the two controls (Fig. 9 c, d). Only the slope of the 1980 regression with control C was significantly different, and that appears to be an artifact of the small number of data. There was thus no clear indication of the nature of changes, if any, in time-to-peak for Carnation Creek.

Valley bottom ground water levels

Summer groundwater levels in the alluvial valley bottom increased significantly after harvesting in the lower portion of the Carnation Creek watershed (Fig. 10). The 1977 and 1978 increases occurred after logging of the valley bottom upstream in 1976-77, while the further 1979 and 1980 significant increases resulted after logging and scarifying the surrounding area in 1978-79. The actual measurement site was not scarified. Groundwater level increases were up to 25 cm in 1977 and 1978, and 20 to over 45 cm in 1979 and 1980. During summer, valley bottom groundwater supplies about 30-40% of low flows.

Summer low flows

In H watershed, minimum daily summer flows increased by an average of at least 78% in 1978 and 1979 (Table 4), the first two post-logging years, but showed no change in 1980. The increases, based on comparisons with pre-logging regressions (not shown), are only statistically significant in relation to control E. The number of post-logging low flow days also decreased in relation to control E (Fig. 11) and control C (not shown). These decreases were greatest in 1978 and 1979, indicating higher low flows, but still fell within the 95% pre-logging confidence band.

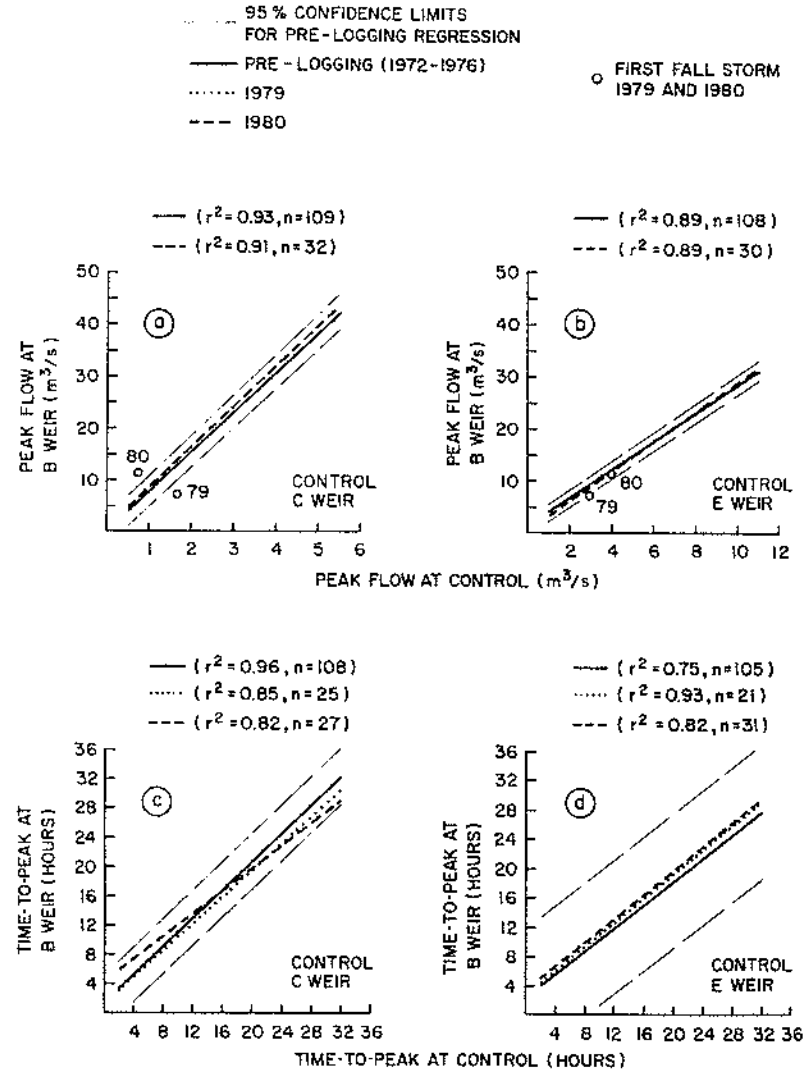

Figure 9. Relationships for peak flow and time-to-peak storm hydrograph characteristics between Carnation Creek watershed at B weir and control watersheds C and E (before logging, 1979 and 1980).

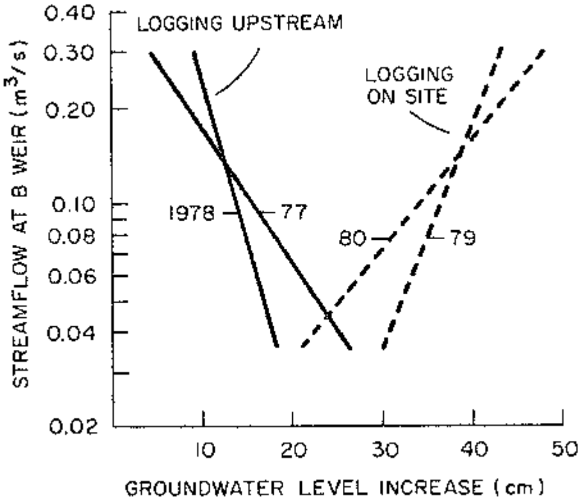

Figure 10. Post-logging relationships between increases in summer valley bottom groundwater levels at one site and streamflow at B weir (1977-1980).

Table 4. Changes in minimum daily summer flows between pre- and post-logging periods at H, B, C and E weirs.

	Minimum daily summer flow (l/s)						
	H	C	E		B	C	E
mean 1973-77	0.20	4.84	5.03	mean 1972-76	53.40	4.25	4.70
mean 1978-79	0.37	5.24	3.36	mean 77,79,81	40.06	6.18	5.74
change	0.17	0.40	-1.67	change	-13.34	1.93	1.04
%	(86)	(8)	(-33)	(%)	(-25)	(45)	(22)

At B weir, minimum daily summer flows apparently decreased by an average of at least 47% in 3 of the 5 post-logging years (Table 4), but showed little or no change in 1978 and 1980. The number of post-logging low flow days also increased in 1977 and 1979 in relation to control E (Fig. 11) and control C (not shown), indicating decreased low flows for these years. Complete 1981

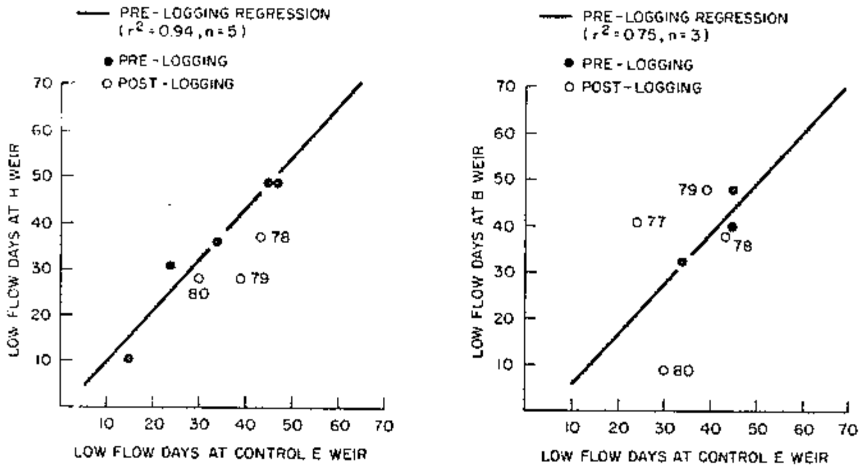

Figure 11. Relationships between low flow days for the logged watersheds at H and B weirs and the control at E weir.

flow data were not available for analysis. Although the 1980 minimum flow showed no change, the number of 1980 low flow days decreased, indicating overall increases in low flows that year. None of the B weir post-logging changes were statistically significant.

The data in Table 4 indicate that post-logging minimum flows were higher at control C relative to control E. However, pre- and post-logging comparisons of the broader range of low flows used to define low flow days did not show this discrepancy.

DISCUSSION

Forest harvesting reduces transpiration and interception losses, leaving more water available for streamflow. This explains the increased water yields and summer low flows in H watershed and the higher valley bottom groundwater levels. Slash burning and scarification augment changes caused by timber removal. Reduced fog interception (fog drip) by the forest canopy (Harr 1980) could explain in part the apparent decreases in water yield and summer low flows at B weir, summer fogs and low clouds being common on the outer west coast. Increased evaporation losses from the exposed, meandering stream would also occur. Yearly variations in summer low flow and water yield changes result from climatic variability, progressive increases in clearcut area and vegetation regrowth. The higher valley bottom groundwater levels should have increased summer low flows, but such increases were not detected.

In other clearcut coastal watersheds, increases in annual water yield of 20 cm (Harr et al. 1979) to 46 cm (Rothacher 1970) and minimum summer low flows of 60 to 400% (Rothatcher 1970, Harr and Krygier 1972, Harr et al. 1979) have been reported. Increases of 36 cm annual yield and 78% in minimum summer low flow were found for the 90% clearcut H watershed.

For partially clearcut watersheds, annual water yield increases of 17 and 9 cm were found for 30% (Rothacher 1970) and 38% (Harr et al. 1979) clearcuts. Rothacher (1970) also noted that increases were not statistically significant until over 40% of one watershed was logged. Harr et al. (1979) reported summer low flow increases of 65 and 44% for watersheds 30 and 50% cut over. For two 25% clearcut drainages, Harr (1980) found decreases of 6% in annual water yields and 15-20% in low flows which he attributed to reduced fog drip input. Apparent decreases of 8% in annual water yield and 47% in minimum summer low flows were found for Carnation Creek at B weir, although these results must be viewed with caution pending further assessment.

Roads intercept seepage water and precipitation, creating overland flow and speeding water delivery to the stream channel. This road effect was probably the main cause of increased peak flows and decreased time-to-peak in H watershed and seems to have reduced down-slope groundwater levels. Harr et al. (1979) reported increased peaks where roads occupied 5 to 12% of the drainage areas. Wetter soils in clearcuts than in forested areas, resulting from reduced evapotranspiration losses, would promote higher early fall peak flows, and possibly mid-winter peaks for smaller storms (Harr et al. 1979). While all of these processes may have occurred in the whole Carnation Creek watershed, their influence on storm hydrograph characteristics was not detected.

In other clearcut coastal watersheds, year-round peak flow increases of 35% (Harr et al. 1979) and 50% (Harr et al. 1975) were attributed to road effects, while an 18% increase was found in one watershed where roads were not an important factor (Harr et al. 1975). Early fall peak flow increases of 40-200% have also been reported (Rothacher 1973, Harr 1976). After soils become recharged in the fall, forested and clearcut areas on the coast tend to respond similarly. Little or no change in mid-winter or large magnitude peak flows was found in a number of other studies (Harris 1973, Rothacher 1973, Harr and McCorison 1979, Ziemer 1981). In H watershed, peak flows increased an average 20% and the first major fall peak increased 102% in one post-logging year.

For partially clearcut watersheds, peak flow increases of 10 and 11% were found for 25% (Rothacher 1973) and 30% (Harr et al. 1979) clearcuts. Ziemer (1981) reported early fall peak increases up to 107% for a 39% selection cut drainage, while Harr (1980) found no change in another 25% clearcut watershed. For Carnation Creek at B weir, no significant change in overall peak flows was found, although an apparent 34% decrease in one fall peak was noted. The reason for this decrease is not clear.

Mineral soil disturbance and exposure, resulting from yarding and slash burning, is the most likely cause of post-logging increases in peak slope groundwater levels. Scouring of surface soil layers could close the openings to water-conducting root channels. The slower water movement in the soil matrix would result in a higher localized groundwater table, producing temporary delayed water storage. De Vries and Chow (1978) documented this shift in flow pathway in a tensiometer plot study, while peak flow decreased 22% and time-to-peak increased in a clearcut coastal watershed with soil disturbance on 50% of the drainage area (Cheng et al. 1975). However, any affect this soil-water slow-down had on streamflow in H watershed, with a 23% soil-disturbed area, was masked by the road effect which increased rather than decreased peaks. Apart from road effects, overland flow was not observed in H watershed. The significance of root channel flow in coastal watersheds has also been noted by others (Nagpal and de Vries 1976, Feller and Kimmins 1979), and rapid water movement to lower soil profiles has been documented by tensiometer studies (Chamberlin 1972, Nagpal and de Vries 1976, de Vries and Chow 1978), Chamberlin (1972) reporting soil profile water flow rates of 67-200 cm/hr.

SUMMARY

Preliminary study of logging effects in the Carnation Creek watershed indicates several changes in the hydrologic regime of the 90% clearcut H watershed, where annual water yield increased by an average 14% of annual runoff, minimum daily summer flows increased by an average 78% in the first two post-logging years, maximum slope groundwater levels decreased after road construction but increased at some locations after yarding, rain storm peak flows increased by an average 20%, while the time-to-peak storm hydrograph characteristic appears to have decreased. For the whole Carnation Creek watershed with up to 40% clearcut, storm runoff showed little detectable change but there were some apparent decreases in annual water yield (8% of annual runoff) and minimum daily summer flows (47%), while valley bottom groundwater levels were higher. These findings are generally within the range of results from other logging impact studies in rain-dominated coastal Oregon and California watersheds.

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REFERENCES

Chamberlin, T.W. (1972): Interflow in the mountainous forest soils of coastal British Columbia. In Mountain geomorphology, Tantalus Research, Vancouver, British Columbia, Slaymaker, O. and McPherson, H.J., eds., pp. 121-127.

Cheng, J.D., Black, T.A., de Vries, J., Willington, R.P. and Goodell, B.C. (1975): The evaluation of initial changes in peak streamflow following logging of a watershed on the west coast of Canada. International Association of Scientific Hydrology, Tokyo Symposium, Publication 117, pp. 475-486.

CNCIHD Secretariat (1971): Canadian progress report International Hydrologic Decade. Information Canada, Ottawa, pp. 53-54.

Feller, M.C. and Kimmins, J.P. (1979): Chemical characteristics of small streams near Haney in southwestern British Columbia. Water Resources Research, Vol. 15, No. 2, pp. 247-258.

De Vries, J. and Chow, T.L. (1978): Hydrologic behavior of a forested mountain soil in coastal British Columbia. Water Resources Research, Vol. 14, No. 5, pp. 935-942.

Harr, R.D. (1976): Forest practices and streamflow in western Oregon. USDA Forest Service General Technical Report PNW-49, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 18 p.

Harr, R.D. (1980): Streamflow after patch logging in small drainages within the Bull Run municipal watershed, Oregon. USDA Forest Service Research Paper PNW-268, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 16 p.

Harr, R.D. and Krygier, J.T. (1972): Clearcut logging and low flows in Oregon coastal watersheds. Forest Research Laboratory, Research Note 54, Oregon State University, Corvallis, 3 p.

Harr, R.D., Harper, W.C., Krygier, J.T. and Hsieh, F.S. (1975): Changes in storm hydrographs after road building and clear-cutting in the Oregon coast range. Water Resources Research, Vol. 11, No. 3, pp. 436-444.

Harr, R.D., Fredriksen, R.L. and Rothacher, J. (1979): Changes in streamflow following timber harvest in southwest Oregon. USDA Forest Service Research Paper PNW-249, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 22 p.

Harr, R.D. and McCorison, F.M. (1979): Initial effects of clearcut logging on size and timing of peak flows in a small watershed in western Oregon. Water Resources Research, Vol. 15, No. 1, pp. 90-94.

Harris, D.D. (1973): Hydrologic changes after clear-cut logging in a small Oregon coastal watershed. Journal of Research, U.S. Geological Survey, Vol. 1, No. 4, pp. 487-491.

Hartman, G.F., ed. (1981): Carnation Creek project report for 1979 and 1980. Department of Fisheries and Oceans, Nanaimo, British Columbia, 21 p.

Hewlett, J.D. and Hibbert, A.R. (1967): Factors affecting the response of small watersheds to precipitation in humid areas. In International symposium on forest hydrology, Sopper, W.E. and Lull, H.W., eds., Pergamon Press, New York, pp. 275-290.

MacMillan and Bloedel (1979): MacMillan and Bloedel Limited logging operations in Carnation Creek watershed 1975-78. Department of Fisheries and Oceans, Fisheries and Marine Service Data Report 157, Nanaimo, British Columbia, 22 p.

Nagpal, N.K. and de Vries, J. (1976): Hydrology of mountain slopes. Interim report to Department of the Environment, Department of Soil Science, University of British Columbia, Vancouver, 29 p.

Oswald, E.T. (1973): Vegetation and soils of Carnation Creek watershed (a progress report). Department of the Environment, Canadian Forestry Service Internal Report BC-43, Victoria, British Columbia, 38 p.

Rothacher, J. (1970): Increases in water yield following clear-cut logging in the Pacific Northwest. Water Resources Research, Vol. 6, No. 2, pp. 653-658.

Rothacher, J. (1973): Does harvest in west slope Douglas-fir increase peak flow in small forest streams? USDA Forest Service Research Paper PNW-163, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 13 p.

Symons, P.E.K., ed. (1978): Carnation Creek project annual report for 1976. Department of Fisheries and Environment, Nanaimo, British Columbia, 14 p.

Ziemer, R.R. (1981): Storm flow response to road building and partial cutting in small streams of northern California. Water Resources Research, Vol. 17, No. 4, pp. 907-917.